Pricing Climate Risks In Asia

ecosperity

TSINGHUA PBCSF 清华五道口 | NIFR 国家金融研究院

Authors:

Dr. SUN Tianyin, deputy director of the Center for Green Finance Research (CGFR), National Institute of Financial Research of Tsinghua University

ZHU Yun, junior research fellow of CGFR

ZHANG Jingyi, junior research fellow of CGFR

JIANG Yiran, research assistant of CGFR

TAO Haoxiang, research assistant of CGFR

Acknowledgements

The authors of this report are grateful for the contributions and comments provided by LAN Huanqi (CUFE), LI Zixuan (HKUST), Matthew Huxham (Willis Towers Watson) and Judson Berkey (UBS). XU Huixin (C9S) copy-edited and formatted the report.

About Ecosperity

Ecosperity is one of Temasek's key platforms for engagement and advocacy around sustainability. The word "Ecosperity" twins ecology with prosperity, reflecting our belief that doing good and doing well can – and must – go together. We work with global leaders from the private and public sectors, academia, and civil society to exchange views, share best practices and push the agenda on sustainable development.

About CGFR

The CGFR was established in 2018 and is led by Prof JU Jiandong, the Unigroup Chair Professor at Tsinghua's PBC School of Finance. As a leading green finance research platform with extensive international cooperation experience, the center is dedicated to academic and policy research, innovation, and global partnerships in sustainable finance. With China's commitment to carbon neutrality, the center strives to serve the nation's climate strategy and sustainable development worldwide. Through researching on the tools and paths towards carbon neutrality, conducting environmental risks analysis and developing green finance standards, the center supports China's policymaking and advises the country's top banks and corporations on green business development and strategic planning.

CONTENTS

EXECUTIVE SUMMARY

As countries around the world seek to recover from the Covid-19 pandemic, there is a substantial risk that the fight against climate change may be deprioritised. Yet environmental degradation, increasing greenhouse gas (GHG) emissions and rising temperatures must be addressed urgently in the face of more extreme weather and ecological catastrophes. The IPCC's Sixth Assessment Report (AR6) made dire predictions of severe droughts, flooding, heatwaves, and a key temperature limit being exceeded in just over 10 years (McGrath, 2021).

Recent research shows that air pollution from burning fossil fuels causes nearly one in five deaths worldwide each year (Vohra et al., 2021). In 2019, the recorded number of disasters globally rose to 396 from an average of 343 per year between 2009 and 2018, and about 95 million people were impacted by natural disasters, with 40% occurring in Asia (CRED, 2020).

Under the Paris Agreement, almost all nations have agreed to move to a sustainable and low-carbon economy. The three big economies in Asia have all expressed political support, with Japan and South Korea committing to net-zero by 2050 and China by 2060. India, a major player in the Asian economy and the world's third-largest emitter of greenhouse gases, has committed to net-zero by 2070.

Climate-related risks matter more than ever. They refer to transition and physical risks related to climate change. Transition risks refer to financial and reputational risks resulting from policy, legal, technology and market changes in the transition to a low-carbon economy. These include increased costs as governments introduce carbon pricing mechanisms, the loss of demand due to changing consumer preferences, market perception of a company's contribution to climate change or the availability of lower carbon alternatives, and even litigation brought about by stakeholders due to an organisation's failure to mitigate climate change.

Physical risks can have acute and chronic impacts on the economy. Acute impacts from extreme weather include business disruptions and property damages, which can impair asset values and raise risks to insurance underwriters. Chronic impacts are longer-term shifts in climate patterns such as rising temperatures, precipitation, and sea levels, affecting labour, capital and agricultural productivities. These changes will require significant investment and adaptation by companies, households, and governments. Climate-related risks are now widely regarded as a source of business, financial, legal and reputational risks, spurring corporations, financial institutions, and regulators to act.

Effective action requires systematic evaluation and pricing of climate risks. Some businesses and researchers have developed nascent climate risk models, but more studies are needed to understand the relevance and importance of climate risks to businesses and the financial sector, and more expertise in such fields needs to be developed. This knowledge gap is more apparent in Asia, where pricing climate risks is an emerging topic.

This report aims to help fill that knowledge gap by presenting an overview on:

Why climate risks need to be incorporated into business decision making

The consequences of disaster events, actions taken to mitigate them, and the physical and transition risks can impact the economy and individual entities differently. Damaged properties and disrupted supply chains cause enormous losses to companies and the economy. Changing markets, rising costs, declining incomes and stranded assets due to transition requirements and technological breakthroughs create both new challenges and opportunities. Companies must then account for climate issues in decision making.

Methods for climate risks analysis – advantages, drawbacks and applications

Climate risks can be categorised into physical and transition risks, each of which could be analysed using different approaches. Most evaluations are simulation or scenario-based. Others use factor or static map-based methods. Chapter 2 discusses the applicability, general frameworks, advantages, and limitations of representative approaches. Case studies in Chapter 3 illustrate possible analytical approaches for various industries facing different climate risks.

Current practices in mitigating climate risks

Businesses in carbon-intensive industries have started to reduce their energy consumption or decarbonise chemical processes through business model transformation and technological development. Companies like Total Energies and Shell are divesting high-carbon assets and entering low-carbon businesses. More are joining disclosure initiatives like the Task Force on Climate-related Financial Disclosures (TCFD), which aims to provide standardised and transparent climate-related information. However, the lack of data, low awareness of climate risks and capacities to perform analysis have hindered the development of climate risks pricing initiatives.

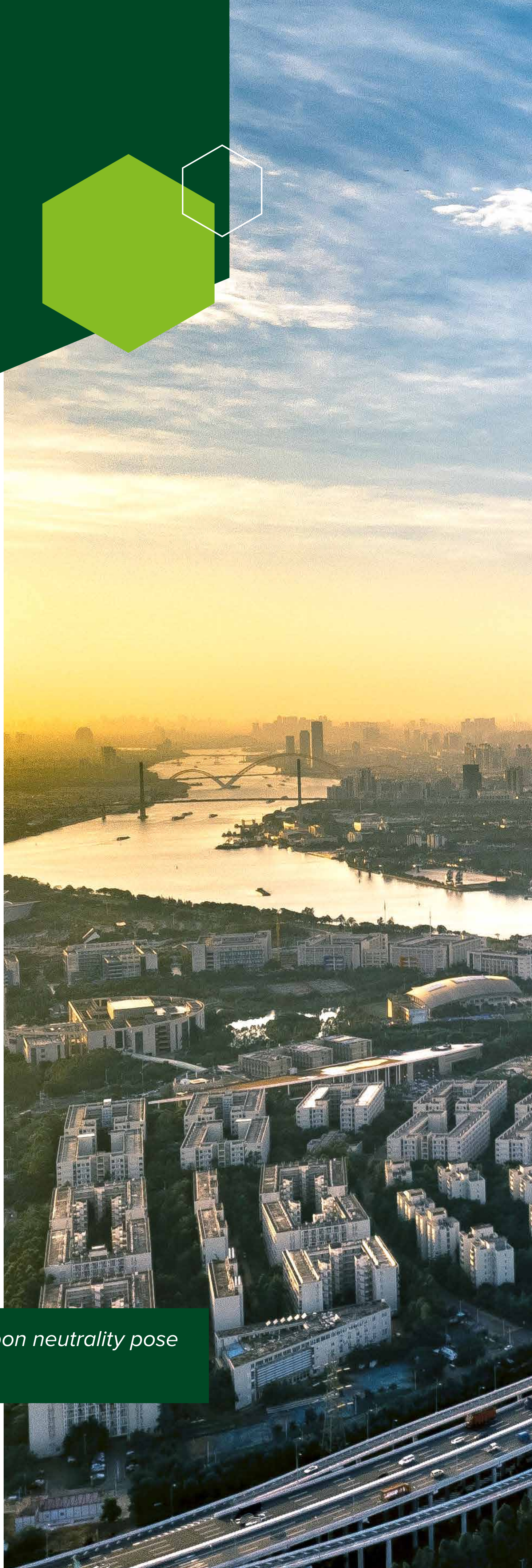
How corporations can better include climate risks pricing initiatives

Both companies and financial institutions face climate-related risks, as the impacts on businesses can affect their lenders and investors. Companies can mitigate climate risks and seize opportunities when they strengthen their capacity to measure GHG exposure, identify transmission pathways, manage and mitigate for these and strategically incorporate climate considerations to drive transition, capture new low carbon opportunities, and reallocate capital. Transparent TCFD-aligned disclosure has also become a best practice. Financial institutions should incorporate climate-related factors in strategies, governance, risk management, asset allocation, and disclosure reports. They can also engage and support existing carbon-intensive clients on transition opportunities.

Analysing climate-related impact factors can help in the early identification and quantification of emerging risks and opportunities, enabling early adopters to be better positioned.

CHAPTER 1

Why Climate Change Matters to Businesses and Financial Institutions



Key messages:

- a. Climate change and low-carbon transitions present both risks and opportunities;
- b. Economic losses from climate change have increased over the previous decades, and are expected to grow in the coming century;
- c. Many Asian countries are more vulnerable to climate change, and bear greater transition burden given their carbon-intensive economies;
- d. Businesses and financial organisations in Asia may face risks from climate change (physical risks), and immediate risks as governments push for a lower-carbon economy and pursue economic reform (transition risks);
- e. The risks from these two sources may interplay with each other;
- f. Businesses in Asia should be better prepared in managing the risks and opportunities according to their exposures.

Worsening climate change and transitions to carbon neutrality pose both risks and opportunities for businesses.


Photo by Dai Yuyang on Pexels

1.1

Climate change risks

1.1.1 Climate change is accelerating and the economic impacts are significant

Compared to 1880, the average surface temperature of the Earth has increased by a little more than 1° Celsius (NASA, 2019). Since the Industrial Revolution, climate change has resulted in more frequent extreme climate events (such as typhoon and floods), rising sea levels, and ecosystem degradation. [1]

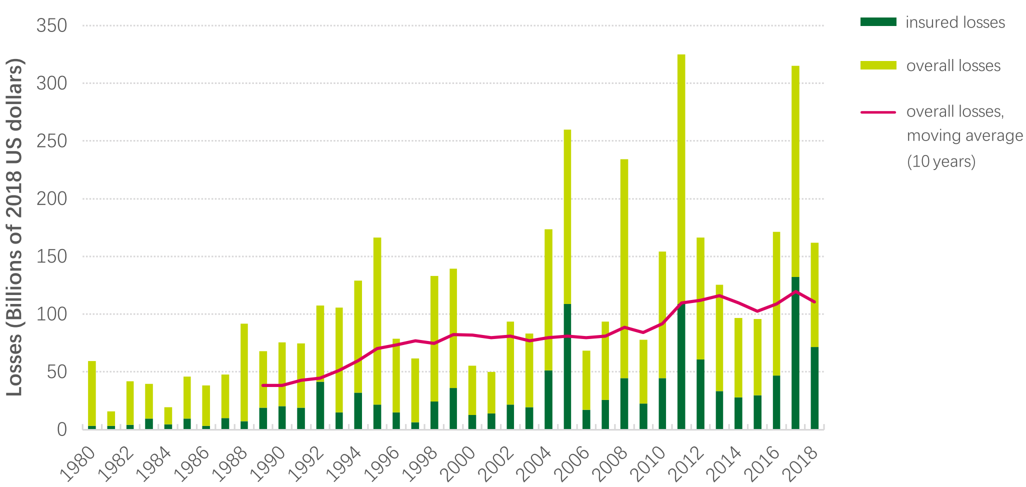


Figure 1: Rising losses from natural disasters

Source: Insurance Information Institute (2020)

1. National Geographic, https://www.nationalgeographic.com/environment/article/global-warming-effects

A worsening climate drives more frequent and extreme natural disasters, leading to enormous economic losses. A recent report by the World Meteorological Organization (WMO) showed the number of natural disasters driven by climate change increased fivefold over the past 50 years. This resulted in USD 3.64 trillion in total losses and more than 2 million deaths (WMO, 2021).

Hurricane Harvey in Texas, said to be a consequence of climate change, caused USD 125 billion total damages, knocking out 10,000 MW of electricity capacity and reducing oil production by 21% in 2017. Businesses were forced shut for a week, and port traffic was delayed. The death toll numbered 107, while around 50,000 homes were destroyed (NGFS, 2020). In 2011, flooding in Thailand paralysed the country's vital automobile and electronic manufacturing sectors. Factories halted production for over 30 days, cutting down annual output by 20%. About 17.5% of the factories were permanently destroyed. Toyota and Honda saw their net profits plunging 60% from 2010 (Haraguchi & Lall, 2015).

1.1.2 Asian countries disproportionately affected by climate change

Asian countries are more vulnerable to natural disasters induced by climate change. The Global Climate Risk Index (CRI) developed by Germanwatch quantifies the impacts of extreme weather events and ranks countries' vulnerabilities to climate change in four categories: the total number of deaths, the number of deaths per 100,000 inhabitants, the sum of losses in US dollars in Purchasing Power Parity (PPP) and losses per unit Gross Domestic Product (GDP).

Figure 2 shows the CRI average of countries for 2000-2019, with a lower score on the index (darkest red) indicating higher vulnerability to climate change. Table 1 ranks the 10 most climate-vulnerable countries according to average CRI scores. Among them, six are in South and Southeast Asia (Myanmar, Philippines, Bangladesh, Pakistan, Thailand and Nepal).

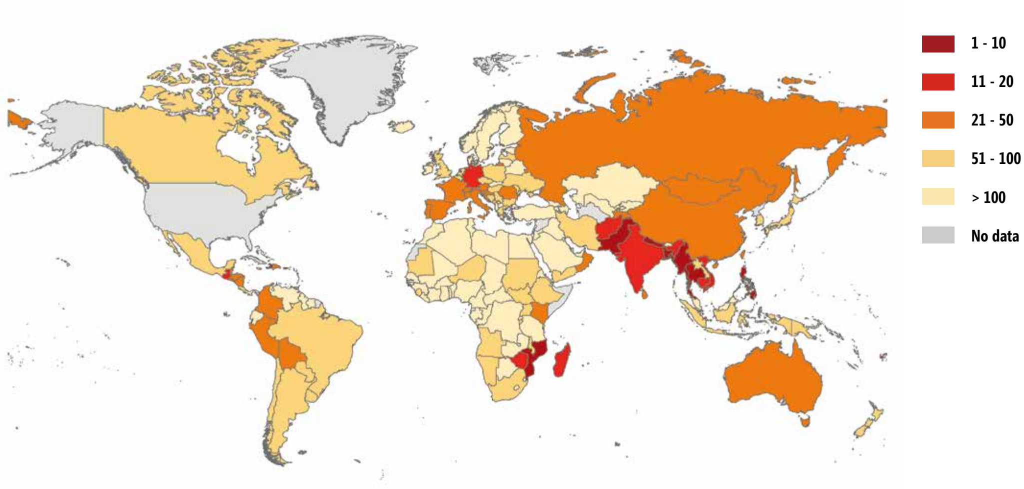


Figure 2: World map of global climate risk index 2000–2019[2]

Source: Eckstein et al. (2021)

Table 1: Top ten climate-vulnerable countries according to the average CRI data in 2000-2019[3]

Rank	Country	CRI score	Deaths	Deaths per 100,000 inhabitants	Losses in million USD PPP	Losses per unit GDP (%)
1	Puerto Rico	7.17	149.85	4.12	4149.98	3.66
2	Myanmar	10.00	7056.45	14.35	1512.11	0.80
3	Haiti	13.67	274.05	2.78	392.54	2.30
4	Philippines	18.17	859.35	0.93	3179.12	0.54
5	Mozambique	25.83	125.40	0.52	303.03	1.33
6	The Bahamas	27.67	5.35	1.56	426.88	3.81
7	Bangladesh	28.33	572.50	0.38	1860.04	0.41
8	Pakistan	29.00	502.45	0.30	3771.91	0.52
9	Thailand	29.83	137.75	0.21	7719.15	0.82
10	Nepal	31.33	217.15	0.82	233.06	0.39

The Climate Economics Index (CEI) developed by the Swiss Re Institute ranks a country's exposure to the potential impact of climate change according to expected economic outcomes, vulnerability to extreme weather risks, and existing adaptive readiness. To measure a country's vulnerability, three scenarios are set up in the indicator model: achieving the target of 1.5°C under the Paris Agreement, an increase of 2-2.6°C, and a more severe increase of 3.2°C by 2050 (see Table 2). The result shows that Asia's GDP may shrink 26.5% by 2048 if no action on climate change is taken, compared to a 18.1% reduction of the global economy under the same scenario. This shows that Asian countries on average face greater risks from climate change compared to the rest of the world.

2. Data collection and analysis are provided by Munich Re's NatCatSERVICE, US data not included.
3. Ranking was taken from the Global Climate Risk Index (CRI) developed by Germanwatch.

Table 2: Mid-century GDP changes with different temperature rises and economic impact severity, relative to a no-climate change world[4]

Temperature path	Well below 2°C increase			2.0°C increase			2.6°C increase			3.2°C increase		
	Paris target			*The likely range of global temperature gains*						*Severe case*		
Omitted channels	√	√	√	√	√	√	√	√	√	√	√	√
(Un)known unknowns	X	√ x5	√ x10	X	√ x5	√ x10	X	√ x5	√ x10	X	√ x5	√ x10
World	-0.5%	-2.2%	-4.2%	-1.3%	-5.7%	-11.0%	-1.7%	-7.2%	-13.9%	-2.2%	-9.4%	-18.1%
Asia	-0.7%	-2.8%	-5.5%	-1.7%	-7.7%	-14.9%	-2.4%	-10.5%	-20.4%	-3.0%	-13.7%	-26.5%
Advanced Asia	-0.4%	-1.7%	-3.3%	-1.1%	-4.8%	-9.5%	-1.3%	-5.9%	-11.7%	-1.7%	-7.7%	-15.4%
ASEAN	-0.8%	-2.3%	-4.2%	-2.4%	-9.0%	-17.0%	-4.1%	-15.4%	-29.0%	-5.0%	-19.7%	-37.4%
Oceania	-0.5%	-2.2%	-4.3%	-1.3%	-5.8%	-11.2%	-1.7%	-6.5%	-12.3%	-2.0%	-8.3%	-16.3%
Australia	-0.5%	-2.2%	-4.4%	-1.4%	-5.8%	-11.3%	-1.7%	-6.6%	-12.5%	-2.1%	-8.4%	-16.5%
China	-0.7%	-3.3%	-6.6%	-1.6%	-7.7%	-15.1%	-1.9%	-9.2%	-18.1%	-2.5%	-12.1%	-23.5%
India	-0.8%	-3.0%	-5.7%	-2.0%	-8.9%	-17.4%	-3.2%	-13.9%	-27.0%	-4.0%	-18.0%	-35.1%
Indonesia	-0.6%	-2.1%	-4.0%	-2.0%	-8.5%	-16.7%	-3.4%	-15.4%	-30.2%	-4.4%	-20.0%	-39.5%
Japan	-0.3%	-1.6%	-3.2%	-0.8%	-4.2%	-8.4%	-0.8%	-4.5%	-9.1%	-1.1%	-6.0%	-12.0%
Malaysia	-1.2%	-2.8%	-4.8%	-4.0%	-12.3%	-22.3%	-6.8%	-20.1%	-36.3%	-7.8%	-25.2%	-46.2%
New Zealand	-0.4%	-1.9%	-3.7%	-1.0%	-4.9%	-9.7%	-1.1%	-5.2%	-10.4%	-1.4%	-6.9%	-13.6%
Philippines	-1.3%	-3.1%	-5.4%	-3.5%	-11.8%	-21.6%	-5.8%	-19.5%	-35.0%	-6.9%	-24.6%	-43.9%
Singapore	-1.0%	-2.7%	-4.9%	-2.9%	-10.6%	-20.2%	-5.0%	-18.6%	-35.6%	-6.1%	-23.9%	-46.4%
South Korea	-0.2%	-1.3%	-2.7%	-0.8%	-4.2%	-8.5%	-0.8%	-4.7%	-9.7%	-1.1%	-6.3%	-12.8%
Thailand	-1.2%	-2.9%	-4.9%	-3.0%	-10.4%	-19.5%	-4.9%	-17.8%	-33.7%	-6.0%	-22.9%	-43.6%

Sources: Swiss Re Institute, Gray (2021)

The CEI Index presents some notable findings when Asian economies were placed in different climate change scenarios (see Table 3). First, China and India, dominant players in the Asian economy and among the biggest contributors to global growth, did not rank well. Secondly, ASEAN nations are affected the most in Asia by climate change. Under the most severe scenario (3.2°C rise in temperature and the most extreme physical outcomes), the collective ASEAN GDP will shrink about 37% by 2048. An island nation, Singapore faces high risks through several channels of impact, including rising sea level, heat stress and reduced tourism revenue. It could lose 46.4% of its GDP in the worst scenario. However, it has demonstrated resilience by preparing to combat the adverse impact of climate change.

