



Climate Risk

Definitions, Measurement, Current Practices and Regulatory Oversight

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IN PARTNERSHIP WITH

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Foreword

The Hong Kong Monetary Authority (HKMA) co-launched the Alliance for Green Commercial Banks (the Alliance) with International Finance Corporation (IFC) in November 2020. Serving as the founding member and the regional anchor of the Asia Chapter, the HKMA, together with IFC, will bring together financial institutions, banking industry associations, research institutions, and innovative technology providers from across Asia to develop, build, and boost the capacity for green finance and promote climate investments.

The HKMA and IFC will jointly launch targeted initiatives and campaigns in the region to undertake green finance research, provide unique market insights, tailor capacity building/training support, and provide practical guidance for banks in order to develop their own roadmap to mainstream green finance as their core business and develop new green capital market products.

This report is the Alliance's first thought leadership paper and is written in collaboration with the Hong Kong Institute for Monetary and Financial Research (HKIMR). As part of the Alliance's knowledge sharing efforts, this report aims to serve as a primer for climate risk and its broad reverberations in the financial services industry. Drawing on a wide range of resources, including policy papers, academic studies, and international surveys, the report provides a curated overview of the effects of climate risk on financial institutions and financial markets, discusses up-to-date methods used to measure climate risk, explores the evolving practices of financial institutions in tackling climate risk, and highlights regulatory initiatives related to climate issues. The report concludes with key insights for the future governance and management of climate risk.

This report targets a wide and non-technical audience including participants in the financial services industry and financial regulators. Where possible, the discussion includes Asian examples and experiences to provide a one-stop practical reference with usable information for the understanding and measurement of climate risk in the region and internationally.

Tackling climate change requires the concerted efforts of global and regional stakeholders. We hope that this report will help to spread this important message, raise awareness among financial practitioners, and play a constructive role in supporting the green transition in the region.

Mr Edmond Lau

Deputy Chief Executive
Hong Kong Monetary Authority

Deputy Chairman
Hong Kong Institute for Monetary and Financial Research

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Executive Summary

In recent years, climate change has become a focal point of discussion in the financial services industry. For financial institutions and regulators, having a keen awareness and thorough understanding of climate-related financial risks is essential to better address the negative impacts of the risks while capitalising on the accompanying opportunities. This understanding will also enable financial institutions and regulators to contribute to the objectives set by the Paris Agreement of holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels.

Against this backdrop, this report provides an in-depth examination of climate risk. It begins by introducing its definition and the channels through which climate risk affects financial institutions and financial markets. It then discusses the various methods used to measure climate risk and its financial impacts. It also explores financial institutions' current practices and financial regulators' oversight of climate risk. The report concludes with key insights to consider for the future.

As a challenge to the financial services industry, climate risk arises from the physical hazards and transitional developments brought about by climate change. Climate risk may manifest as the physical risk resulting from acute and chronic changes in weather and climate, such as wildfires, droughts, rising temperatures, and rising sea levels. It may also emerge as transition risk, which arises from developments in regulations, technologies, and consumer preferences associated with the transition towards a low-carbon economy. Examples include the implementation of climate policy to reduce carbon emissions and the adoption of innovative technologies that use renewable energy. A combination of physical

and transition risks may materialise in a variety of ways, depending on how orderly and timely mitigating actions are taken to tackle these risks.

Climate risk primarily influences financial institutions by disrupting their lending and underwriting activities, in addition to their investments and operations. For instance, intensifying droughts can induce significant losses for agricultural firms and impair their ability to repay debt, which increases the credit risk of commercial banks. In addition, droughts may also lead to a surge in weather-related insurance claims, which increases the underwriting risk of insurance companies. Furthermore, the equity prices of these firms could become depressed and the market risk faced by asset managers subsequently increases. The academic literature confirms that climate risk has non-negligible effects on the prices of real estate, equities, and bonds. Moreover, climate risk influences financial institutions' decision-making behaviour. As a typical example, many institutional investors have divested from highly polluting companies to address the increased climate risk.

It is critical to measure climate risk and its financial impacts for effective monitoring and management. Thus, financial institutions apply a variety of indicators to quantify their exposure to climate risk. For example, carbon emission indicators, including carbon footprints and carbon intensity, are frequently used to measure the degree of transition risk that a company or an investment portfolio carries. This is because a higher level of carbon emissions implies a greater vulnerability to regulatory and technological changes during the transition to a low-carbon economy.

Scenario-based methods are also becoming prevalent in climate risk measurement. To account for the uncertainties

about when, how, and to what extent climate risk will materialise, scenario-based methods allow for the exploration of a range of plausible impacts under different climate scenarios. For example, banks may use two scenarios to estimate the default probability of a mortgage loan that is affected by the risk of rising sea levels. The first scenario shows low risk if climate policies are implemented in a timely and orderly manner, while the second scenario shows high risk if insufficient and delayed mitigation policies are in place. This type of exercise better prepares financial institutions for different possibilities that may occur in the future. One well-known application of scenario-based methods is stress testing, which is often applied by financial regulators to monitor the resilience of the financial system under extreme but plausible climate scenarios.