4. Notes: Temperature increases are from pre-industrial times to mid-century. Columns labelling indicate specific variable adjustments in our scenario analysis: inclusion of omitted channels (i.e., channels that have not been quantified in previous research), and multiplicative factors (x5 and x10) for potentially increased severity of unknowns.

Rank	Country	Physical risk(70%)			Current adaptive capacity (30%)	Climate Economics Index
		Chronic risk (GDP impact) (30%)	Acute risk(extreme weather risk)			
			Dry climate risk score	Wet climate risk score		
11	Japan	22	35	16	9	19.5
14	Australia	33	16	17	13	20.4
18	New Zealand	29	2	27	24	21.7
20	Korea	24	30	14	20	22
39	Singapore	47	44	29	5	30.2
41	China	38	33	21	35	32.7
44	Thailand	45	43	11	39	36
45	India	42	37	13	46	36.4
46	Philippines	46	48	5	43	37.3
47	Malaysia	48	47	23	33	38.3
48	Indonesia	44	45	19	44	39.2

Table 3: Climate Economics Index: mid-century[5]

Sources: Verisk Maplecroft, Gray (2021)

Extreme weather events often leave the greatest impact on poorer countries, given their lack of resources (Eckstein et al., 2021). Some studies show that Asia may be the worst-affected region by sea level rise, given the combination of its population density, hydrology, and asset concentration (Collins, 2019). In India, officially recorded heat waves numbered 484 in 2018, more than 10 times the total from the 1970s, Figure 3 shows this comparison (Antia & Klausner, 2021).

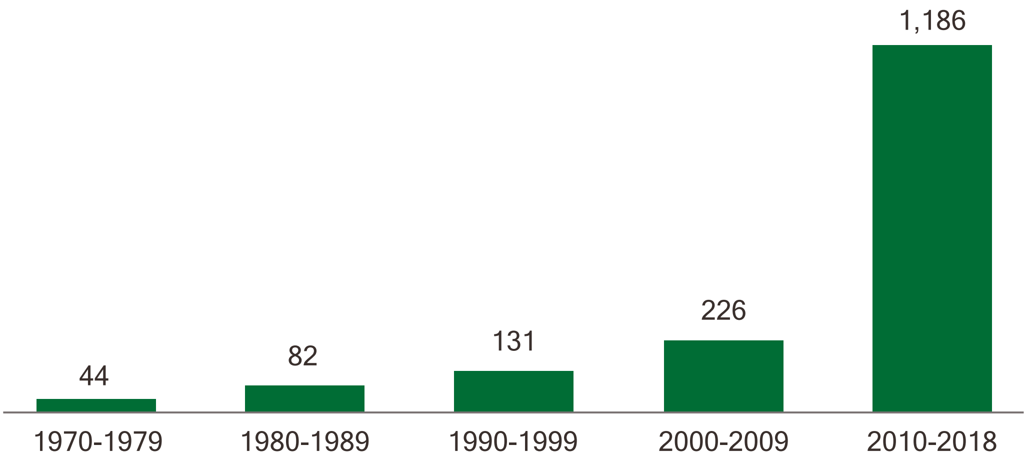


Figure 3: Officially recorded heat waves in India by decade, 1970-2018[6]

Asian countries must be more proactive in combatting climate change. Businesses with operations in these countries should incorporate the physical climate risks into daily operations and build up resilience.

5. Notes: All measures are constructed on the basis of the RCP 8.5 scenario. The ranking of chronic physical risk refers to the percentage loss of GDP by mid-century under the average 2.6°C warming scenario but with x10 stress-tested factors, as specified in Table 2. The ranking for adaptive capacity are derived from Maplecroft, where it serves as one proxy for transition risk. Table colours denote the different degrees of vulnerability to climate change, with dark green indicating the most resilient and dark red the countries most severely impacted.

6. Extreme events and disasters, India Meteorological Department, Ministry of Earth Science

1.1.3 Asian countries are also exposed to risks from low-carbon transition

To mitigate climate change and economic losses, humans need to take immediate actions to limit greenhouse gas (GHG) emissions. The 2015 Paris Agreement urged for net-zero emissions by 2050, limiting the rise of global average temperature to below 1.5°C from pre-industrial levels. In the last two years, many governments have begun to set targets for carbon neutrality, including Canada, China, France, Germany, Japan, UK and USA. As of 1 December 2021, 136 countries have set net-zero carbon goals. [7]

Most Asian economies will face difficulties making the transition given the high reliance on carbon-intensive resources, such as fossil fuels and steel for growth and economic development. Carbon-neutral targets and measures to mitigate carbon emissions will heavily affect the economy, businesses, and financial activities in these countries. While China contributes to 17% of the global GDP[8], it accounts for 26.1% of the total energy consumption[9], and 30.3% of global carbon dioxide emission[10]. The carbon emission per unit of GDP in China is about 1.8 times the global average.

World oil consumption growth was led by China (680,000 barrels per day)[11] and other emerging economies in 2020. While the overall global coal consumption fell by 0.6% in 2019 compared to 2018 (-0.9 exajoules, or EJ), coal consumption rose in emerging economies, particularly in China (1.8 EJ), Indonesia (0.6 EJ) and Vietnam (0.5 EJ) (BP, 2020). To achieve the goals set out in the Paris Agreement, coal consumption must be slowed and aggressively curtailed.

Asian countries take up the major share of today's global carbon dioxide emissions from fossil fuels combustion. China produced the most CO_2 emissions in the world in 2018. Along with India, Japan, Korea, Iran and Indonesia, the six top emitters account for more than 65% of the global total (see Figure 4).

---

7. The end targets named by countries vary, not all countries set their carbon targets to be "net zero"; they can be called for example "carbon neutral(ity)" or "climate neutral", for more details see https://www.zerotracker.net/

8. Calculated according to world economic statistic from the World Bank: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?end=2020&most_recent_value_desc=false&start=1960&view=chart

9. China consumed 26.1 percent of global primary energy, the largest share of any country in the world in 2020: https://www.statista.com/statistics/274200/countries-with-the-largest-share-of-primary-energy-consumption/

10. Calculated based on world CO_2 emission statistics from the World Bank: https://data.worldbank.org/indicator/EN.ATM.CO2E.KT?view=chart

11. BP's Statistical Review of World Energy 2020: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

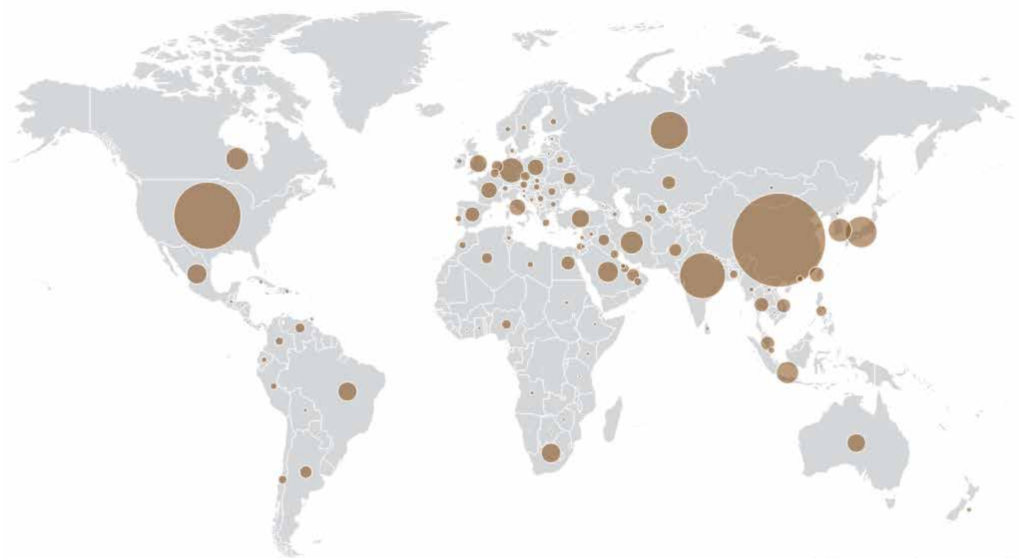


Figure 4:
Carbon emissions from burning fossil fuels in 2018

Source: IEA (2020a)

A joint study by Tsinghua University and Vivid Economics indicated that the 126 countries participating in the Belt and Road Initiative (BRI)[12] produced 28% of the world's emissions in 2015. This share is projected to rise to 66% in 2050 if no actions are taken. Measures taken by the rest of the world will not succeed if these countries do not limit their emissions (Ma et al., 2019).

Due to pressure from their international peers and wanting to seize the opportunities presented by a low-carbon economy, the governments in Asian countries have already started to implement carbon-mitigation measures, including increasing costs of carbon emissions and adopting renewable energy technologies. This will, in turn, affect the operations of related industries and companies.

12. BRI is a transcontinental long-term policy and investment program which aims at infrastructure development and acceleration of the economic integration of countries along the route of the historic Silk Road; BRI is a global initiative but by its nature of building on the historic Silk Road puts a major focus on countries in Asia, Eastern Africa, Eastern Europe and the Middle East, a region mainly composed of emerging markets. The number "126" of BRI countries indicated by the study was taken from the official website: https://www.yidaiyilu.gov.cn/, at the time when the study was conducted.

1.2

Climate-related business and financial risks

1.2.1 Definition and classification of climate-related risks

Both climate change and the responding mitigation efforts can lead to business and financial risks that can be further categorised into physical and transition risks.

Physical risks refer to the impact from climate or environmental events (e.g., floods, tropical storms, droughts or heat waves), and can affect economies in two ways.

Acute impacts from extreme weather events can lead to business disruptions and property damage. Chronic impacts, such as those from higher temperatures and sea levels may limit agricultural yield, human productivity, tourism, and cause mass migration. Lower property values, disrupted business, or reduced productivity will increase the rates of defaults by companies and their Loss Given Default (LGD), in turn causing economic losses to banks. For insurers, property damage could result in higher and more frequent claims.

Transition risks refer to financial and reputational risks resulting from policy, legal, technology and market changes in the transition to a low-carbon economy. A transition requires the revaluation of financial assets, creating uncertainties and risks to businesses and investments. For example, transition risks could result from government policies that limit the use of fossil fuels, bans on internal combustion engine vehicles, carbon tax and emissions trading systems, tightened environmental regulations such as taxes on pollutants and penalties for polluting companies. Technological progress can also lead to transition risks. Lower costs of solar and wind power generation and electricity storage reduce the competitiveness of fossil fuels. A study by Bloomberg[13] showed that the average costs of solar, wind and power storage have declined 85%, 49% and 85% respectively from 2010 to 2020. As technology advances, the costs of renewable energy can be expected to decline further. Moreover, as renewable resources are not constrained by scarcity, prices tend to decline towards zero.

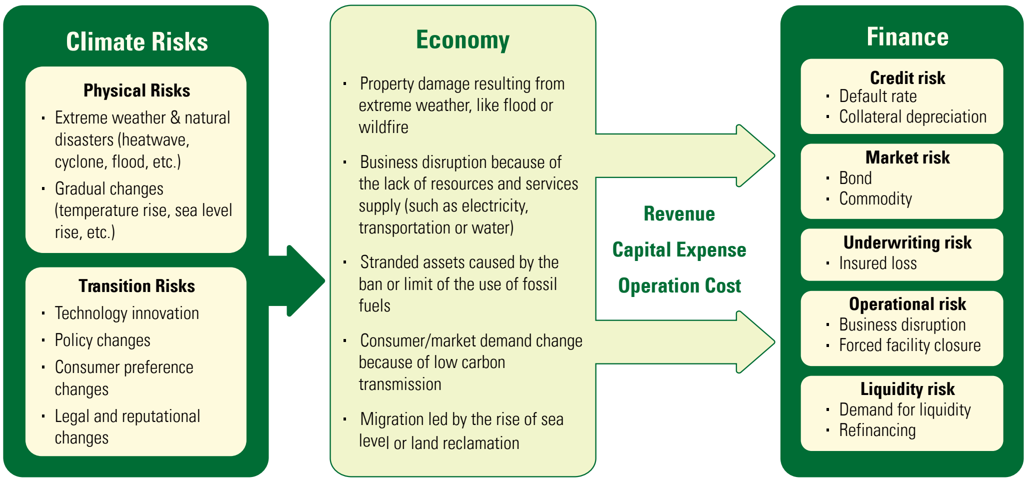


Figure 5: How climate risks induce financial risks

Physical and transition risks may interplay with each other (Peel et al., 2020). If we decarbonise the global economy without thoughtful preparation and delivery, transition risks will increase. On the other hand, failing to make the timely transition will lead to greater physical risks to businesses and financial institutions (see Figure 6) .

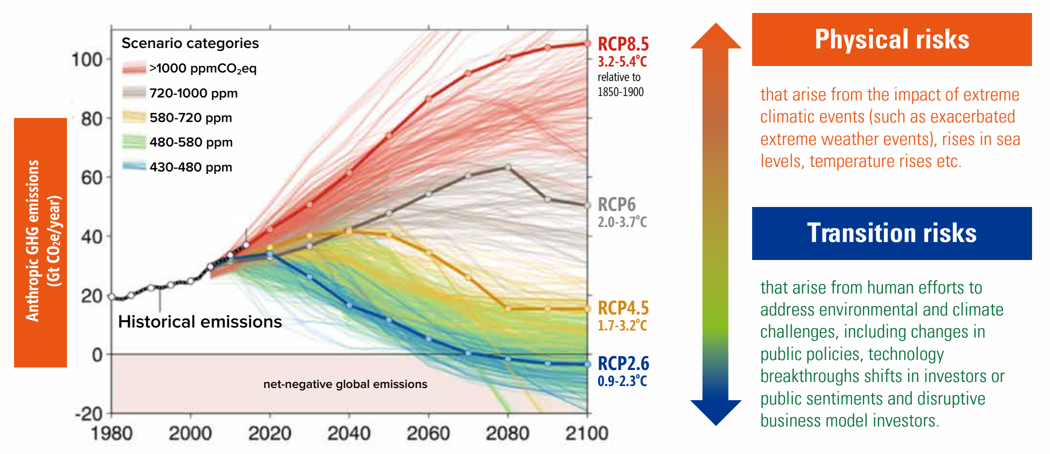


Figure 6: Relationship between transition risks and physical risks

Source: adapted from Fuss et al. (2014)

13. Bloomberg New Energy Outlook, 2020.

1.2.2 Using climate risks analysis will better position businesses and financial institutions to mitigate risks and seize opportunities

Conducting climate risks analysis will gradually be required for internal risk management and regulatory compliance. It is also increasingly expected by investors and clients.

Climate risk assessments should be conducted for companies and financial institutions. Climate change can threaten a company's assets by disrupting supply chains, operations, and distribution networks. It can also cause economic losses to customers and markets. A corporation's resilience to climate change depends on its business plan, risk management ability, and governance. Climate risks can be directly or indirectly reflected in financial statements. For example, companies with high water consumption are more sensitive to drought and water availability, while those that consume high energy or use fossil fuels are sensitive to energy costs and regulations.

In some countries, companies are required by law to assess and quantify climate risks. The Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD) published recommendations in 2017 for the voluntary disclosure of climate-related risk and opportunities. Organisations are encouraged to develop systems for assessing climate risks and opportunities. The UK's Financial Conduct Authority proposed to have the framework applied to all companies, making the disclosure framework mandatory in London (Financial Conduct Authority, 2020).

In December 2020, the Monetary Authority of Singapore (MAS) released Guidelines[14] on Environmental Risk Management for banks, insurers, and asset managers to better prepare financial institutions for environmental risks and strengthen the financial sector's expertise in sustainability. The guidelines are generally aligned with TCFD recommendations and centred around environmental risks, defined by MAS.

Similarly, Hong Kong's Green and Sustainable Finance Strategy released in December 2020 called on all sectors in the city to carry out mandatory TCFD-aligned disclosures by 2025 and to conduct climate scenario analysis.[15]

---

14. MAS 2020, guidelines series on Environmental Risk Management for banks, insurers and asset managers: Guidelines on Environmental Risk Management for Banks

15. Hong Kong Monetary Authority 2021, Cross-Agency Steering Group announces next steps to advance Hong Kong's green and sustainable finance strategy: https://www.hkma.gov.hk/eng/news-and-media/press-releases/2021/07/20210715-4/

Some of the economic responses to the COVID-19 pandemic by governments have included climate-related disclosures. Canada, for example, requires businesses with revenues over CAD 300 million to publish TCFD-aligned annual climate disclosure reports to qualify for corporate relief.[16] As more governments require companies to step up their response to climate change and transit to more sustainable business models, their COVID-19 recovery responses can enable long-term financial resiliency with climate change taken into consideration. COVID-19 has illustrated how systemic risks can impact the economy and shock the financial system. As governments plan for recovery, they are trying to avoid leaving the economy vulnerable to systemic risks such as climate change.

Investors are under pressure to report on climate issues by either the regulatory agencies or their clients. The climate risk analysis ecosystem is evolving rapidly: credit rating agencies are racing to incorporate the costs of carbon and broader ESG risks into assessment methods, and a series of investor initiatives was launched to encourage investees in sectors facing transition difficulties to take a pathway aligned with the Paris Agreement.

Lastly, investors are becoming more aware of how non-financial performance impacts a corporation's financial potential and are pushing for more climate-related disclosures. A 2019 study showed that 51% of the surveyed institutional investors believe that climate risk reporting is as important as traditional financial reporting, with 33% considering it more important (Ilhan et al., 2019). Some investors see climate risk assessment and disclosure as the most important means to fully understand the financial health of their portfolio companies.

Low-carbon transition also creates tremendous economic opportunities. A joint analysis by IEA and IMF found that annual investments in energy will surge to USD 5 trillion in 2030 as the world pursues net-zero targets, adding 0.4% to the global annual GDP growth. The jump in private and government spending creates millions of jobs in clean-energy generation and energy efficiency development, driving growth in engineering, manufacturing, and construction. These investments will lift global GDP growth by 4% in 2030 (IEA, 2021).

16. Manifest climate 2020, Federal LEEFF Program – How to Get Started on Disclosing your Climate Risk: https://manifestclimate.com/blog/federal-leeff-program/

Solar and wind are expected to be the predominant renewable energy sources, accounting for 24% of the total power generation in 2040, up from the current 7% (IEA, 2020b).

According to research by Tsinghua University, China will need to invest close to USD 21.7 trillion in low carbon sectors to meet its targets under the Paris Agreement, which is 35% more than China's annual GDP (Tsinghua, 2020). Another research estimated the number to be as much as USD 78.6 trillion needed for China to reach net-zero (Ma, 2021).

A joint study by Tsinghua University and Vivid Economics in 2019 showed that the potential investment required to meet Paris Agreement for the 126 BRI countries creates a market opportunity totalling USD 11.8 trillion by 2030. Investments required will involve the power, transport, housing, and industry sectors. The annual green investment in these countries to meet Paris Agreement is 2.4 times of the global total in clean-energy investment in the year 2018 (Ma et al., 2019).

The enormous scale of investment needed for a low-carbon transition in the coming decade presents huge opportunities for corporations operating in China and the rest of Asia. Incorporating the outcome of a climate risk analysis into corporate governance provides a top-down guidance for businesses. Understanding the potential costs helps the management grasp challenges ahead and steer the company onto the right path to capture the opportunities.

In conclusion, assessing climate-related risks and opportunities is increasingly crucial in order for a company to meet regulatory compliance requirements and to develop core competencies. It helps a company to better manage climate-related risks and seize the opportunities presented by the transition toward a carbon-neutral economy. However, pricing climate-related risks is still in the early stages of development. Businesses and the financial sector should be made more aware of the relevance and importance of climate risks and start to develop the expertise for conducting such analysis. The knowledge gap is particularly apparent in Asia, where pricing climate-related risks is an emerging topic.