Despite progress in climate risk measurement, a number of challenges remain. The primary obstacle is the lack of available data. For example, there is a shortage of climate risk data for emerging markets, making climate risk measurement difficult for financial institutions operating in these markets. Besides, the reliability of existing data sources and the comparability of climate risk measurement methods are also issues to be explored. These challenges underscore the importance of introducing mandatory and standardised frameworks for climate-related financial disclosure, as well as building human capacity, especially on expertise to process data, calculate measures, and make judgments about the quality of the resulting measures.

Apart from measuring climate risk, financial institutions have also become more engaged in other aspects of climate risk management. According to several international surveys conducted between 2019 and 2021, many financial institutions are aware of the severity of climate risk and have begun engaging in climate risk management. Concrete plans to tackle climate risk include providing green loans, underwriting low-emission projects, and investing in sustainable assets. Furthermore, an increasing number of financial institutions have started

to measure climate risk and incorporate climate-related disclosures in financial reports.

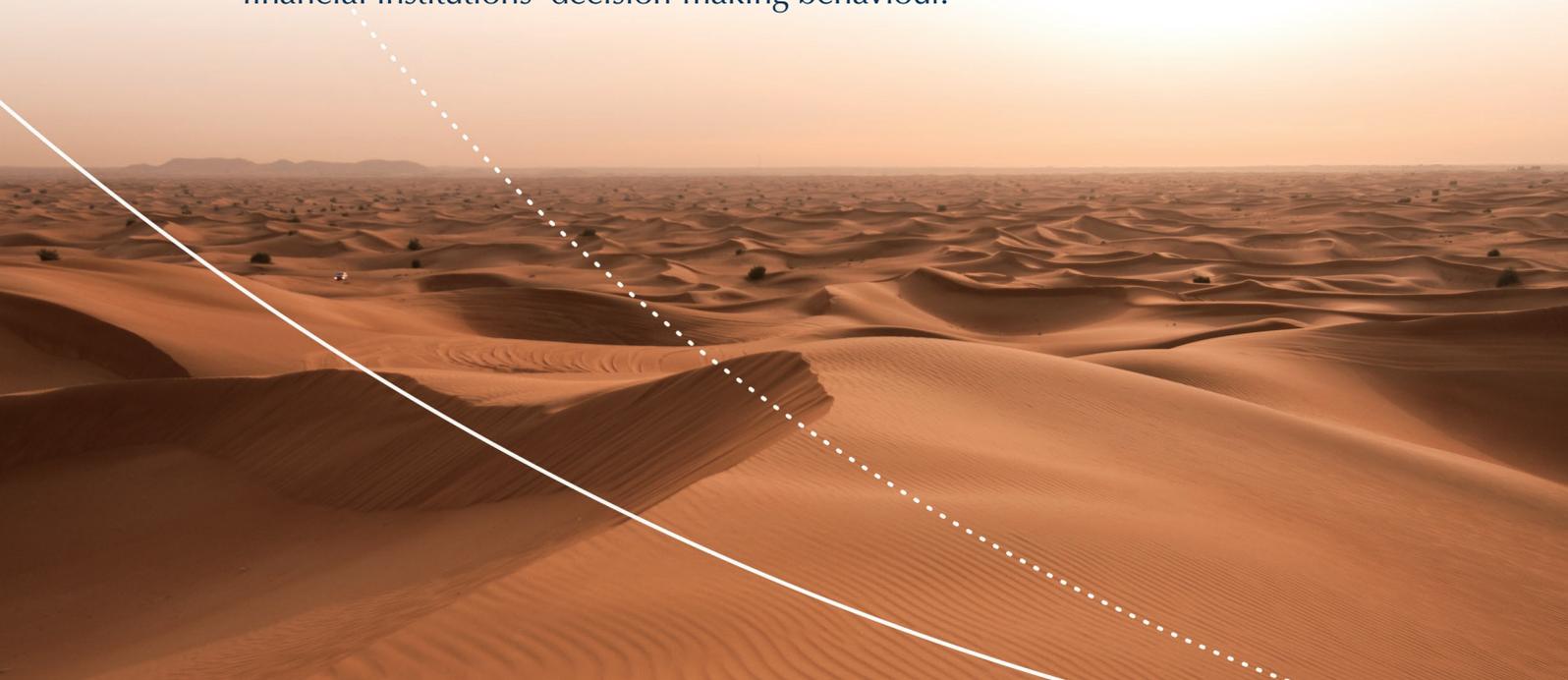
Meanwhile, financial regulators around the world have increased their oversight of climate risk, such as by working towards mandatory and standardised disclosure frameworks and conducting climate stress tests. To increase the transparency and consistency of climate-related financial risk disclosure, financial regulators have begun to enact mandatory disclosure requirements. In addition, they seek multilateral co-operation to develop standardised disclosure frameworks, including setting out commonly accepted taxonomies that define environmentally friendly and harmful activities. Various supervisory bodies and international organisations have completed, are conducting, or plan to perform climate stress tests. Available findings suggest that some financial institutions may face potentially sizeable losses from climate risk, and the implementation of timely and effective mitigating policies is key to minimising those losses. These lessons will be valuable for setting out regulatory expectations and requirements in terms of the risk and responsibilities associated with climate change in the future.