CHAPTER 2

Latest Developments in Pricing Climate Risks

Key messages:

- a Most methodologies of climate risk analysis are scenario-based;
- b Factor-based approach serves as an alternative method to evaluate climate transition risks;
- c There are two main categories of climate-related risk analysis methods: assessing transition risk and assessing physical risk;
- d Applications of these models and approaches are still to be publicised;
- e Methodologies have limitations given the early stage of their development; future developments are needed.

Photo by Toby Yang on Unsplash

2.1

Classification of approaches used to analyse climate risks

Climate-related risks differ by sectors, regions, and time horizons. Correspondingly, dozens of tools and methodologies have been developed. End-users must identify their objectives and prioritise the requirements. This section discusses the main approaches available, their advantages, drawbacks, as well as further development that may be needed.

The most common approach is the scenario analysis, a type of stress test under alternative climate scenarios often based on temperature targets.[17] Many approaches share core elements, drawing on similar datasets, modelling components and methods for evaluating financial performance. However, methodology developers may offer different (and sometimes complementary) methodologies across asset classes, scenarios, and output formats. Figure 7 outlines the analytical framework of scenario-based impact assessment.

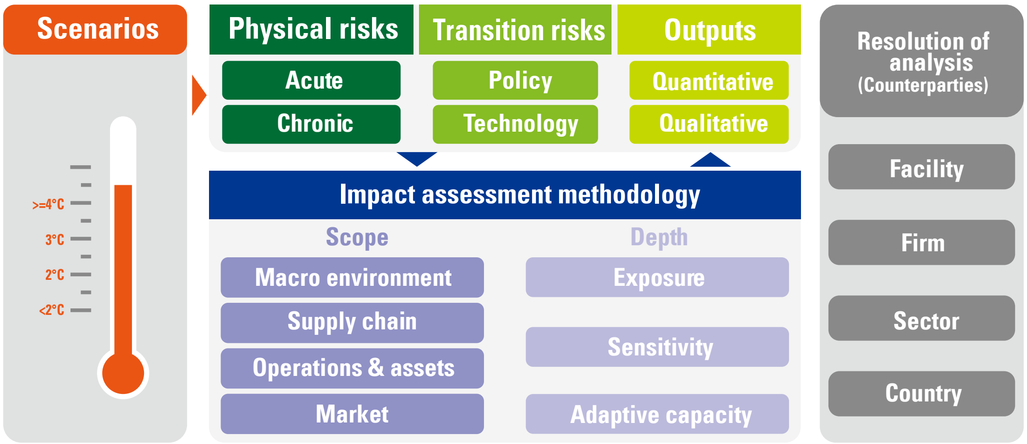


Figure 7
General analytical framework of climate-related risk assessment

Source: Adapted from Vivid Economic 2019[18]

17. For instance, the Paris Agreement scenario indicates 2 degrees or 1.5 degrees climate target; temperature-based targets also correspond IPCC's Representative Concentration Pathway (RCP) scenarios.

18. Taken from UNEP FI changing course report, 2019.

A non-exhaustive list of methodologies can be found in the Appendix, highlighting the commonalities and differences, and areas for development.

In this report, a number of methodologies for analysing both transition and physical risk have been explored. In the following section, each category will be elaborated on and discussed with regard to the modelling rationales, applicability, advantages, and drawbacks.

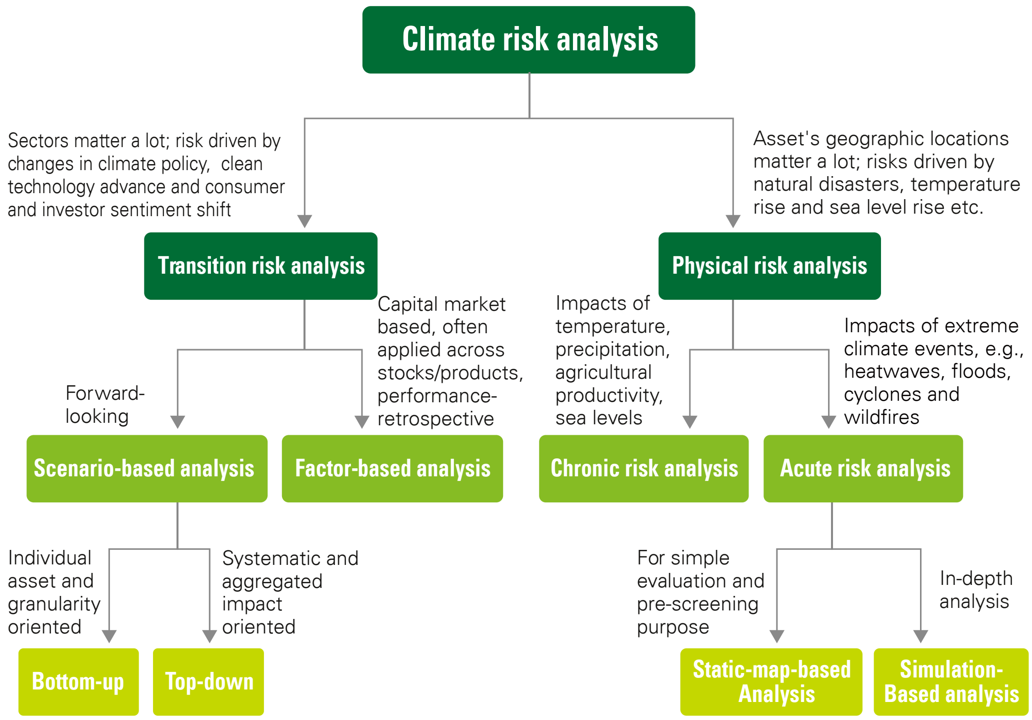


Figure 8
Climate-related risk analysis approaches explored in the report

2.1.1 Transition risk methods

Scenario-based

Translating transition risk into financial risks can be done in four steps[19] (Ma & Sun, 2020).

▶ **Step 1: Setting climate scenarios**

Users select scenarios based on their needs. Scenarios include a benchmark often represented by Business-As-Usual (BAU) scenario, and the alternatives

19. Three steps for corporation to conduct scenario analysis

such as 2 degrees or 1.5 degrees Scenarios of Paris Agreement[20], and Nationally Determined Contributions (NDCs).

▶ Step 2: Transition impact evaluation

Tools such as sector-specific, macroeconomic and Integrated Assessment Models (IAMs) are used to translate the scenario into necessary and optimised efforts, as well as consequent macroeconomic and sectoral impacts, such as adjusted economic growth, sectoral development, carbon cost and renewable energy deployment.

▶ Step 3: Corporation-level impact analysis

This step translates the sector and country-level macro indicators into a corporation's financial performance under the transition scenario given the impact in the previous step. The output is the financial performance of the corporation under different transition scenarios.

▶ Step 4: Financial risk assessment

The output from Step 3 is applied into the financial risk analysis by credit risks models (default model, Merton model, etc.) and valuation models. For example, a bank can feed financial ratios produced in Step 3 into a Probability of Default model (PD model) to determine the default rate of its client. An asset manager can insert data into a Discount Cash Flow (DCF) model to evaluate changes in total asset value. Asset owners can employ the Vector Autoregression model to analyse the impact of expected ROI given the transition risks.

Top-down and bottom-up approaches of impact assessment models

A scenario-based approach must have an impact assessment, which can be either top-town or bottom-up.

A top-down methodology typically refers to a macroeconomic model, of which Computable General Equilibrium (CGE) -based models are most common. They allow assessment of the impact of changes in one part of the economy on the whole, and include variables such as factors of production, sectoral composition and trade. Examples include MAGNET, E3ME, and ViEW. The output of top-down models is presented through adjusted GDP growth, stock market price, CPI/PPI, inflation, interest rate, etc. Top-down approaches

20. Under the group of Paris Agreement scenario (transition scenario), there can be several sub-scenarios describing different settings to achieve Paris Agreement targets.

start with macro-economic models using variables like consumer and government spending, taxation, trade, and production. These approaches often capture systemic risks, but a drawback is the lack of details.

The bottom-up models are often described as Integrated Assessment Models (IAMs). IAMs consider the socioeconomic factors causing GHG emissions and the biogeochemical cycles and atmospheric chemistry that determine how these emissions affect climate and human welfare. One example is the Potsdam Institute for Climate Research's (PIK) Regional Model of Investments and Development (REMIND). These models simulate industrial structure changes and carbon price development under specific climate scenarios. The output of IAMs can be used to project the sensitivity of individual companies according to their climate efforts. Bottom-up approaches look at a company's data such as carbon footprint and mitigation measures to understand how such risks would impact its equity portfolio. One obvious drawback is that such analysis cannot capture the interdependence effect of the economic system.

Box 1, Box 2 and Box 3 (in page 41, page 45 and page 47 respectively) illustrate case studies applying scenario-based climate transition risk analysis.

Factor-based

While most transition risk analysis methodologies are scenario-based, an exception is the factor-based CARIMA model, developed by the University of Augsburg and the Association for environmental management and sustainability in financial institutions (Verein für Umweltmanagement und Nachhaltigkeit in Finanzinstituten e.V., VfU). [21]

The CARIMA concept presents a capital market-based approach, quantifying risks and opportunities of the economy's transition using the historical returns of global stock prices.

Figure 9 outlines the five modules of the CARIMA concept.

21. VfU is a German abbreviation of Verein für Umweltmanagement und Nachhaltigkeit in Finanzinstituten e.V., or the Association for environmental management and sustainability in financial institutions in English.

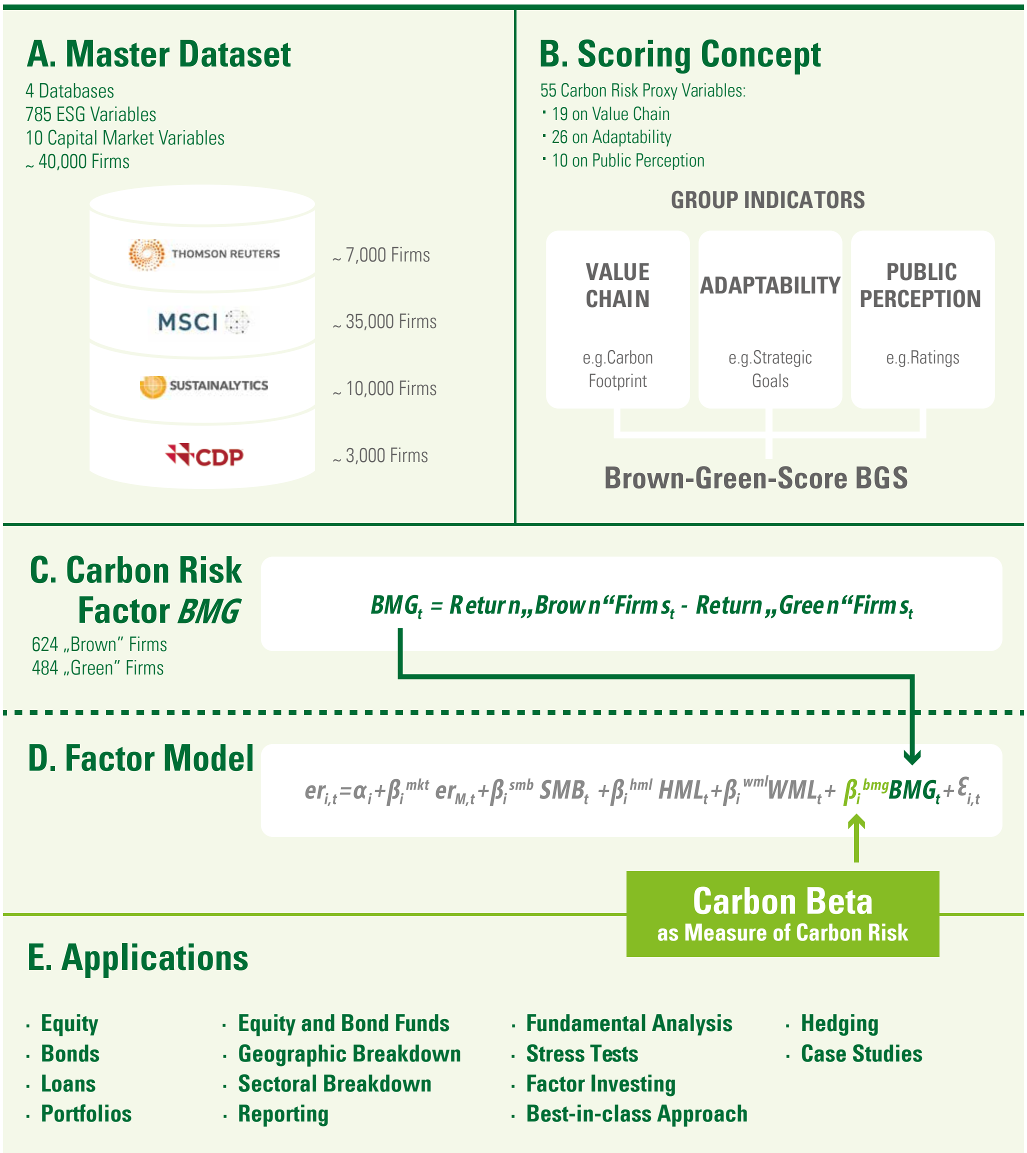


Figure 9
Five modules of the CARIMA concept

Source: Chapter 34 of NGFS (2020a)

Module A (Master Dataset) collects information from firms through combined ESG databases. It assesses a firm's change in value given any unexpected changes during the transition. Combining the databases reduces distortions and integrates several estimation methods, allowing a meaningful Carbon Risk Factor Brown Minus Green (BMG) to be calculated.

Module B describes the 55 Carbon Risk Proxy Variables that help assess how firms' valuations are influenced by unexpected changes in the transition. These variables are assigned to Value Chain, Adaptability, or Public Perception, which represent three channels of carbon risk impact. These scores are then aggregated with weightings into a single Brown-Green-Score (BGS).

Module C constructs the Carbon Risk Factor BMG by putting firms into either a "brown" or "green" group, using the tercile of the average BGS as the breakpoint. The BMG reflects a hypothetical portfolio that longs "brown" and shorts "green" stocks, thus reflecting the return difference between "brown" and "green" firms.

Module D determines the Carbon Beta by applying a regression analysis with historical carbon risks and returns. Carbon Beta reflects the market's perception of the carbon risk of the asset or portfolio, the impact on firms, and valuation changes in a transition.

Box 4 (in page 49) shows an application of CARIMA.

2.1.2 Physical risk methods

Acute risks analysis

1) Scenario based approach

A scenario-based acute climate risk analysis consists of two major components[22]: a disaster loss model and a group of financial models, as illustrated in Figure 10.

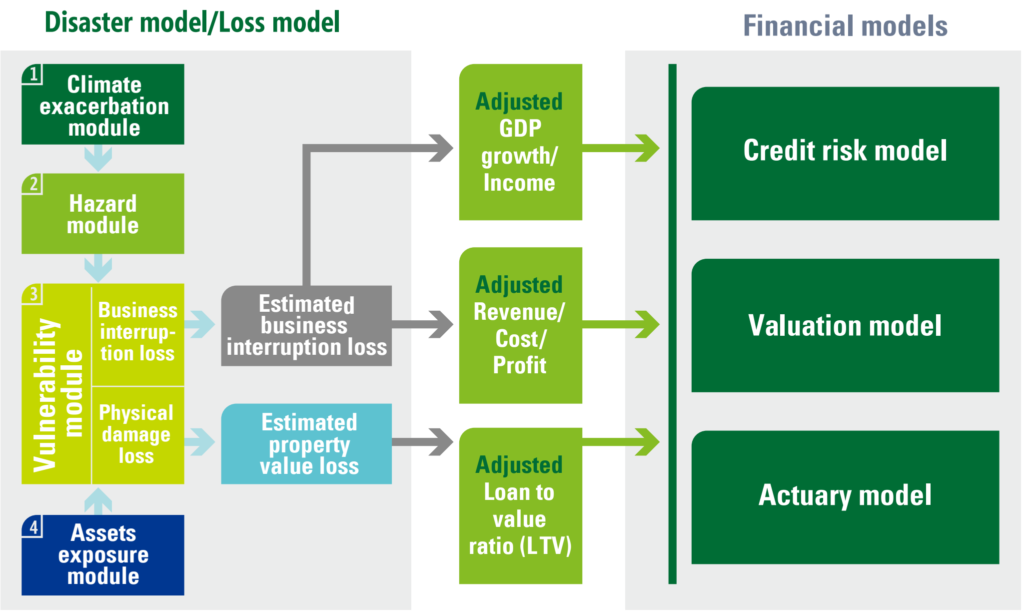


Figure 10 General acute physical risk assessment framework

Source: Sun & Ma (2020)[23]

22. This general concept is proposed by Sun and Ma (2020)'s chapter in NGFS' Occasional Paper 2020.

23. Taken from the Chapter 6 of the NGFS Occasional Paper Case studies of Environmental Risk Analysis Methodologies, 2020.

The disaster loss model estimates the reduction in physical property value, wider economic losses, or losses due to business interruptions from natural disasters. The result is applied into a financial model to adjust the estimated financial statement items of an entity. The adjusted items are later used to calculate financial ratios such as return-on-equity, asset/liability and interest coverage.

The disaster loss model consists of climate exacerbation, hazard, asset exposure and vulnerability submodules. The financial models used in the analysis may include actuarial models for insurance, Probability of Default (PD) models for banking, and valuation models for asset management. The disaster loss and financial models are interconnected by economic and financial variables such as GDP, household income, revenues, costs, and the loan-to-value (LTV) ratio.

Box 6 (in page 56) illustrates an application of this framework that estimates the impact of future typhoons on property prices and consequent mortgage defaults along China's coastal cities.

2) Map-based approach

The map-based approach evaluates the physical risk of a climate hazard by overlapping the geolocation data of assets with the hazard's future geographical profile using a geographical information system. A scoring index of the assets faced with the future hazard can be generated as illustrated in Figure 11. The sensitivity of an asset to the hazard's intensity is derived from empirical observation. For example, facing the same intensity of a typhoon, a wooden structure and a steel structure react differently. The risk index of assets facing physical risks can be used to screen investments.

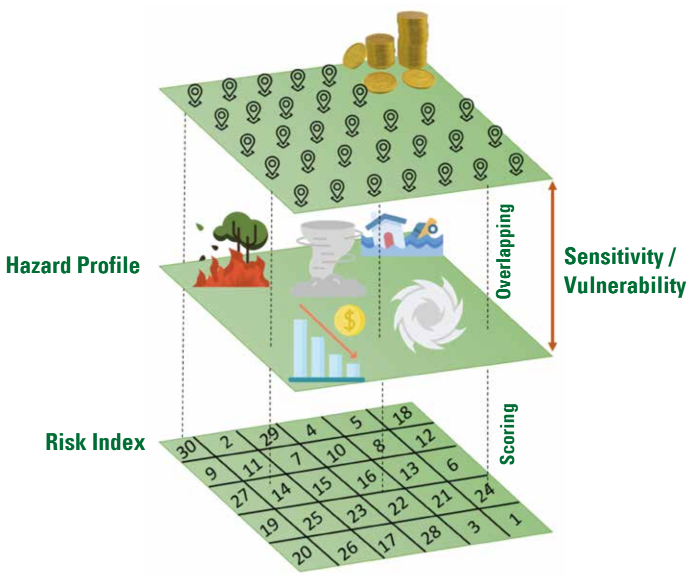


Figure 11
Framework of a map-based climate physical risk evaluation approach

Box 7 in chapter 3 shows an application of the map-based framework.

Chronic risk analysis

Chronic climate risks account for a large share of the potentially adverse impacts. Climate change impacts such as higher global temperature and sea level rise lead to permanent changes in living conditions affecting health, labour productivity, agriculture and ecosystems.

Evaluating impacts from chronic climate risks can be formulated as:

$$\Delta Output = f\,(\Delta Temperature\ Rise)$$

The output is dependent on temperature rise, where the output includes labour productivity, crop yields and tourism income, etc.

Rising temperatures reduce labour productivity as the human body's capacity to function significantly declines with increasingly hot and humid climate conditions. As Figure 12 shows, global physical labour productivity is projected to decrease by up to 18.3% in a 3°C warmer world, about three times worse than if warming was limited to 1.5°C.

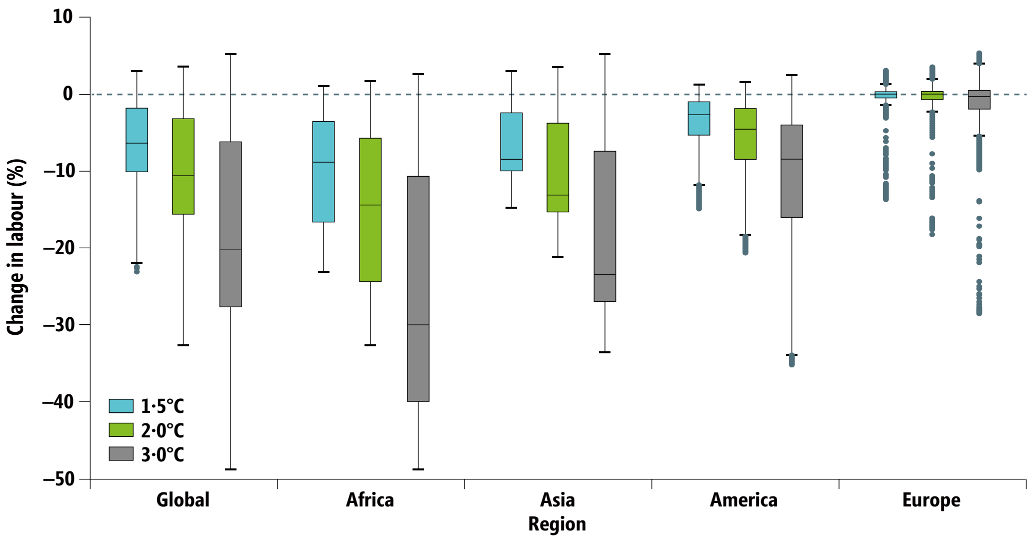


Figure 12 Change in physical labour productivity under climate change

Source: Dasgupta et al. (2021)

The impact is most pronounced in tropical regions, particularly Africa and Asia.

There is also evidence suggesting climate change has a particularly negative impact on crops particularly in tropical regions, and yields are likely to worsen with greater degrees of warming (Moore & Lobell, 2015). Figure 13 shows the differences in low production (10-year minima) at 1.5°C and 2°C. The intensification of low production years is significant across wheat, maize, rice and soybeans, particularly in tropical regions. When temperatures rise by more than 2 °C, the risks are more substantial. Higher mean temperatures increase the chance of reaching the biophysical limits for crop production. This could have implications for food security and employment in regions with relatively large agricultural sectors.

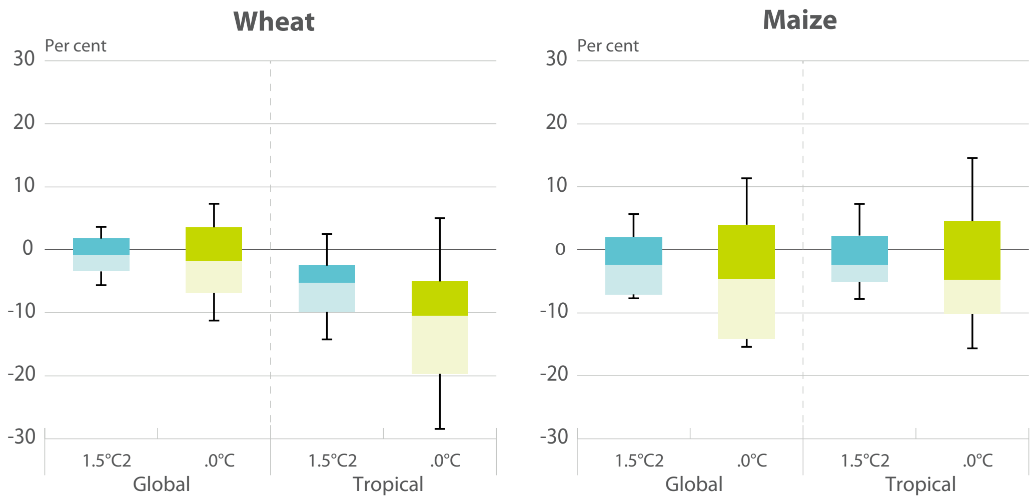


Figure 13
Box-plots of change in crop yields due to temperature rise[24]

Source: Schleussner et al. (2018)

Energy-intensive sectors like the built environment industry are likely to be affected as the demand for cooling and heating changes. There may also be a rising demand for cooling as global temperatures increase.

Climate change may adversely affect transport on some rivers. In Europe, some rivers are losing transportation capacities due to low water levels.[25] Tourism activities could also be slowed in hot areas particularly in South Asia (OECD, 2015). Moreover, rising sea levels will create more damaging superstorms[26] and forced mass migration. The increased costs of damage from extreme weather (storms, hurricanes, typhoons, floods, droughts, and heat waves) will increase rapidly at higher temperatures. Based on simple extrapolations, costs of extreme weather alone could reach 0.5–1.0% of world GDP per annum by the middle of the century, and will keep rising if the world continues to warm (Stern, 2007).

24. Box-plots (also known as box and whisker plot) is a type of chart often used in explanatory data analysis. Box-plots visually show the distribution of numerical data and skewness through displaying the data quartiles (or percentiles) and averages. Box-plots show the five-number summary of a set of data: including the minimum score, first (lower) quartile, median, third (upper) quartile, and maximum score. The boundary lines between bold and lighter colour boxes indicate the median values.

25. See "Market Insight", Central Commission for the Navigation of the Rhine, April 2019.

26. The 20cm rise in sea level the 1950s was estimated to have raised the surge losses associated with the 2012 superstorm Sandy in New York by 30%, see Toumi & Restell (2014).

2.2

Limitations of pricing climate-related risks and future developments

Climate-related risk assessment is complex, and still only in its infancy. Tools or methodologies are being constantly updated to allow for more granular analysis that takes into account a broader, more plausible set of scenarios, access to more granular datasets. Current methods assessing transition risks have limitations (Peel et al., 2020; UNEP FI, 2018, 2021).

Key limitations and suggested avenues for addressing them are:

- **Limited consideration of adaptation and impact transfer.** A business' ability to adapt can directly affect risks and should be explored. Few of current approaches and case studies discuss if the impacts arising from climate transition can be transferred to or shared by a firm's downstream or its clients. Strategies to transform and adapt to the transition pathways are examples of adaptive capacity indicators.

- **Other scenario types.** Until now, many models have relied on one type of scenario, particularly those defined by the IEA, targeting sectors with high carbon emissions. However, IEA scenarios have had to be updated to account for fast-developing low-emission technologies which results in the increasing usage of multiple or bespoke scenarios. Several bespoke transition scenarios at the sector level are being developed to improve accuracy or to model alternative transition or demand shocks. However, a bespoke approach and complex risk assessment tools may mask the parameters and assumptions of the risk analysis. To improve transparency and comparability, the NGFS released a set of reference scenarios in early 2020. The NGFS scenarios also need further improvement to address sectoral and regional granularity. They should also incorporate market drivers such as technological changes and alternative policy responses (Pierfederici, 2020).

- **Other risk drivers.** The transition risk drivers studied so far are mostly policies-related, quantified through a carbon price variable. Technological changes and reputational risk factors are less covered. Policy risk coverage should include wider climate policies, such as minimum standard, energy regulation, emission cap, and technology phase-out.
- **Longer time horizon.** Quantitative tools of climate risks analysis face challenges when modelling time horizon is extended to a longer term, given that conventional modelling for forward-looking purpose is very often short-term based. Building forward-looking transition risk models using historical data can also be challenging, given that historical data cannot predict climate changes. The lack of longer-term consideration makes it difficult to include transition risks into risk management frameworks.

While the current methods to quantify physical climate risks are also limited, the quality of the models and data will improve if investors demand for actionable decisions (Hubert et al., 2018; UNEP FI, 2021).

- **Limited scope of analysis.** The approaches do not sufficiently address the interdependent nature of climate impact. Most approaches analysing climate impacts fail to fully address the macro- and socio- economic consequences of climate hazards. Some methods have limited scope on a company's value chain, while others lack separate information based on the types of impacts.
- **Limited transparency.** Most analyses do not disclose the core of the methodology, such as the characteristics of some databases and the sensitivity of entities exposed to climate hazards. The tools and models are often provided by commercial vendors, so the detailed information and analysis process are not fully provided to users or commissioners. Transparency is a key requirement to properly use the information to make decisions (Bruin et al., 2019).
- **Entities' specific characteristics.** Methodologies analysing impacts on companies require large company-specific data. There is a lack of data on production sites and the company's key partners, therefore adaptive capacity is not accounted. Sensitivities are at sectoral rather than company level, and empirical evidence should be more precise. A forward-looking approach may better anticipate how counterparties evolve and adapt to climate hazards.

- **Limited data availability.** A low availability has been a major issue for both hazards and assets-related geospatial data. Geospatial data are fundamental to physical climate risks analysis, as extreme weather and climate hazards are highly location dependent, especially acute risks such as coastal and fluvial flooding and wildfires. Such data are largely missing in the collection and management systems of financial institutions (FIs). Increasing access to third-party may make physical risk analyses more granular, and allow for more accurate risk analysis.
- **Limited compatibility with financial institutions' decision-making.** Some aspects of physical climate risk information are incongruent with FIs' decision-making processes. For example, the time horizons available from climate scenarios are much longer and therefore incompatible with the shorter investment time horizons of FIs. These climate models also explore the uncertainties of future climate conditions, and socio-economic behaviours that financial models cannot properly integrate. In addition, data limitations make these approaches difficult to replicate on larger portfolios. Further research is needed to help FIs better use physical climate risk information (Depoues et al., 2019).

Table 4 and Table 5 below present the common methodologies and models for analysing climate-related risks, highlighting features including top-down or bottom-up approaches, time horizon, strengths and weaknesses, complexity, and applicability as well as granularity and aggregation.

Table 4: Comparison of the climate transition risk analysis approaches[27]

Sources of risk	Transition risks		
Risk drivers	1. Policy - e.g. introduction of carbon pricing mechanism; 2. Technology - e.g. clean technologies of power generation, e-vehicle replacing combustion engine; 3. Market - e.g. consumers prefer products with less carbon footprints; more investors changing their investment appetite to climate-friendly assets; 4. Legal - e.g. litigation claims brought by various stakeholders on an organisation's failure to mitigate climate change; 5. Reputational - e.g. scandals of violating environment or climate goals.		
Sensitivity factors	Sectors; carbon-intensive or clean technologies		
Model types	Scenario-based		Factor-based
Impact modes/Assessment model	**bottom-up approaches:** different integrated assessment models (e.g. GCAM. REMIND, MESSAGE models). financial models. Climate VaR	**top-down approaches:** large scale econometric models, e.g. NIGEM,E3ME etc.	regression based factor model
Examples	Tsinghua's transition risk model, 2 degrees initiative investing, Vivid Economics, Oliver Wyman, Carbon Delta (Climate VaR)	Ortec Finance	University of Augsburg and VFU
Intermediate outputs: Financial implications& Financial models linked	counterpart's financial ratios+PD model and valuation model	GDP & macro econometric model inflation, interest rate; carbon intensity of sectors; allocation of impacts on macroeconomic variables to sectors and corporations	quantified risks and opportunities for firm values (carbon betas) & capital market-based approach
Time horizons typically applied	5-15 years	5-10 years	N/A
Strengths	allows for a very granular, company level view	captures systemic risks (the networked effects)	no need for detailed fundamental climate change-relevant information about firms, which is difficult and expensive to obtain or even not available
Weaknesses	ignores networked effects	weak in assessing micro level risk	based on historical data, weak in forward-looking feature
Applicability versus complexity	complex	relatively complex	less complex
Granularity	granular	less granular	granular
Aggregability	can be aggregated across sectors and firms	already aggregated	can be aggregated across sectors and firms

27. Note: time horizon explicated for different models and risks types here are only indicative not precise, it can be specifically defined according to needs. The indication of "Applicability and complexity" aims to qualitatively describe the relative ease of use of specific methodologies; "granularity" indicates the granularity of objects to be analysed, for instance if individual firms or sectors or even the macroeconomic system as a whole are/is analysed; "Aggregability" refers to the ease and level of aggregating risks of individual firms and assets and the interconnected effects between them.

Table 5: Comparison of the climate physical risk analysis approaches

Sources of risk	Physical risks		
Risk drivers	**acute types of risks:** more frequent and intensive extreme weather events and natural disasters, less predictability in the occurrence of these extreme weather events		**chronic types of risks:** temperature associated impacts including decrease in labour productivity, crop yields and tourism industry etc. sea level rise
Sensitivity factors	geographical locations, if the assets located in areas where is natural disasters prone or sensitive to global temperature rise		
Model types	scenario simulation- based	static map - based	scenario analysis based
Impact modes/Assessment model	simulation - based CAT models and econometric models (e.g., relationship between hazard frequency and GDP)	CAT map overlapping models and scoring system with sensitivity or vulnerability assessment	damage functions (e.g., FUND, RICE, DICE) of labour productivity, crop-yields, tourism income, infrastructure functionality
Qualitative or quantitative outputs	quantitative	ordinal	quantitative
Examples	Tsinghua's physical risk model, Acclimatise's advanced model, Carbon Delta's Climate VaR model	Moody's 427, Acclimatise's pre-screening tool	Yale, UCB, Climate Analytics, PIK
Intermediate outputs: Financial implications& Financial models linked	physical damage of property and assets, loss of revenue, profit, production and income + PD model and valuation model	hazard map, vulnerability of assets, risk index	reduced production, income, crop yields and macroeconomic output
Time horizons typically applied	10-80 years	10-80 years	10-80 years
Strengths	analyse tail risks effectively; addresses some climate uncertainty	simple and easy to implement, final results are intuitive and user-friendly	address systemic impacts
Weaknesses	high technical requirement, data intensive, high uncertainties	only rough estimation and for a preliminary assessment	underestimated results magnitude, most not taking into account the evolution of socio - economic systems
Applicability versus complexity	highly applicable	highly applicable	use case dependent
Granularity	can be highly granular or aggregated	highly granular (project component level)	can be highly granular or aggregated
Aggregability	can be aggregated across different levels	can be aggregated at company or company - country level	can be aggregated across different levels

CHAPTER 3

Case Studies of Climate Risk Analysis

Key messages:

a. Case studies are selected and organised first by either transition risks or physical risks. Under each risk, case studies for most relevant industries or sectors are illustrated;

b. The financial performance of companies with core businesses in fossil fuel-based power generation, cement and beef protein production will suffer more from increased carbon costs, declining demand and price of products. This is due to substitution and other indirect risk factors, characterised by deteriorated financial metrics, increased PD, depreciated values of equity or bonds;

c. Businesses can better understand their current situations through climate risks analysis. They can choose the appropriate transition pathways, apply strategies in their business portfolio or invest in mitigation efforts depending on their business models, EBITDA and other characteristics;

d. Banks and other FIs can benefit from having more detailed information on asset valuation that account for changes from transition events.

Photo by Road Trip with Raj on Unsplash

3.1

Transition risk analysis

This section illustrates case studies (see brief summary in Table 6 and Table 11) to help readers understand how the representative sectors are impacted by climate change and climate change mitigation efforts, and how this analysis may be conducted.

Table 6 Summary of illustrative cases for transition risk analysis

Box	Sectors	Geographic Scope	Methodologies	Risk Drivers	Financial Metrics
1	A: Thermal power	China	Scenario-based analysis	1) **Policy:** Carbon price increase, shrinking quota 2) **Market:** Market demand change, rising funding/financial costs 3) **Technology:** Aggressive cost reduction of renewable technologies	Financial performance, PD
	B: Cement	BRI countries in Asia	Scenario-based analysis	**Policy:** Carbon price increase	Solvency, liquidity, profitability
2	Livestock (meat)	Global	Scenario-based analysis	1) **Policy:** Increased cost of energy and electricity due to introduction of carbon price 2) **Market:** Lower demand due to higher meat price considering carbon cost 3) **Technology:** Availability of substitutes	Profitability
3	Wind and Solar	Europe, USA, Latin America	Scenario-based analysis	1) **Policy:** Benefit from carbon credits 2) **Market:** Growing market demand	PD, equity valuation
4	Stocks and Funds	Global	Factor model (capital market approach)	Different from the cases above, and risks drivers are not much applicable here, the impact or risk are dependent on the overall market carbon risk and the specific Beta a stock or portfolio has to the carbon risk	Return

Box 1
Pricing climate transition risks in Asia's carbon-intensive sectors

Key takeaways

- The one-year default probabilities on the loans of coal-fired power companies can increase eightfold in a transition scenario from the baseline in 2020 to 2030.
- The financial performance of a cement production company in terms of solvency, liquidity and profitability deteriorates significantly in 10 years if a carbon tax is introduced without proactive mitigation measures.

Case A Pricing transition risk into coal-fired power companies in China

This case study estimates the average Probability of Default (PD) of representative Chinese companies in the thermal power sector under various climate-related transition scenarios.

Methodology

The climate risk drivers of energy transition that may impact companies include changing demand, progressive cost reduction of renewable technologies, increasing carbon prices and rising funding costs. More specifically, the study estimates the differences in companies' financials among alternative climate mitigation scenarios and the changes in PD of these companies receiving financing from banks and the bond market.

As shown in Figure 14, the climate risk pricing framework consists of four steps (for businesses and FIs): setting climate scenarios, transition impact evaluation, corporate impact analysis, financial risk assessment.

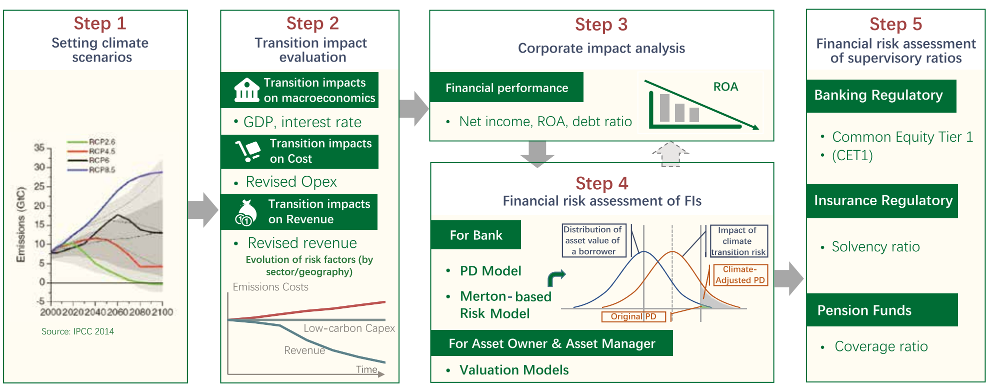


Figure 14
Framework of climate transition risk analytical model

▶ Step 1: Setting climate scenarios

A climate risk analysis first requires setting the climate scenarios based on the annual global emission targets and the public policies needed to achieve them. Two climate scenarios are considered: baseline and the 2-degree scenario. The baseline scenario assumes that no changes in climate measures are taken in China, i.e., no further mitigation efforts to curb demand, no changes in carbon prices, no further development of renewable and energy-saving technologies, and no changes in funding costs for thermal power firms. It serves as a benchmark for the other scenarios to evaluate the variables being studied. For the 2-degree scenario, the demand reduction (dropping nearly half by 2030 compared to baseline scenario) projection of coal-based power generation was provided by the IEA ETP's scenario (International Energy Agency, 2017). The carbon price increase (a surge of up to USD 70 by 2030 from the current USD 10) was estimated by World Bank and the cost reduction of renewables was estimated by Bloomberg.

▶ Step 2: Transition impact evaluation module

The transition impact module describes a sector's potential changes in its performance under a set climate scenario or pathway compared to baseline. The sector's performance includes changes in demand, changes in production costs and sale prices under the given climate scenarios. For example, under IEA ETP's 2DS scenario, coal-fired power generation is estimated to drop nearly 50% accumulated from 2020 to 2030 (International Energy Agency, 2017). In this study, the output of IEA's ETP-TIMES supply model is used to parameterise the demand or production changes of coal-fired power generation and renewables (wind and solar power). They then serve as input for analysis in the corporate impact module.

▶ Step 3: Corporate impact analysis module

The corporate impact analysis module incorporates climate scenarios (e.g., impact on demand and funding costs) into the company's financial analyses, and estimates the changes in financial indicators, such as revenues, costs, profits, assets, liabilities, and equities and various financial ratios of the affected companies. Specifically, the module projects changes in the three main financial statements to reflect the direct effects of climate-related transition. The outcomes are then used as inputs or explanatory variables in financial risk models, such as the PD and valuation models, which study the impact on banks and investors.

▶ Step 4: Financial risk assessment module

The financial risk assessment module can utilise various financial models, such as PD models, to quantify the impact of the climate transition shocks on credit by integrating the outcome from the corporate impact module. In this case study, a PD model is employed to estimate the impact of the climate transition on the default rates of thermal power companies in China.

Results

Figure 15 shows the estimated average annual PD values of the three Chinese thermal power companies. Under the 2 degrees scenario, which considers carbon price increase, competition from renewables, and increasing funding cost, the average PD surges from about 3% in 2020 to 23% in 2030, a more than eightfold increase. This clearly shows that in 10 years, the likelihood of credit default by thermal power companies will be extremely high and unsustainable.

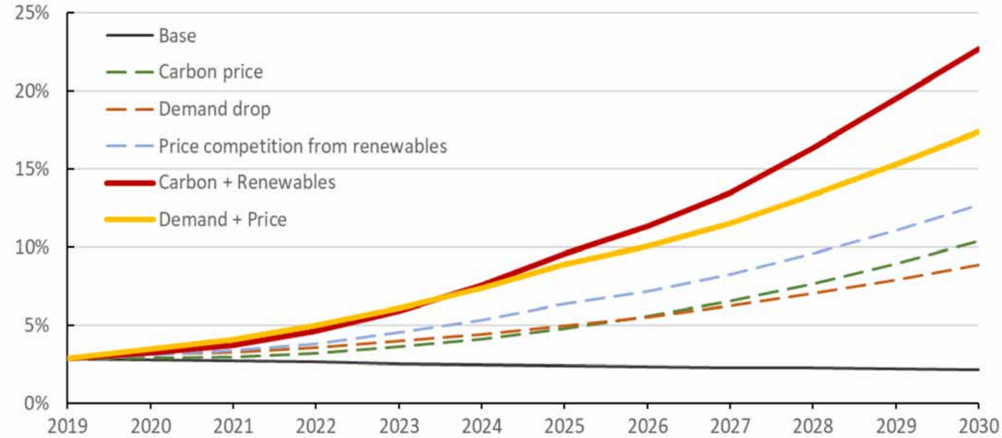


Figure 15
Average PD value of Chinese thermal power companies under different scenarios

A deeper look into the key drivers and the results shows that:

- Among reduced demand, carbon price and price competition from renewables, price competition is the greatest contributor to the incremental Probability of Default, implying that technological progress should be of greater concern to businesses and their stakeholders.
- Carbon price is the second biggest driver. Combined shocks from carbon price and renewables led to the most severe PD deterioration, so they should be comprehensively considered by thermal power companies.
- The PD impact on financial costs will accumulate and exert greater stress on the company's financing costs each year.

Case B Pricing transition risks for an Asian cement producer

The case study looks at a typical cement company in a developing Asian country. The key financial metrics on solvency, liquidity and profitability are stress-tested under scenarios of NDC and 2DS in the period between 2020 and 2030, benchmarked to a baseline scenario.

Baseline: no internal or external shocks and the business operates as usual.

NDC (or 2DS) scenario: Under the carbon budgets designed to achieve the National Determined Contributions (and 2 Degrees Scenario) goals, business face increased carbon price costs induced by the transition policies.

When considering a single carbon price shock compared to baseline, the financial indicators of the company deteriorate under NDC and worsen further in a stricter 2DS scenario (see Table 7).

Table 7
Financial impact of transition on a cement company under two scenarios

Aspects	Indicators	Scenarios	2020	2025	2030
Solvency	Debt ratio	Baseline	0.34	0.31	0.29
		NDC	0.34	0.32	0.32
		2DS	0.34	0.34	0.50
	Interest coverage ratio	Baseline	3.17	2.67	2.66
		NDC	3.06	1.95	1.03
		2DS	2.99	0.35	-3.96
Liquidity	Current ratio	Baseline	1.16	1.46	1.79
		NDC	1.16	1.34	1.34
		2DS	1.15	1.12	0.40
Profitability	Return on assets	Baseline	3.4%	2.7%	2.4%
		NDC	3.2%	1.6%	0.1%
		2DS	3.1%	-1.1%	-10.4%

- The profitability of the cement company decreases significantly with higher carbon prices under 2DS scenario.
- When comparing the results, one should note that the metrics under the baseline also change, so the metric changes (deterioration) under transition should be seen together with the results under baseline.

Source: J. Ma and T. Y. Sun (2020)

Key takeaways

- The urgent transition risks faced by the meat sector include increasing carbon cost, reducing market demand and increasing cost of electricity.
- Companies with higher EBITDA, more diversified protein portfolio and exposures to alternative protein will be more resilient.

Box 2
Impacts of transition factors on livestock sector - meat value chain

The Coller Farm Animal Investment Risk and Return (FAIRR) initiative identifies the key transition risks faced by the protein sector and estimates how the profitability of the representative companies in the protein/ livestock sector may be impacted.

Using its in-house modelling tool, FAIRR analysed how the profitability of meat companies can be impacted by protein substitutes, demand constraints and rising costs due to climate change. A *FAIRR high substitution pathway* and a *FAIRR low substitution pathway* are both considered in order to project the future market demand for alternative protein. Changing consumer preferences and the speed and scale of alternative protein development, can also impact profitability.

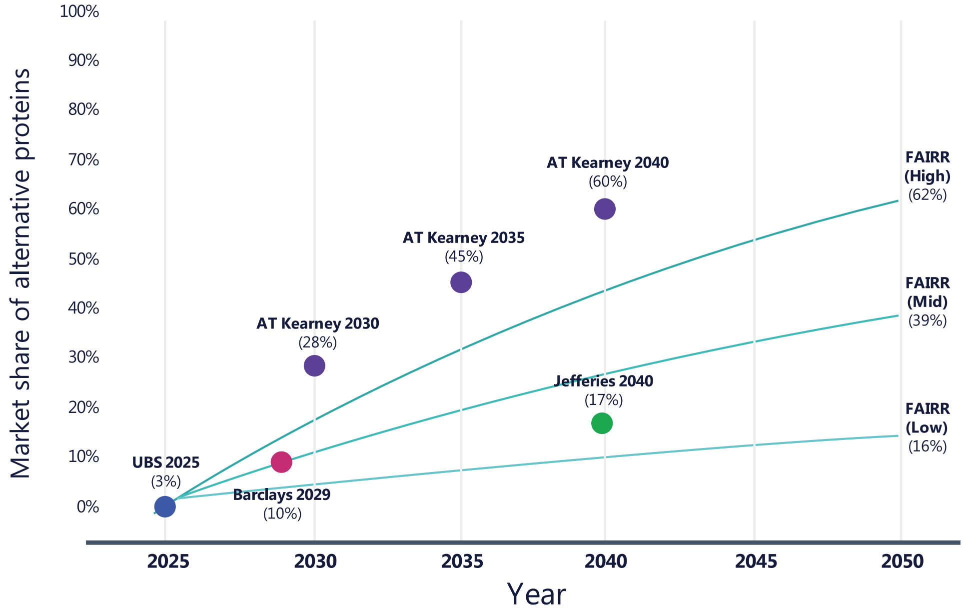


Figure 16
Market share of alternative protein

Also, the three optional pathways a company may take are *Baseline (market pathway), Climate progressive pathway* and *Climate regressive pathway*, where the company makes *limited, strategic* and *no shift* in protein mix respectively.

The tool, focusing on the processing step in the protein value chain, was applied to five meat companies (Maple Leaf, Tyson, JBS, Minerva Foods and BRF) that produce beef, poultry and/or pork. The following diagram briefs the key outputs of the analysis.

The results (see Figure 17) on the five companies suggest that the profitability of companies would benefit from high EBITDA margin, diverse protein mix and exposure to alternatives.

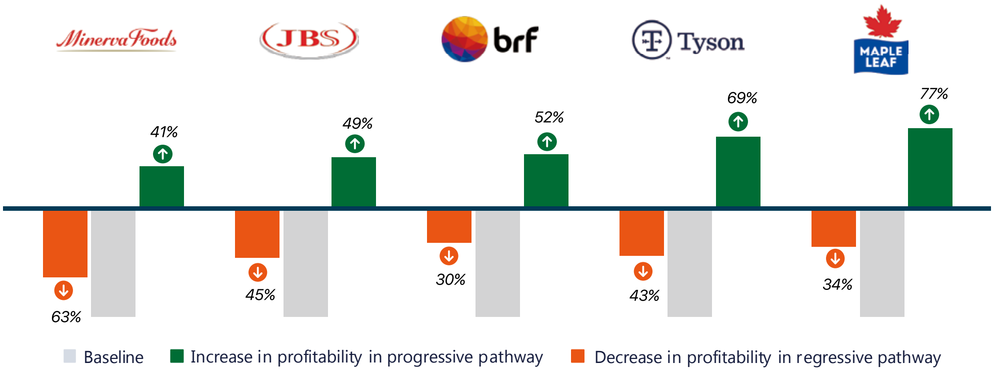


Figure 17
Profitability of the companies when different pathways are taken

Taking a deeper dive to interpret the model results, here we summarise two examples provided by FAIRR.

Maple Leaf Foods

- Higher EBITDA enables it to better absorb the costs induced by climate risk events.
- Progressive mitigation efforts can lead to 77% increase in the profitability compared to the baseline (limited efforts).
- No shift in efforts can lead to 34% reduction in the profitability compared to the baseline (limited efforts).

Minerva Foods

- Relatively low EBITDA makes it harder to absorb incremental costs.
- The lack of alternative protein business leaves the company vulnerable to the undiversifiable risks of shocks.
- Progressive mitigation efforts can lead to 41% increase in the profitability compared to the baseline (limited efforts).
- No shift in efforts can lead to 63% reduction in the profitability compared to the baseline (limited efforts).

Source: The FAIRR Initiative (2020)

Key takeaways

- Equity values of both sectors benefit from the transition.
- Bond defaults can be reduced from the transition.

Box 3
Appreciation of assets in wind and solar power sectors

The 2° Investing Initiative (referred to as 2DII hereafter) stress-tests the equity values and bond's default probabilities of wind and solar power sectors under a "too late, too sudden" transition scenario. The following describes the climate risks stress test (also see summary in Figure 18).

- **Step 1:** Identify relevant financial indicators
- **Step 2:** Identify granularity and sourcing of data
- **Step 3:** Establish "too late, too sudden" scenarios
- **Step 4:** Adopt evaluation methodologies according to asset classes
- **Step 5:** Benchmark results of each firm/portfolio under BAU scenario against the "late and sudden" scenarios

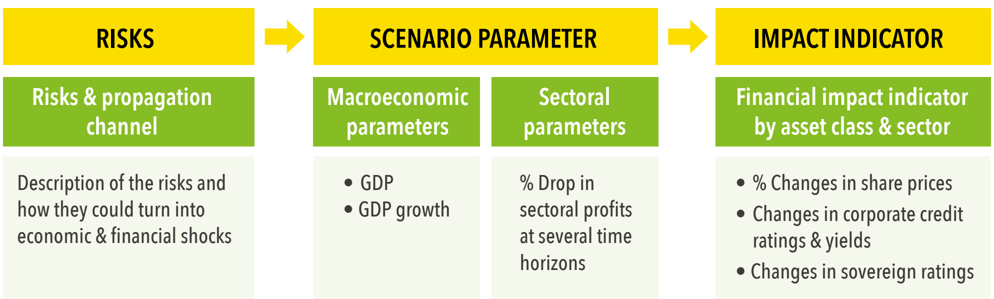


Figure 18
Stress-testing framework & indicators displayed

Financial indicators

Table 8 shows potential financial indicators identified by 2DII. In the case of wind and solar power sector analysis, *production, prices, Levelised Cost of Electricity (LCOE) and subsidies* are used to quantify the transition impacts.

Table 8
Financial indicators needed to quantify the transition impact

How transition risks impact profits?	Relevant indicators to quantify
Increased cost of emitting carbon	Production, carbon intensity of production, carbon tax
Increased costs of production inputs	Prices of production inputs
Extra depreciation and R&D expenditures	CAPEX, R&D expenditures, all other OPEX
Fluctuations of revenues	Production, selling prices

Scenarios

The “too late, too sudden” transition scenario was first introduced by ESRB (2016) and further developed by UN PRI (2018), assuming a “Climate Minsky” moment by 2025.

Risk (opportunity) drivers considered in this case study are changes in market demand and carbon cost/benefit.

Asset value deviation in the wind and solar sector

New equity assets are estimated using the dividend valuation model, while debt assets are valued through adjustment of future cash flows based on the adjusted Probability of Default (PD) estimated by Zmijewski’s bankruptcy model.

For the solar PV and wind electricity sectors, 2DII obtains the results below (see Table 9). The changes in equity value, reflecting the profitability and asset quality of the companies, indicate a 19.2% and 12.8% appreciation in solar PV and wind electricity. The favourable changes in the PD and bond values in both sectors reflect improved cash flow and profitability, indicating opportunities favouring the sectors.

Sector	Mean change in equity value	Mean change of 1-year PD (2018-2035)
Solar PV	19.2%	2%→0%
Wind electricity	12.8%	2%→0%

Table 9
Sector impact compared to BAU scenario under a "too late, too sudden" scenario

- The assets in the solar PV and wind electricity sectors appreciated by nearly 20%, reflecting opportunities from possible carbon price income and rising demand.
- Annual probability default decreased from the baseline’s 2% to almost 0% due to the improved financial performance, having benefited from the transition.

Source: The 2° Investing Initiative (2019)

Box 4
A factor-based approach to estimate the transition risks of "green" and "brown" sectors

Key takeaways

- The Carbon Betas of "brown" stocks are positive, while that of "green" stocks are negative.
- The US GI World Precious Minerals Fund has a high carbon risk with a Carbon Beta of 2.59, suggesting that in a transition event, the fund would be adversely affected. Funds with negative Carbon Betas, would benefit from transition.

CARIMA offers a market-based approach to quantifying carbon risks using factor models. The estimated Carbon Betas can be used to compare the carbon risk exposures of different firms. If the Carbon Beta is greater than zero, the asset value may fall in a transition event[28]. If the Carbon Beta is negative, the asset value will rise.

Methodology

▶ Step 1: Master Dataset

Collect fundamental information from firms to assess a firm's change in value in the event of unexpected changes as the economy makes the transition.

▶ Step 2: Scoring Concept

Select 55 Carbon Risk Proxy Variables to support a fundamental assessment of whether the value of a firm is influenced positively or negatively by unexpected changes in the ongoing transition. The information from these 55 variables is condensed into three groups of indicators, Value Chain, Public Perception and Adaptability, via a simple scoring concept to calculate the Brown-Green-Score BGS for each firm.

28. A transition event can be interpreted as a policy release or a measure taken by government to facilitate transition towards to low-carbon economy.

▶ Step 3: Carbon Risk Factor BMG

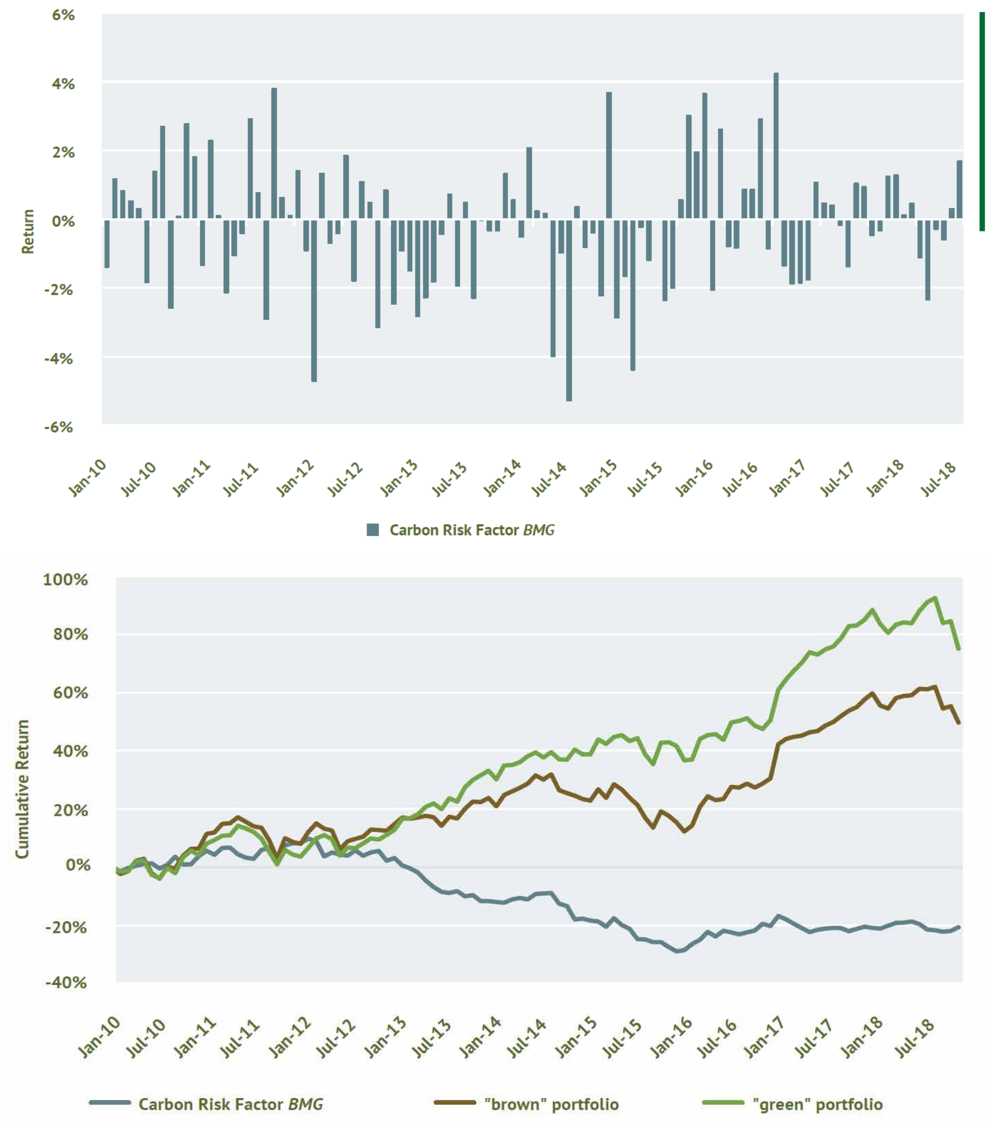


Figure 19
The monthly and cumulative returns of the Carbon Risk Factor BMG (2010-2018)

Construct the Carbon Risk Factor BMG based on the firm's average BGS and divide them into a group of "brown" and "green".

Figure 19 shows the monthly and cumulative returns of the Carbon Risk Factor BMG in 2010-2018 respectively. BMG is the difference between the historical returns from "brown" firms and those from "green" firms. There is a cumulative return of -20% overall from 2010 to 2018.

▶ Step 4: Factor Model

Add the Carbon Risk Factor BMG to the Carhart four-factor model, an updated model of the very well-known Fama and French three-factor model.

$$er_{i,t}=\alpha_i+\beta_i^{mkt}\, er_{M,t}+\beta_i^{smb}\, SMB_t+\beta_i^{hml}\, HML_t+\beta_i^{wml}\, WML_t+\beta_i^{bmg}\, BMG_t+\varepsilon_{i,t}$$

With:

$er_{i,t}$ = return on an asset i minus return on a risk-free investment in period t (excess return)

$er_{M,t}$ = excess return of the market in period t

SMB_t = return of the global size factor in period t

HML_t= return of the global value factor in period t

WML_t = return of the global momentum factor in period t

BMG_t = return on the global Carbon Risk Factor BMG in period t

$\alpha_i,\beta_i^{mkt},\beta_i^{smb},\beta_i^{hml}$ and β_i^{wml} = parameters α_i and β_i^x of the Carhart Model

β_i^{bmg} = Carbon Beta of the asset i

Determine the Carbon Beta by applying a simple regression analysis with historical carbon risks and returns. Carbon Beta reflects the capital market's assessment of the carbon risk of the respective financial asset or portfolio.

Results

Table 10 shows the descriptive statistics of the monthly Carbon Risk Factor BMG and its correlations with other global risk factors. The average monthly return on the BMG is negative at −0.25%, the standard deviation is 1.95%. The correlations between the Carbon Risk Factor BMG and the market, size, value, and momentum factors are all relatively low, meeting the requirement of adding BMG to the four-factor model.

Table 10 Descriptive statistics of the monthly BMG

Factor	Average return (%)	Standard deviation (%)	T-stat.	Correlations				
				BMG	er_M	SMB	HML	WLM
BMG	-0.25	1.95	-1.17	1.00				
er_M	0.76	4.02	1.74	0.09	1.00			
SMB	0.06	1.39	0.37	0.20	-0.02	1.00		
HML	-0.00	1.68	-0.02	0.27	0.19	-0.06	1.00	
WML	0.57	2.53	2.06	-0.24	-0.20	0.00	-0.41	1.00

Carbon Betas for Stocks

Figure 20 shows the calculated Carbon Betas using some firms as examples. "Brown" firms show higher Carbon Betas while firms with low Carbon Betas are usually classified as "green". Some firms have Carbon Betas close to zero, which means they are not sensitive to carbon risk.

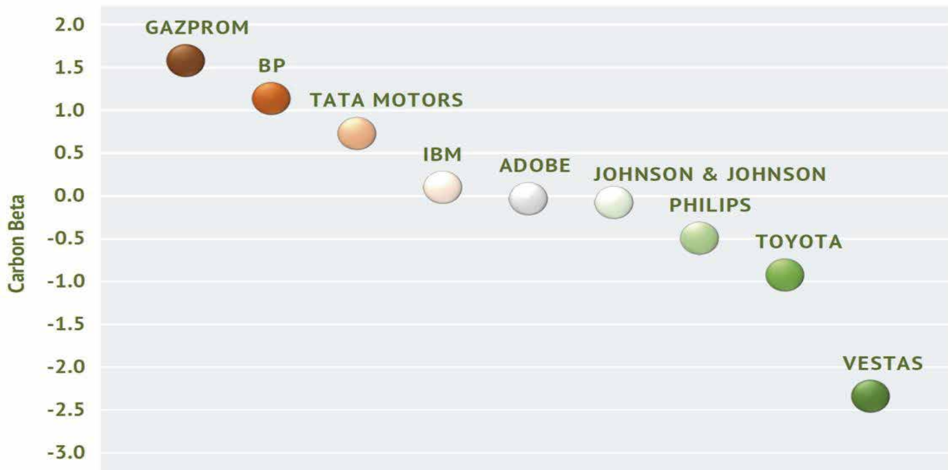


Figure 20
Carbon Betas of some example stocks

However, a firm that does not burn fossil fuel itself and is commonly seen as "clean", can also have a positive Carbon Beta and be a "brown" firm by CARIMA definition. This depends on whether it relies heavily on "brown" assets.

Carbon Betas for funds

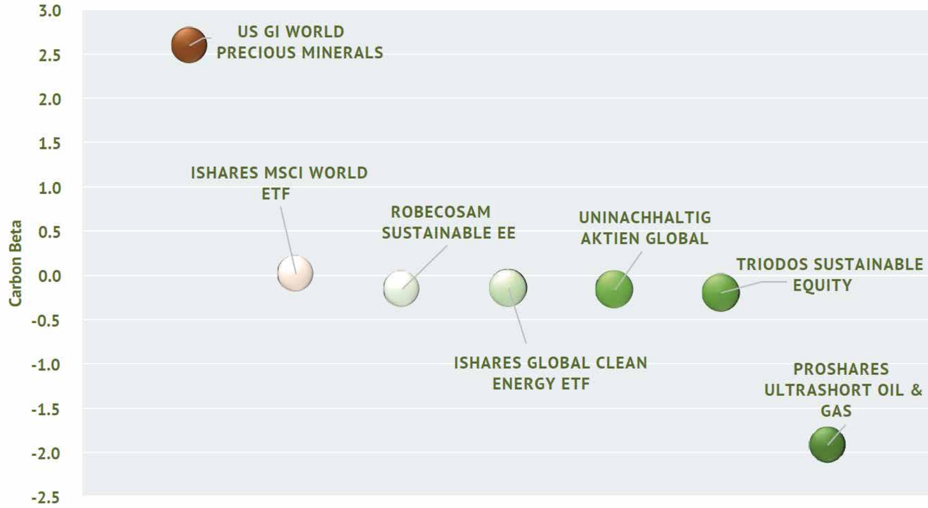


Figure 21
Examples of the Carbon Betas of some funds

Figure 21 shows the Carbon Betas for some funds estimated using monthly data from January 2010 to December 2018. The US GI World Precious Minerals fund has a high carbon risk with a Carbon Beta of 2.59, suggesting that it can be negatively impacted in a transition event. In contrast, ProShares UltraShort Oil & Gas which has a negative Carbon Beta, can benefit much from a low-carbon transition. While some funds such as RobecoSam Sustainable EE and iShares Global Clean Energy ETF, have Carbon Betas around zero and are not sensitive to transition.

Source: Chapter 34 of NGFS (2020)

3.2

Physical risk analysis

Table 11
Summary of illustrative cases for physical climate risks analysis

Box	Sector	Geographic Scope	Methodo-logies	Risk Drivers	Financial Metrics
5	Agriculture	Multi-national, not specified	Scenario simulation-based analysis	**Acute types of risk:** Increased frequency of climate disasters	PD, rating
6	Real Estate (mortgage loan)	Coastal cities of China	Scenario simulation-based analysis	**Acute types of risk:** Increased frequency and intensity of Typhoons	Property value, PD of mortgage loan
7	Multi-sector	Global	Static map-based analysis	**Acute and chronic types of risks:** Increased frequency of climate disasters, sea level rise, temperature rise	Risk scores (not financial metrics, but relative levels of risk)

Box 5
Assessing physical climate risks on agriculture

Key takeaways

- Under the 2040s' 4°C scenario, an agriculture firm can lose more than 20% of its annual revenue from climate change.
- Under the 2040s' 4°C scenario, the bank's agriculture portfolio rating can deteriorate by a one-notch downgrade, with the sectors of mixed farming and cotton deteriorating by a two-notch downgrade.

This is a scenario-based stress test assessment of agricultural physical risks to determine the change in Probability of Default (PD) of its overall agricultural portfolio from the impact of incremental climate change.

Methodology: stress test the sample under the extreme climate events

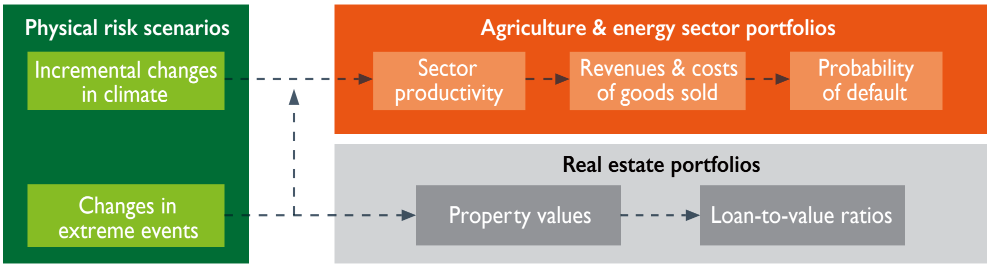


Figure 22
Overview of the physical climate risk methodology

The methodology (see Figure 22) could be divided into several steps as follows:

▶ Step 1: Assess changes in sector productivity

The essential part of this step is the peer-reviewed literature and empirical evidence that quantify the relationships between the change in frequency of these events and production losses. The baseline extreme-event conditions use the data of storm/cyclone/flooding from the fire-UNEP Global Risk Data Platform, extreme heat from GFDRR Think Hazard and drought from Princeton Climate Analytics. Drivers include losses of crops and livestock from extreme events, but exclude losses from damages to plant, equipment, and infrastructure, assuming insurance coverage.

▶ Step 2: Adjust income statement metrics

This step translates the production losses in sectors into the revenues and cost of goods sold (COGS) of the borrower, based on empirical evidence. [29] For each borrower, historical data and projected changes are determined for each of their property locations and the impact of both incremental changes and extreme events are considered.

▶ Step 3: Determine changes in the Probability of Default

In a bank's rating model, holding constant all the factors unrelated to the revenue and cost of goods sold such as farming costs, a borrower's risk is assessed individually. The finding is then extrapolated to the entire portfolio. The model also assesses other factors, such as increased funding to support lost production or rescheduling loan amortisation.

29. Empirical evidence supplied by Acclimatise' based on peer-reviewed literature and published work.

Results

Table 12 shows the results of the application of the revenue impact. It shows that the borrowers with businesses in grain and beef farming sub-sectors are impacted the least in the portfolio, while the borrowers in cotton and "others" are the victims of the worst scenario (4°C 2040s scenario). Calibrated to portfolio level, the deteriorating effect looks less significant as the credit rating only moves down by one notch.

Table 12 Physical risk stress test analysis outputs for representative sample group

INDUSTRY	2020s SCENARIO	2040s SCENARIO	
	2°C & 4°C	2°C	4°C
Mixed farming	1 notch	1 notch	2 notches
Grain	<1 notch	<1 notch	1 notch
Cotton	1 notch	1 notch	2 notches
Horticulture	1 notch	1 notch	1 notch
Beef farming	<1 notch	<1 notch	<1 notch
Dairy farming	1 notch	1 notch	1 notch
Others	1 notch	1 notch	2 notches
Total portfolio	<1 notch	<1 notch	1 notch

Note: Where customer's PD profile deteriorates across the stress-tested scenarios, but the movement is insufficient to shift the rating band by a notch, '<1 notch' is recorded above. For segments where reliable data on the underlying portfolio breakdown are not available, for example mixed farming, the bank assumes 50% livestock and 50% cropping. This is also applied to the balance of the portfolio described as "Other".

Findings and lessons include:

- Cotton and mixed farming sectors are more vulnerable to physical risks in the longer run under more severe rising temperatures. The reason is that livestock and crops are more vulnerable to high temperatures and frequent heatwaves.
- The stress test did not factor in adaptation; however agriculture is a good example of how practice and crop selections adapt to changes in climate and market conditions.

Source: UNEP FI (2018)

Box 6
Physical risks to properties in Chinese coastal cities

Key takeaways

- Higher intensities and frequencies of typhoons/hurricanes cause worse destruction to properties and assets, increasing the default rates of collateralised loans.
- Under severe climate change scenarios, the expected annual credit loss of mortgage loans can rise nearly threefold in 2050 from the baseline scenario.

Figure 23 presents a general modelling framework developed to quantify climate physical risks. As an application of the framework, this case study estimates the expected loss of mortgage loans due to typhoons. The collaterals are located in some of China's coastal cities.

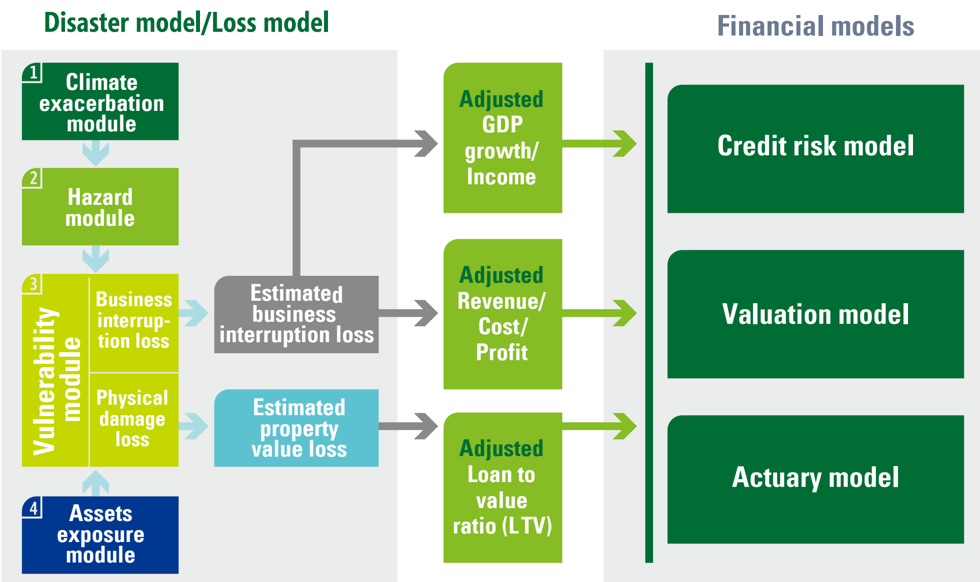


Figure 23
Framework of physical risk analysis

Disaster loss model

This model consists of four submodules: exacerbation, hazard, asset exposure and vulnerability. The exacerbation submodule correlates temperature gains from carbon concentration with incremental changes in the intensity and probability of a hazard, using different percentiles (mean, 90th and 99th) of exacerbation effects from the study (Knutson et al., 2019) to establish mild, severe and extreme scenarios. The asset exposure submodule mainly describes the geographical locations and value distribution of the target assets exposed to disaster. The vulnerability submodule uses the data from empirical studies and expert judgement to address the correlation between damage magnitude of assets and the hazard intensity.

Financial loss model

Various financial models may be applied for different purposes and assets. With the output from the disaster loss model used as intermediate inputs, the study adopts Expected Loss (EL) model to assess the potential loss:

$$\sum EL_i = \sum PD_i * LGD_i * EAD_i$$

Components of PD and LGD are estimated separately using typical models and result from empirical studies. EAD is estimated based on the values of real estate properties in the coastal cities underwritten by the bank's mortgage loans.

The assessment process in this case is divided into the following seven steps:

▶ Step 1: Select cities

Based on the independent analysis of historical loss data, the study selected 40 coastal cities in eight provinces that received 85% of their economic losses from typhoons between 2004 and 2016.

▶ Step 2: Estimate outstanding mortgage loans

Limited by the data availability, the study scaled the 2018 national mortgage loan data to district municipality level which became proportional to GDP share after assumption validation using available data samples.

▶ Step 3: Identify locations of the properties

Use an online tool to geocode the centre of municipal districts with output in latitude and longitude.

▶ Step 4: Generate typhoons' profiles under climate scenarios

Combine historical data on tropical cyclone by NOAA's IBTRACS with exacerbation effects estimated by Knutson et al. (2019).

▶ Step 5: Develop vulnerability curves

Based on Emanuel (2011)'s vulnerability curve, the study adjusts the shape parameters using local empirical data to generate the new vulnerability curve of properties against typhoons. This is denoted by the relationship between loss of property value and wind speed.

▶ **Step 6: Estimate losses of property value**

Under the two climate scenarios of RCP 6.0 and RCP 8.5 (IPCC, 2014a), combined with the three levels of exacerbation effects (mean, severe and extreme), the study estimates how annual value loss of the properties could be impacted by the GDP loss (proxy for decline in household income) compared to baseline.

▶ **Step 7: Estimate changes in PD, LGD and EL of mortgage loans due to typhoons**

As shown in the equation below, the key to estimating the PD deviation is to define the elasticity of delta PD and delta LTV (loan to value ratio) and that of delta PD and delta PTIR (Payment-to-Income Ratio), of which the coefficients are taken from relevant empirical studies.

$$\Delta PD \approx \alpha \times \left(\frac{1\text{-}down\ paymen}{1\text{-}\Delta collateral\ Value} \text{-}(1\text{-}down\ payment) \right) + \beta \times \left(\frac{payment}{\Delta household\ income} \right)$$

Findings

The results indicates that under RCP 8.5 with extreme exacerbation effects, in 2050, the PD and EL of mortgage in China's coastal cities may increase by up to 2.5 times compared to the baseline.

Source: Tsinghua University Chapter in NGFS (2020a)

Key takeaways

- Map-based climate physical risk analysis tools can be used to preliminarily assess a project's risks before a serious decision-making process.

Box 7
Mapping physical risks across sectors and supply chains

Acclimatise and Vivid Economics developed an analytical toolkit with two phases of portfolio-wide physical risk mapping and risk quantification in financial metrics, of which allows simple and quick assessment of physical risks.

Phase I: Portfolio-wide physical risk mapping

Risk heatmapping consists of three key components: vulnerability, hazard, exposure and heatmapping outputs.

Vulnerability

In order to fully cover the entire value chain, the model uses four vulnerability indicators, including the degree of reliance on climate-sensitive supplies, demand, transport routes and natural resources. These indicators are assigned to each sub-sector carrying a score of low, medium, or high that measures the severity of the impact (see Table 13 as an example).

Table 13 Vulnerability indicator scores for a selection of sectors and sub-sectors

		Vulnerability Indicator scores			
Sector	Sub-sector	Natural resources	Asset & processes	Market demand	Labor health & productivity
Agriculture, forestry and fisheries	Animal raising, production, support activities	3	2	2	2
	Crop growing, production, support activities	3	2	2	3
Metals and mining	Ore mining	3	2	1	3
Power and energy	Hydropower	3	2	2	1
	Solar	1	2	2	1
	Thermal power station	3	2	2	2
	Wind	2	2	2	1
Oil and gas	Extration of crude petroleum and natural gas	3	2	3	3
	Liquefaction and regasification	3	1	1	1
	Manufacture of refined petroleum products	2	1	1	1
	Oil & natural gas transmission & distribution	1	2	1	1
	Support activities for petroleum and natural gas extractio	1	2	2	2
Manufacturing	Chemical manufacturing	3	2	1	1
	Basic metals and fabricated products	3	2	2	2
Real estate	Commercial property	2	2	3	2
	Residential property	2	1	3	1

Hazard

Relating the hazard data to vulnerability indicators by normalising the data to a common scale can layer and aggregate the datasets of different units to location-specific risk scores, which could be summed up for each vulnerability indicator. One example is linking the "secure transport routes" to hazard events of storm, flood, wildfire, sea level rise and storm surge.

Exposure

A matrix of investment sectors, subsectors and associated geographies are required to represent the core exposure data. For example, individual investment data could be assessed at different granularity according to the categories of sectors, sub-sectors and geographies.

Heatmapping output examples

The vulnerability indicator scores are summed for each location and normalised back to the common scale. The results can be analysed to determine the risk ratings and colour brandings in charts and maps (see Figure 24).

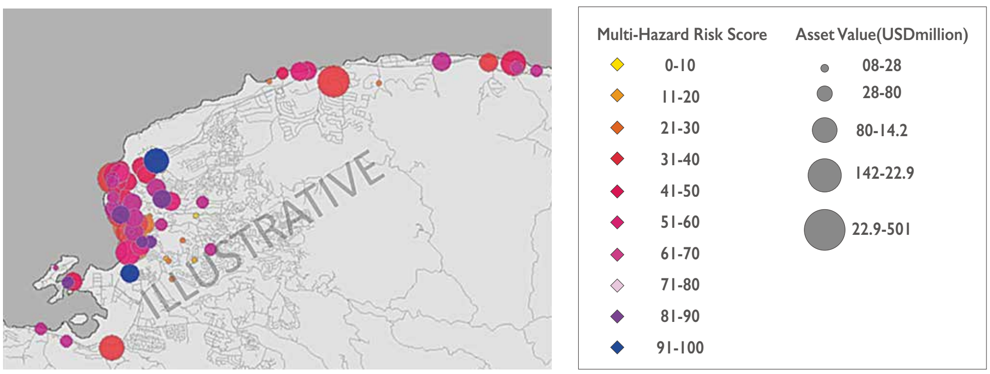


Figure 24
Illustrative risk scores for a portfolio of hotels and resorts

Note: The illustrative scores cover multiple climate hazards, including coastal and river flooding, cyclone risk, extreme heat, and water stress.

Phase II: Physical risk quantification in financial metrics

Businesses or FIs interested in the effects at economy, sector level or company-specific value chain may require a deeper analysis of phase I results. This can be achieved by using a Computational General Equilibrium (CGE model) to assess the interaction among sectors or regions. Estimating the effects on company-specific value chain should consider channels such as facility-level production, facility-level extreme weather damages and facility-level business and supply chain interruptions.

In facility-level business and supply chain interruptions, the study combines empirical data on business interruptions due to hazards with hazard maps to estimate associated production losses. Also, potential supply chain disruption and associated production loss across the sector are estimated by supply chain data and hazard data of significant supply locations for the sector.

- Agriculture, forestry, and fisheries are vulnerable due to their high reliance on natural resources, including availability and quality of water and land.
- Metals and mining industries rely heavily on availability of natural resources and labour productivity. Labour productivity is also heavily affected by increasing temperatures and more frequent heatwaves.
- The power and energy sectors' vulnerabilities vary by subsectors, though a common vulnerability is the dependence on water. Thermal plants depend more on water due to the need for cooling water, while solar and wind are less dependent.
- Oil and gas are vulnerable to the seasonal demand for fuels and heating. Liquefaction and gasification are more dependent on adequate supplies of water.
- Manufacturing of chemical and fabricated products are vulnerable to the availability of water and large land for fixed assets.
- Real estate is vulnerable to consumer demand, which may be impacted by floods, storms, wildfires, and rising sea levels.

Source: Acclimatise and Vivid Economics Chapter of NGFS (2020a), Connell et al. (2020)

CHAPTER 4

Current Practices in Managing Climate-related Risks

Key messages:

a. Companies facing climate risks are exploring transition solutions or pathways, which begin with a rigorous climate risk analysis;
b. A company's active participation in disclosure initiatives and better performance in ESG scoring will lead to higher investor confidence and increased competitiveness in capital markets;
c. More FIs are strategically managing climate and sustainability issues;
d. More FIs are considering physical and transition risks when allocating assets;
e. Regulators and investors are more concerned about how climate issues affect FIs and companies;
f. FIs can be more proactive in providing services to support high-carbon emitting clients shifting to low-carbon business models.

Photo by Meng Jia on Unsplash

4.1

Current business practices

4.1.1 Climate risks analysis and business transformation

A climate risk analysis targets both transition and physical risks. The output of a rigorous climate risk analysis aids decision making on business strategies, such as the evolution of business models, or investments/ divestments from certain regions, sectors or companies. For energy, utility and resource companies, managing legacy businesses and assets are essential in ensuring a successful transformation.

Companies facing climate risks have started to explore transition solutions or pathways. Galp Energia, SGPS, S.A. in Europe took the view that the transition to a low-carbon economy will impact its business model, either due to regulatory changes or shifts in consumption and technological patterns (Galp, 2021). Using more than 10 risk categories including market, regulations and technology, the company measured its transition risks in the short, medium, and long terms in its TCFD report. It then integrated them in their risk management process and implemented a three-line defence framework. Hong Kong's Swire Properties Limited completed a quantitative assessment in 2020 to project the financial impact of physical and transition risks on the company's real estate business operations which helped to develop risk management strategies (Swire Properties, 2021). Traditional chemical manufacturers like BASF and Methanex have also started to develop advanced technologies to enable low-carbon industrial processes and zero-carbon electricity production.

4.1.2 Active participation in disclosure initiatives and proactive carbon accounting

Investors are increasingly aware of how non-financial performance impacts a corporation's financial future and are demanding standardised regular climate disclosures. A company's active participation in disclosure initiatives and outstanding performance in climate risk management can enhance investors' confidence. Also, the information provided by carbon accounting is likely to facilitate the understanding of climate risks in risk management.

Internationally accepted disclosure frameworks and standards include TCFD, GRI, SASB, CDSB, CDP, ISSB, etc. Companies voluntarily choose the initiatives and disclose the corresponding environmental information. For example, Japan's KDDI Corporation integrates several disclosure frameworks into its sustainability report (KDDI, 2021). It issues sustainability reports annually and adopts GRI, SASB, IIRC, JISZ and other standards.

With more accounting standards and guides for carbon footprints available, many entities have strengthened their carbon accounting and have disclosed relevant data in their reports. For example, KDDI calculated and disclosed its supply chain's greenhouse gas emissions (Scopes 1, 2 and 3; 15 categories in all) for fiscal years 2015-2019 according to GRI Standards in Sustainability Report 2020 (KDDI, 2021). Singapore's Trafigura Group Pte. Ltd further improved its methodology to calculate GHG emissions from vessels carrying oil and petroleum products in accordance with the GHG Protocol in 2020 (Trafigura, 2021). Puma SE reduced Scope 3 carbon emissions by buying less carbon-intensive raw materials (PUMA SE, 2021).

4.1.3 ESG Integration

ESG investing is often used synonymously with sustainable investing. The environmental criteria may include a company's energy usage, waste, pollution, natural resource conservation, and treatment of biodiversity. The criteria can also measure a company's environmental risks and its mitigation efforts. Some studies have shown that companies with higher ESG ratings are more competitive in the capital market and are less exposed to systemic risks (Wang & Wu, 2020). For an environmentally responsible enterprise, setting up an ESG scoring system and monitoring ESG performance over time is essential. Japan's Daiwa House Industry Co., Ltd is an example (Daiwa House Group, 2021). After identifying core ESG issues, the company established an ESG management framework and improved its performance according to third-party assessments such as MSCI, FTSE, STOXX, etc.

4.1.4 Rebalancing high-carbon and low-carbon assets in portfolio

As investors recognise that global warming is accelerating, climate transition risks will increasingly be priced in by the market, leading to a potentially dramatic repricing across asset classes, sectors, companies, and individual securities. Tools such as carbon pricing, penalties and stranded asset management are highly valued. Some corporations have accelerated rebalancing in high-carbon assets, while some have started to invest more in low-carbon businesses such as renewable energy production.

By conducting internal climate-related scenario analysis, several leaders in the energy sector have formulated plans to decide which assets to hold and which to dispose of. France's Total Energies reduced oil and gas exploration activities while increasing investments in renewable energy (TOTAL SE, 2020). Seeking to become a net-zero company by 2050, BP said it formed an integrated low-carbon portfolio including growing its renewables, bioenergy, hydrogen and carbon capture and storage businesses, while also strengthening its natural gas position (BP, 2020).

4.2

Current practices of FIs

4.2.1 Integrating climate change into corporate strategies and governance

An increasing number of FIs are strategically managing climate and sustainability issues. Some FIs have laid out a clear timetable for developing sustainable finance activities, addressing climate-related risks, as well as placing responsibilities on the board committee and executives to implement strategies. Deutsche Bank (DB) set up a sustainability council in 2018 to advise the management board and to drive the bank's sustainability strategy. In 2020, DB reinforced its sustainability push by linking management compensation to sustainability targets and by setting up a new sustainability committee chaired by the CEO (Deutsche Bank, 2020)[30]. After China introduced its 2060 carbon-neutrality goal, Haitong International said it aims to be carbon-neutral by 2025 and will deploy USD 20 billion in ESG and sustainable financing and investment by the end of 2025. Haitong will establish an ESG committee and executive office to execute this strategy (Haitong International, 2020).

4.2.2 Incorporating climate risks into current risk management and pricing system

Risk management teams of many banks, insurance and asset management firms have developed methods to identify, assess, monitor and report on their climate-related risks. China's SPD Bank integrated E&S risk analysis into its credit management of all domestic and foreign projects (Ma, 2018). For domestic operations, SPD Bank divides existing and potential clients into three groups: A (high E&S risks), B (medium-high E&S risks with feasible risk

30. The news about Deutsche Bank's plans to link management compensation to sustainability criteria was released on the website of Deutsche Bank on December 7 2020, link: https://www.db.com/news/detail/20201207-deutsche-bank-plans-to-link-compensation-to-sustainability-criteria?language_id=1

mitigation measures), and C (others). The bank makes it necessary to include an internal E&S risk assessment report for A and B clients to adjust credit line, loan interest rate and economic capital allocation accordingly. It also requires clauses on clients' actions to strengthen E&S risk management be included in the contract. For foreign projects, SPD Bank requires the borrowers to set up a contingency plan and a communication channel with stakeholders to respond to significant E&S risks. The bank will also hire third parties to assess and disclose E&S risks for controversial projects. The French bank Natixis designed a Green Weighting Factor (GWF) methodology and has incorporated climate-related risks into its risk appetite framework. It defines a green-and-brown taxonomy by classifying each financing request on a 7-level colour scale based on the degree of impact on the environment and climate (ranging from dark brown to dark green). Natixis will reduce the risk-weighted assets (RWA) pledged against a deal by 50% if it is marked dark green, while the RWA will be increased by 24% for a deal rated dark brown (Natixis, 2019).

4.2.3 Mitigating and managing climate risks in asset allocation and hedging strategies

More FIs are considering physical and transition risks when allocating assets. For example, alternative asset investors will consider asset devaluation and write-offs for a property located in coastal areas with the risk of sea-level rise. Many asset managers have increased exposure to renewable energy while cutting that of fossil fuels. The Institute for Energy Economics and Financial Analysis (IEEFA) found that over 100 large global financial institutions had divested from thermal coal. Some MDBs and several FIs in Japan and Singapore have led the way in Asia (IEEFA, 2019). Some FIs also explored derivatives as a hedge against high-carbon industries. "WWF stranded asset total return swap" illustrates a way to profit from a long-term put position (Resources Radio, 2020).[31]

4.2.4 Regular disclosures of carbon footprints and climate risk exposure

Today, both regulators and investors are taking the impact of climate change more seriously and are demanding more information. Hong Kong Exchanges and Clearing (HKEX) has required mandatory and regular ESG disclosure reports for companies listed on the HKEX as of July 2020, and will request

31. Example illustrated in an interview by Robert Litterman, link: https://www.resources.org/resources-radio/pricing-climate-risk-markets-robert-litterman/

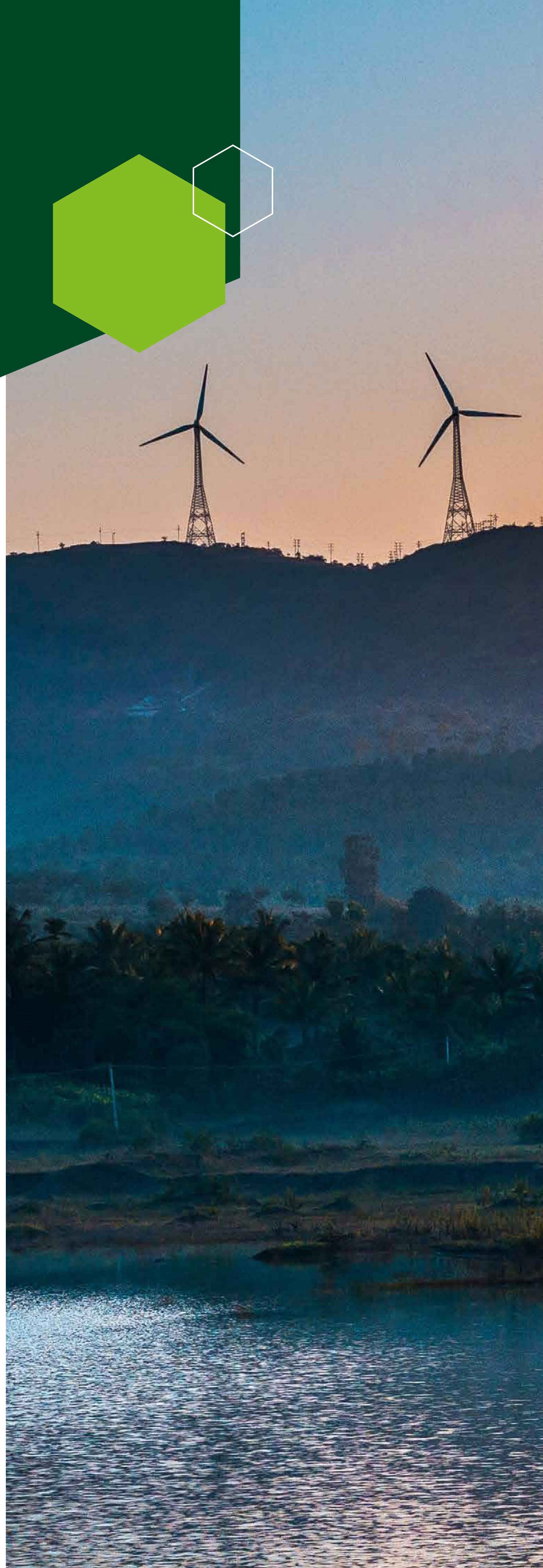
for mandatory disclosure of the financial impact of climate change on the businesses by 2025 (HKEX, 2020). The Monetary Authority of Singapore (MAS) is also accelerating its climate information disclosures. A task force from MAS has issued a detailed implementation guide for climate-related disclosures by FIs in 2021 (MAS, 2021). Many big firms in the financial sector already disclose some climate-related information, such as GHG emissions, through their sustainability/CSR/ESG reports. The 2017 TCFD recommendations urged the disclosures of more climate-related financial information. Several FIs have supported disclosures under the TCFD recommendations. The Royal Bank of Canada (RBC) released its TCFD report for 2020, which analysed and disclosed the bank's credit exposure to most sensitive sectors and its sensitivities to climate risks (Royal Bank of Canada, 2020). Moreover, RBC also revealed its GHG emissions covering all three scopes from 2016 to 2020.

4.2.5 Engaging and supporting existing carbon-intensive clients on transition opportunities

Some FIs proactively provide consulting services to support their high-carbon clients in shifting to greener business models. Several have created transition finance instruments to fund the decarbonisation activities of these carbon-intensive clients. In January 2021, BPCE issued its first EUR100 million transition bonds which was fully subscribed by AXA Investment Managers to finance Natixis' energy transition assets. The selected portfolio includes sustainability-linked corporate loans and project loans shortlisted based on Natixis' GWF methodology (Natixis, 2021).

CHAPTER 5

Conclusion



A number of corporations, FIs and financial regulators around the world have started to recognise the importance of climate risk analysis for managing the emerging climate risks. Most small corporations and FIs, especially in developing countries, do not understand the significance and are not actively identifying and managing climate risks.

Photo by Nitin Sharma on Pexels

5.1

Challenges

5.1.1 Lack of awareness

Many of the Asian countries are more likely to be exposed to physical climate risks due to their geographical locations. Even if some are moving towards low carbon transition, few have a thorough understanding and high awareness of the associated impacts. While some central banks in Southeast Asia, such as those of Singapore, Malaysia and South Korea, have incorporated climate risks into policy frameworks with sustainability mandates (Anwar et al., 2020), most businesses in these societies and economies may not fully understand how their operations and profits may be affected by the transitions due to limited expertise and exposure. While all Asian central banks acknowledge climate risks' increasing threat to financial stability, their capabilities to manage these risks are still nascent (Anwar et al., 2020).

5.1.2 Capability

Few businesses and organisations can conduct climate risk analyses or climate pricing without inter-disciplinary expertise. A mismatch between the long-term nature of climate risks and businesses' preferences for short-term profits further weakens the motivation for significant initial investments.

5.1.3 Data gap

Most businesses that are beginning to account for climate risks, do not have sufficient high-quality data. Only a few Asian countries have widely collected climate-related data, such as carbon emission data of companies in key industries. The lack of communication between public authorities and private businesses further limits data availability.

5.2

The way forward

5.2.1 For businesses

Standardised, transparent and regular disclosures by corporations can keep the public, clients, investors and corporations equally informed. SASB, GRI, CDP, CDSB, FASB and IIRC are widely accepted disclosure standards on sustainability and climate change. Together they promote a unified disclosure framework under the IFRS ISSB recommendations. More than 1,500 organisations with combined assets over USD 150 trillion have committed to TCFD recommendations (TCFD, 2020), an 85% increase from 2019.

A comprehensive understanding of an entity's current carbon footprint is a crucial prerequisite for the disclosure and management of climate-related risks, especially in terms of transition risks. GHG Protocol, PAS 2050, ISO series of standards provide guidance for businesses and organisations to conduct carbon accounting and quantify carbon footprint. Based on their carbon accounting, corporations should then set their own carbon targets in line with regional or national carbon-related targets.

The strategic integration of climate considerations may also enable businesses in identifying and capturing new opportunities.

5.2.2 For FIs

Good practices include the thorough integration of climate risk management measures into corporate governance. Climate governance is a board responsibility, and companies should put in place the right people, rules and structure to effectively assess climate-related risks and opportunities. This includes detailed and explicit policies on investment, lending, bond issuance, etc. There should be adequate manpower staffing to perform on-going analysis as the pricing of climate risks also requires additional manpower capacity. Finally, regular monitoring of FIs' exposures to assets that are sensitive to climate risks should not be ignored.

5.2.3 For governments and regulators

Governments, financial supervisors and regulators should follow the best practices and promote the most relevant and suitable methodologies for all stakeholders. The supervisors and regulators in the countries with higher level of awareness of these risks should mobilise resources to conduct advanced research to further improve the tools and methodologies for climate risk pricing and management, while nations without a significant degree of awareness should learn from them. Regulations should be designed in alignment with overall climate risk management goals.

As the Covid-19 pandemic upends life for the third year around the globe, the rallying cry for combating climate change is at the risk of being muffled. But while we can tame the virus through vaccines, border closures and technology, the looming catastrophes brought about by a faster-warming planet far exceed our current capacities to cope. We must remain vigilant of an enemy whose destructive forces threaten to put us into extinction, and we must change our way of living and conducting business immediately. As climate change presents unprecedented risks, businesses cannot count on conventional tools to measure and manage them; they must be prepared to be even more adaptable and acquire the newest tools and methodologies from all sources available to accelerate the transition to a zero-carbon economy.

Appendix

Actions of Fortune 500 companies and Financial Institutions

Measures by corporations		
Business transformation and re-balance of carbon sensitive assets	Total (France)	Reduce its exploration of oil and gas resources; Further increase its operational and R&D investments in renewable energy (TOTAL SE, 2020).
	Equinor ASA (Denmark)	Operate several floating offshore wind projects replacing traditional energy resources (Equinor, 2021).
	BP (UK)	Form an integrated low carbon portfolio; Grow renewables and bioenergy; Seek early positions in hydrogen and carbon capture; Storage and strengthening gas position (BP, 2021).
	Shell (The Netherlands)	Invest in new furnaces and replace older units for petrochemicals complex (Shell, 2021).
Active participation in disclosure initiatives and proactive carbon accounting	KDDI Corporation (Japan)	Adopt GRI, SASB, IIRC, JISZ and other standards as compilation reference; Issue sustainability reports annually; Calculate and disclose its supply chain greenhouse gas emissions (Scopes 1, 2 and 3; 15 categories in all) (KDDI, 2021).
	Trafigura Group (Singapore)	Further improve methodology to calculate GHG emissions from vessels carrying oil and petroleum products chartered on a 'spot basis' (known as 'wet spot charters') in accordance with the GHG Protocol in 2020 (Trafigura, 2021).
	Puma SE (Germany)	Reduce Scope 3 carbon emissions at the factory level by purchases of less carbon-intensive raw materials (PUMA SE, 2021).

Conducting forward-looking scenario analysis	Galp Energia (Portugal)	Measure the transition risk in the short, medium and long term in TCFD report based on 10 categories; Implement a three-line risk defence framework (Galp, 2021).
	Swire Properties (China)	Complete a quantitative assessment to identify potential financial impact on the company's real estate business operations; Develop risk management strategies (Swire Properties, 2021).
Integration of ESG	Daiwa House Industry (Japan)	Identify ESG issues relevant to the core; Establish a ESG management framework; Improved ESG performance according to third parties' assessment and advice (Daiwa House Group, 2021).
Measures by Financial Institutions		
Integrate climate change into corporate strategy and corporate governance	Haitong International (China)	Set up a goal "achieve Carbon Neutrality and provide USD 20 billion in ESG and sustainable finance by the end of 2025"; Establish ESG Committee and ESG executive office (Haitong International, 2020).
Incorporating climate-related risks into current risk management system	Natixis (France)	Design green weighting factor (GWF) methodology and incorporated climate-related risks into its risk appetite framework (Natixis, 2019).
Mitigation and management of climate-related risks in asset allocation and hedging strategies	WWF (Global)	Design "WWF stranded asset total return swap" with Deutsche Bank as the counterparty (Resources Radio, 2020).
Regular disclosures of carbon footprints and climate risk exposure	Royal Bank of Canada (Canada)	Disclose the bank's credit exposure to most sensitive sectors and the relative sensitivity to different climate-related risks; Disclose GHG emissions, carbon reduction targets and actions (Royal Bank of Canada, 2020).
Providing green transition consulting services and innovative transition finance financial products for existing high-carbon clients	BPCE (France)	Issued the bank's first EUR 100 million transition bond (Natixis, 2021).

Source: Author's collection

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

Model developers	Environmental/ climate risks covered	Sector focuses	Financial risks assessed	Juris-dictions studied	Types of models	Benefits	Limitations
427 (a Moody's affiliate)	Climate physical risk	Real estate	Credit risk	Europe	CAT model	Extensive coverage of hazards	Incomplete translation from climate risk into quantifiable financial risk
Oliver Wyman	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)
WU & UZH	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, lack of macroeconomic impact assessment
ICBC	Environmental transition risk	Thermal power, cement	Credit risk	China	PD model	Quantification of credit risk for environment factors	Relatively simple assumptions about risk drivers
SUN Tianyin and Ma Jun/ Tsinghua	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
Ma Jun and SUN Tianyin/ Tsinghua	Climate transition risk	Thermal power, oil	Credit risk	China	Energy sector model/IAMs, PD model	Multiple macro and micro factors (including funding costs) considered in impact assessment	High requirement on multi-sector data and expertise, incomplete macroeconomic feedback loop
Francisco Ascui and Theodor F. Cojoianu	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
Henrik Ohlsen and Michael Ridley	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
Vivid Economics	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
CO-Firm (a PWC company)	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
Acclimatise and Vivid Economics	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
Climate Policy Initiative	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
AFD	Climate transition risk	Coal and related sector and infrastructure	Market risk	South Africa	Input-output model	Consideration of cascading impacts derived from an initial shock on sectors	Detailed input-output table required
CUFE	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
Carbone4	Climate physical risk	Real estate and others		Global	CAT Model	Extensive coverage of physical risk categories	Limited analysis on financial risk metrics
Ortec Finance	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 risks

2 degrees initiative	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"	Oversimplified assumption of "disorderly transition scenario", high data and expertise requirement
Cli-mateWise	Climate physical risk	Real estate and others	Market risk and insurance liability risk	UK, North America, Asia	CAT model, valua-tion model	Extensive modelling of future hazards	High data requirement, limited coverage of hazard types so far, limited consid-eration of indirect damage of physical events
Cli-mateWise	Climate transition risk	Gas distribution	Market risk	Germa-ny	Energy sector model, valuation model	Clear impact transmission mechanism	Lack of macroeconomic feedback mechanism
CarbonDel-ta (an MSCI company)	Climate transition and physical risks	Multi-sectors	Market risk and oppor-tunities	Global	IAMs, CAT models, Merton model, DCF model	Coverage of both transition and physical risks, inclusion of preparedness/adaptation mea-sures, 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 conven-tional climate risks and risks induced by climate change
AVIVA	Climate transition and physical risk	Not specified	Credit risk and market risk	not speci-fied	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
RMS	Climate physical risk	Real estate	Insurance liability risk	USA	CAT model	Extensive modelling of future hazards	High requirement on data and expertise
Swiss Re	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
Moody's	ESG	Energy, building materials, chemi-cals, mining, auto-mobile, logistics	Credit risk	Global	ESG scoring, ESG in-tegration into rating	Drawn experience from credit rating approaches; extensive coverage of issuers	Limited transparency in data source and scoring methods
MSCI	ESG	Not specified	Credit risk	Global	ESG scoring, ESG in-tegration into rating	Clear presentation of methodolo-gies, data sources and applications	Limited inclusion of environ-mental indicators
VfU and University of Augsburg	ESG	Not specified	Market risk	Global	ESG scoring, factor pricing model	Good application potential	Limited data on country specific carbon risk beta
ISS	ESG	Not specified	Credit risk	Global	ESG scoring, ESG index construction	Clear presentation of method-ologies	Relative smaller number of issuers covered
Intesa San-paolpo	ESG	Not specified	Credit risk	Italy	PD model, LGD mod-el, rating analysis	Introduction of practical integra-tion of ESG into rating analysis	Insufficient details in scoring ESG factors
Carbone4	Carbon accounting of portfolio	Power and others		Global	Bottom-up ap-proach, life-cycle GHG accounting	More accurate approaches to estimate carbon emissions and carbon footprints	High requirement on data and expertise
EcoAct	Carbon accounting of portfolio	Not specified		Global	GHG accounting, compliance assess-ment	Extensive coverage of financial products and comparability of assessed results	Quality of self-reported data by issuers
ISS	Carbon accounting of portfolio	Utility and others		Global	GHG accounting, com-pliance assessment	Absolute & relative carbon footprint calculation	Quality of self-reported data by issuers
I4CE	Discussion of climate physical risk models/tools	Review and discussion of various physical risk analysis model/methodologies					
CarbonTrust	Discussion of climate transition risk models/tools	Review and discussion of various transition risk analysis model/methodologies					
CICERO	Discussion of climate scenarios	Review and discussion of various climate scenarios					
Olaf Weber	Discussion of ESG rating and data	Review and discussion of ESG data and rating methods					
RepRisk	Discussion of ESG rating and data	Review and discussion of ESG data providers, rating agencies, development and challenges of ESG data, rating methods					

Glossary

Adaptive capacity	The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.[32]
Carbon neutrality	Carbon neutrality is achieved when anthropogenic CO2 emissions are balanced globally by anthropogenic CO2 removals over a specified period. Carbon neutrality is also referred to as Net Zero CO2 emissions.[33]
Climate Risk Index	An analysis based on one of the most reliable data sets available on the impacts of extreme weather events and associated socio-economic data, the MunichRe NatCatsSERVICE.[34]
Credit risk:	The potential that a bank borrower or counterparty will fail to meet its obligations in accordance with agreed terms.[35]
IAM model	Integrated assessment model
ICE	Internal Combustion Engine
Carbon budget	The amount of carbon dioxide allowed to emit over a period to keep within a certain temperature threshold.[36]
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.[37]
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.[38]
Hazard	Potential events with possibilities of occurrence and severity of any potential disaster, such as a tropical storm or flood, at a given location, within a specified time period.[39]

32. adapted from (Hassan et al., 2005).
33. adapted from (IPCC, 2018).
34. adapted from (Eckstein et al., 2021).
35. adapted from (BCBS, 2000).
36. adapted from the definition from Carbon Tracker, https://carbontracker.org/carbon-budgets-where-are-we-now/.
37. 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.
38. Partly adapted from NGFS first comprehensive report in 2019.. 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 considered.
39. Adapted from background papers commissioned by the Global Commission on Adaptation to inform its 2019 flagship report (Stadtmueller et al.,2019).

Collateral	An asset or third-party commitment that is used by a collateral provider to secure an obligation vis-à-vis a collateral taker.[40]
Exposure	The inventory of elements/assets exposed to a hazard or risk.[41]
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 emphasises that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome.[42]
Transition risk	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.[43]
Market risk	The risk of losses arising from volatilities in market, including but not limited to the price changes of equities, bonds, foreign exchanges, and commodities.[44]
Operational risk	The risk of loss resulting from inadequate or failed internal processes, people, controls, systems or from external events. It is better viewed as the risk arising from the execution of an institution's business functions.[45]
Scenario analysis	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., temperature change) and relationships. Note that scenarios are neither predictions nor forecasts, but are useful to provide a view of the implications of developments and actions.[46]
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.[47]
Underwriting risk	The potential loss to an insurer emanating from faulty underwriting. The same may affect the solvency and profitability of the insurer in an adverse manner.[48]
Vulnerability	The propensity of predisposition to be adversely affected, encompassing a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. [49]

40. Adapted from glossary of online database of European Central Bank (2020).
41. Adapted from background papers commissioned by the Global Commission on Adaptation to inform its 2019 flagship report (Stadtmueller et al.,2019).
42. Adapted from IPCC (2014a).
43. 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.
44. Adapted from (Peel et al., 2020).
45. Adapted from (BCBS, 2011).
46. Adapted from (Hubert et al., 2018).
47. Adapted from publications of (BCBS, 2009).
48. Adapted from the definition in The Economic Times, https://economictimes.indiatimes.com/definition/underwriting-risk?from=mdr.
49. Adapted from (IPCC, 2014b).

Abbreviations

2DS	2 Degrees Scenario
2DII	2°Investing Initiative
ALM	Asset Liability Management
BAU	Business-As-Usual
BGS	Brown-Green-Score
BMG	Brown-Minus-Green
BPCE	Banque Populaire, Caisse d'Epargne
BRI	Belt and Road Initiative
CAPEX	Capital Expenditure
CARIMA	Carbon Risk Management
CDP	Carbon Disclosure Project
CDSB	Climate Disclosure Standards Board
CGE	Computable General Equilibrium
COGs	Cost of Goods Sold
CRI	Climate Risk Index
CSMAR	China Stock Market & Accounting Research (Database)
DCF	Discounted Cash Flow
EAD	Exposure At Default
EBITDA	Earning Before Interests, Taxes, Depreciation and Amortisation
EL	Expected Loss
ESG	Environmental, Social, and Governance
ESRB	European Systemic Risk Board
ETP	Energy Technology Perspective
EU	European Union
FAIRR	Farm Animal Investment Risk & Return
FASB	Financial Accounting Standards Board
FCA	Financial Conduct Authority
FIs	Financial Institutions
GDP	Gross Domestic Product
GFDRR	Global Facility Disaster Reduction & Recovery
GHG	Greenhouse Gas
GRI	Global Reporting Initiative
GWF	Green Weighting Factor
HKEX	The Stock Exchange of Hong Kong Limited

IAM Model	Integrated Assessment Model
IEA	International Energy Agency
IEEFA	Institute for Energy Economics & Financial Analysis
IIRC	The International Integrated Reporting Council
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
ISIC	The International Standard Industrial Classification
KPI	Key Performance Indicator
LGD	Loss Given Default
LTV	Loan-To-Value
MAS	Monetary Authority of Singapore
MDBS	Multilateral Development Banks
NASA	National Aeronautics and Space Administration
NDC	National Determined Contributions
NGFS	The Network of Central Banks and Supervisors for Greening the Financial System
OPEX	Operating Expenses
PD	Probability of Default
PPP	Purchasing Power Parity
PTIR	Payment-to-Income Ratio
R&D	Research and Development
RBC	Royal Bank of Canada
RCP	Representative Concentration Pathway
REMIND	Regional Model of Investments and Development
ROI	Return on Investment
RWA	Risk-weighted Assets
SAA	Strategic Asset Allocation
SASB	Sustainability Accounting Standards Board
Solar PV	Solar Photovoltaic
TCFD	The Financial Stability Board's Task Force on Climate-related Financial Disclosures
UN PRI	United Nations Principles for Responsible Investment
UNEP	United Nations Environment Programme
UNEP FI	UN Environment Programme Finance Initiative
VAR	Vector autoregression
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
WMO	World Meteorological Organization
WWF	World Wildlife Fund

References

- Antia, S., & Klausner, D. (2021). Weathering Climate Change: Opportunities and Risks in an Altered Investment Landscape. PGIM Megatrends-February.
- Anwar, R. S., Mohamed, M., Hamzan, S. M., Malek, N. S. A., Zain, M. H. M., Jaafar, M. H., . . . Hong, J. (2020). Report on The Roles of ASEAN Central Banks in Managing Climate and Environment-related Risks.
- BCBS. (2000). Principles for the Management of Credit Risk.
- BCBS. (2009). Principles for sound stress testing practices and supervision. In: BIS Basel.
- BCBS. (2011). Principles for the sound management of operational risk. Basel, Switzerland: Bank for International Settlements Communications.
- BP. (2020). Statistical Review of World Energy 2020 69th edition.
- BP. (2021). bp Sustainability Report 2020.
- Bruin, K. d., Hubert, R., Evain, J., Clapp, C., Stackpole Dahl, M., & Bolt, J. (2019). Physical climate risk Investor needs and information gaps.
- Collins, A. (2019). The Global Risks Report 2019.
- Connell, R., Hamaker-Taylor, R., Khosa, B., Firth, J., Rycerz, A., Turner, S., . . . Haworth, A. (2020). Charting a new climate - State-of-the-art tools and data for banks to assess credit risks and opportunities from physical climate change impacts.
- CRED. (2020). Natural Disasters 2019.
- Daiwa House Group. (2021). Daiwa House Group Sustainability Report 2020.
- Dasgupta, S., van Maanen, N., Gosling, S. N., Piontek, F., Otto, C., & Schleussner, C.-F. (2021). Effects of climate change on combined labour productivity and supply: an empirical, multi-model study. The Lancet Planetary Health, 5(7), e455-e465.
- Depoues, V., Cardona, M., Nicol, M., & Vincent, B. (2019). Towards an alternative approach in finance to climate risks: taking uncertainties fully into account.
- Deutsche Bank. (2020). Deutsche Bank plans to link compensation to sustainability criteria [Press release]. Retrieved from https://www.db.com/news/detail/20201207-deutsche-bank-plans-to-link-compensation-to-sustainability-criteria?language_id=1
- Eckstein, D., Künzel, V., & Schäfer, L. (2021). Global Climate Risk Index 2021. Who Suffers Most from Extreme Weather Events, 2000-2019.
- Emanuel, K. (2011). Global warming effects on US hurricane damage. Weather, Climate, Society, 3(4), 261-268.
- Equinor. (2021). Equinor Sustainability Report 2020.

- ESRB. (2016). Too late, too sudden: Transition to a low-carbon economy and systemic risk: Reports of the Advisory Scientific Committee.
- Financial Conduct Authority. (2020). Green Horizon Summit: Rising to the Climate Challenge. Retrieved from https://www.fca.org.uk/news/speeches/green-horizon-summit-rising-climate-challenge
- Fuss, S., Canadell, J. G., Peters, G. P., Tavoni, M., Andrew, R. M., Ciais, P., . . . Yamagata, Y. (2014). Betting on negative emissions. Nature Climate Change, 4(10), 850-853. doi:10.1038/nclimate2392
- Galp. (2021). Galp Non-financial information 2020- TCFD Recommendations.
- Gray, C. (2021). The Economics of Climate Change: Impacts for Asia. Retrieved from https://www.swissre.com/risk-knowledge/mitigating-climate-risk/economics-of-climate-change-impacts-for-asia.html
- Haitong International. (2020). Haitong International ESG Statement.
- Haraguchi, M., & Lall, U. (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.
- Hassan, R., Scholes, R., & Ash, N. (2005). Ecosystems and human well-being: current state and trends.
- HKEX. (2020). Cross-Agency Steering Group Launches its Strategic Plan to Strengthen Hong Kong's Financial Ecosystem to Support a Greener and More Sustainable Future [Press release]. Retrieved from https://www.hkex.com.hk/-/media/HKEX_Common/Market/Stage/News-Centre/Cross-Agency-Steering-Group-Announcement_20201217.pdf
- Hubert, R., Evain, J., Nicol, M., Cardona, M., Clapp, C., Sillmann, J., . . . Lepousez, V. (2018). Getting started on Physical climate risk analysis in finance-Available approaches and the way forward. ClimINVEST Research Project Work.
- IEA. (2020a). CO2 Emissions from Fuel Combustion. Retrieved from http://energyatlas.iea.org/#!/tellmap/1378539487
- IEA. (2020b). Energy Technology Perspectives 2020 - Special Report on Clean Energy Innovation.
- IEA. (2021). Net Zero by 2050.
- IEEFA. (2019). Over 100 Global Financial Institutions Are Exiting Coal, With More to Come.
- Ilhan, E., Krueger, P., Sautner, Z., & Starks, L. T. (2019). Institutional Investors' Views and Preferences on Climate Risk Disclosure.
- Insurance Information Institute. (2020). Facts + Statistics: U.S. catastrophes. Retrieved from https://www.iii.org/fact-statistic/facts-statistics-us-catastrophes
- International Energy Agency. (2017). Energy Technology Perspectives 2017.
- IPCC. (2014a). AR5 Climate Change 2014: Mitigation of Climate Change.
- IPCC. (2014b). Climate Change 2014: Impacts, Adaptation, and Vulnerability.
- IPCC. (2018). Global Warming of 1.5 °C.

- KDDI. (2021). Sustainability Report 2020.
- Knutson, T., Camargo, S. J., Chan, J. C., Emanuel, K., Ho, C.-H., Kossin, J., . . . Walsh, K. (2019). Tropical cyclones and climate change assessment: Part II. Projected response to anthropogenic warming. Bulletin of the American Meteorological Society (2019).
- Ma, J. (2018). Environmental Risk Analysis by Financial Institutions: China Financial Publishing House.
- Ma, J. (2021). Chongqing's green finance roadmap to support green and low-carbon development goals. Research Center for Green Finance Development, Tsinghua University.
- Ma, J., & Sun, T. (2020). Methodologies of transition risk and physical risk analysis: cases of coal-fired power companies and mortgage loans. Tsinghua Financial Review (09), 31-35.
- Ma, J., Zadek, S., Sun, T., Zhu, S., Cheng, L., Eis, J., . . . Stumhofer, T. (2019). Decarbonizing the Belt and Road: A green finance roadmap.
- MAS. (2021). Accelerating Green Finance [Press release]. Retrieved from https://m.marketscreener.com/news/latest/MAS-Monetary-Authority-of-Singapore-nbsp-Accelerating-Green-Finance--33295889/
- McGrath, M. (2021). Climate change: IPCC report is 'code red for humanity'. BBC News. Retrieved from https://www.bbc.com/news/science-environment-58130705
- Moore, F. C., & Lobell, D. B. (2015). The fingerprint of climate trends on European crop yields. Proceedings of the National Academy of Sciences of the United States of America, 112(9), 2670-2675.
- NASA. (2019). New Studies Increase Confidence in NASA's Measure of Earth's Temperature [Press release]. Retrieved from https://www.giss.nasa.gov/research/news/20190523/
- Natixis. (2019). Natixis rolls out its green weighting factor and becomes the first bank to actively manage its balance sheet's climate impact [Press release]. Retrieved from https://pressroom-en.natixis.com/news/natixis-rolls-out-its-green-weighting-factor-and-becomes-the-first-bank-to-actively-manage-its-balance-sheets-climate-impact-2dce-8e037.html
- Natixis. (2021). BPCE issues €100 million of transition bonds, invested by AXA IM [Press release]. Retrieved from https://gsh.cib.natixis.com/our-center-of-expertise/articles/bpce-issues-100-million-of-transition-bonds-invested-by-axa-im
- NGFS. (2020a). Overview of Environmental Risk Analysis by Financial Institutions.
- NGFS. (2020b). Occasional Paper: Case Studies of Environmental Risk Analysis Methodologies.
- OECD. (2015). The Economic Consequences of Climate Change.
- Peel, B., Zhao, K., Wu, T., & Zhao, L. (2020). How to Anticipate a Green Swan Event.
- Pierfederici, R. (2020). The new climate scenarios for central banks and supervisors.
- PRI. (2018). The inevitable policy response: Act now.
- PUMA SE. (2021). Puma Responsibility Report 2020.
- Resources Radio. (2020, 2020/01/07) Pricing Climate Risk in the Markets, with Robert Litterman/ Interviewer: DANIEL RAIMI. Resources Radio.

- Royal Bank of Canada. (2020). Royal Bank of Canada TCFD Report 2020.
- Schleussner, C.-F., Deryng, D., Müller, C., Elliott, J., Saeed, F., Folberth, C., . . . Rogelj, J. (2018). Crop productivity changes in 1.5°C and 2°C worlds under climate sensitivity uncertainty. Environmental Research Letters, 13(6), 064007. doi:10.1088/1748-9326/aab63b
- Shell. (2021). Shell Sustainability Report 2020.
- Stern, N. (2007). The economics of climate change: the Stern review: Cambridge University Press.
- Swire Properties. (2021). Swire Properties Sustainable Development Report 2020.
- TCFD. (2020). TCFD 2020 Status Report.
- The 2° Investing Initiative. (2019). Storm Ahead: A Proposal for a Climate Stress-Test Scenario.
- The FAIRR Initiative. (2020). Assessing climate-related risks in the global meat industry.
- TOTAL SE. (2020). Getting to Net Zero - September 2020.
- Trafigura. (2021). Trafigura Responsibility Report 2020.
- Tsinghua, I. o. C. C. a. S. D. (2020). Comprehensive report: low-carbon transition strategies and pathways of China.
- UNEP FI. (2018). Navigating a New Climate: Assessing Credit Risk and Opportunity in a Changing Climate.
- UNEP FI. (2021). The Climate Risk Landscape - A comprehensive overview of climate risk assessment methodologies.
- Vohra, K., Vodonos, A., Schwartz, J., Marais, E. A., Sulprizio, M. P., & Mickley, L. (2021). Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem. Environmental Research, 195, 110754.
- Wang, X., & Wu, Z. (2020). The methodology and application of ESG Risk Analysis. Tsinghua Financial Review, No.82(09), 53-56.
- WMO. (2021). Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970-2019).

Cover Photo by Chopsticks on the Loose on Unsplash