1

Climate Risk: A Challenge for the Financial Services Industry

HIGHLIGHTS:

- Climate risk arises from physical hazards caused by climate change, and from developments in regulations, technologies, and consumer preferences associated with the transition to a low-carbon economy.
- Various climate scenarios are designed to encompass a range of plausible future states of the world, each corresponding to a combination of physical and transition risk outcomes depending on the orderliness and timeliness of the transition.
- Climate risk translates into financial risks by disrupting financial institutions' operations, lending and underwriting activities, and investments in affected securities. By affecting company profits, household income and government revenue, climate risk may impact the prices of their associated financial assets.
- Evidence from the academic literature confirms that climate risk has non-negligible effects on the prices of real estate, equities, and bonds, and affects financial institutions' decision-making behaviour.



1.1 Sources of climate risk

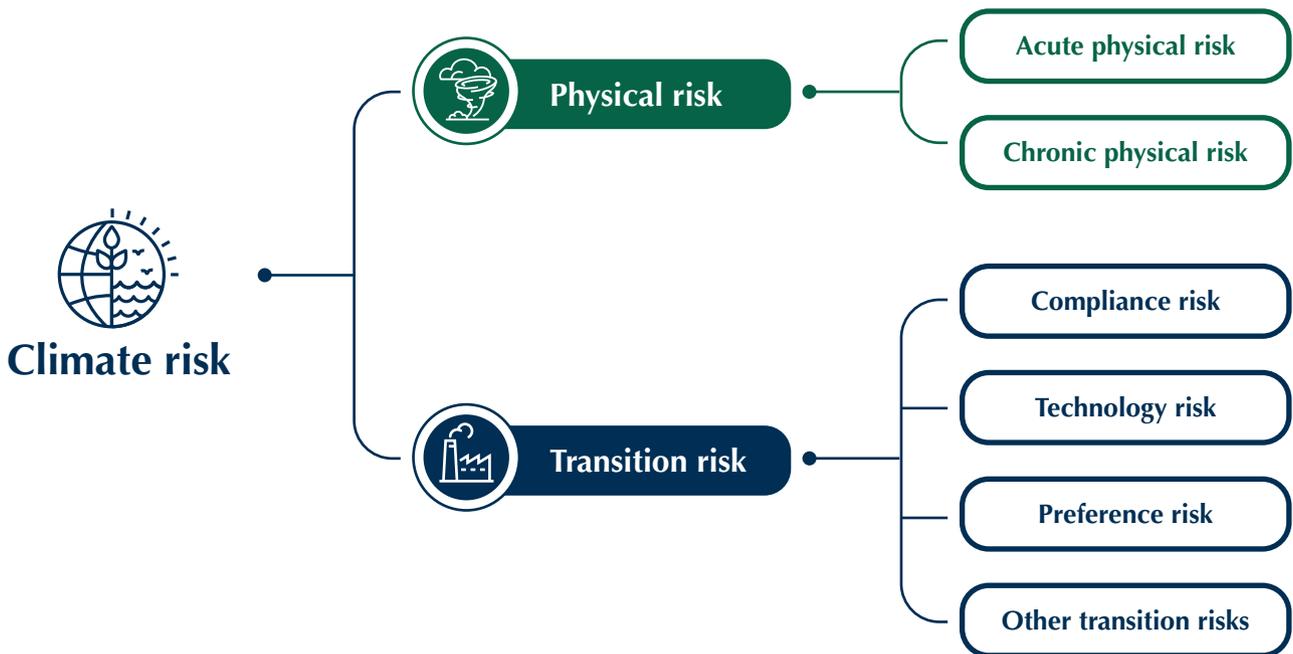
Climate risk refers to the exposure to physical hazards and transition developments associated with climate change.¹ There is a broad consensus that the sources of climate risk fall into two categories: (1) the physical risk from direct changes in weather and climate; and (2) the transition risk from indirect changes during the transition from a fossil fuel-based economy to a low-carbon economy.² Figure 1.1 shows the classification of climate risk and the sub-categories that are examined next.

Physical risk affects the economy in two ways. **Acute physical risk** arises from extreme weather events that occur over short periods of time, such as floods, wildfires, and tropical cyclones. As Figure 1.2 shows, natural

disasters have resulted in increasing economic losses in recent years, with an 81% growth in such losses during 2011-2020 compared with the decade before.

Chronic physical risk results from long-term climate change and landscape evolution, such as global warming and ocean acidification. Global temperatures have risen by more than 1°C above pre-industrial levels.³ The latest findings in the literature suggest that this warming trend is strongly related to greenhouse gas (GHG) emissions (Figure 1.3), and it has already caused observable consequences such as rising sea levels and intensifying heatwaves. The materialisation of chronic risk may lead to serious economic consequences such as loss of arable land and reduction in labour productivity, which pose persistent threats to the global economy.⁴

Figure 1.1 Classification of climate risk



Source: HKIMR staff compilation.

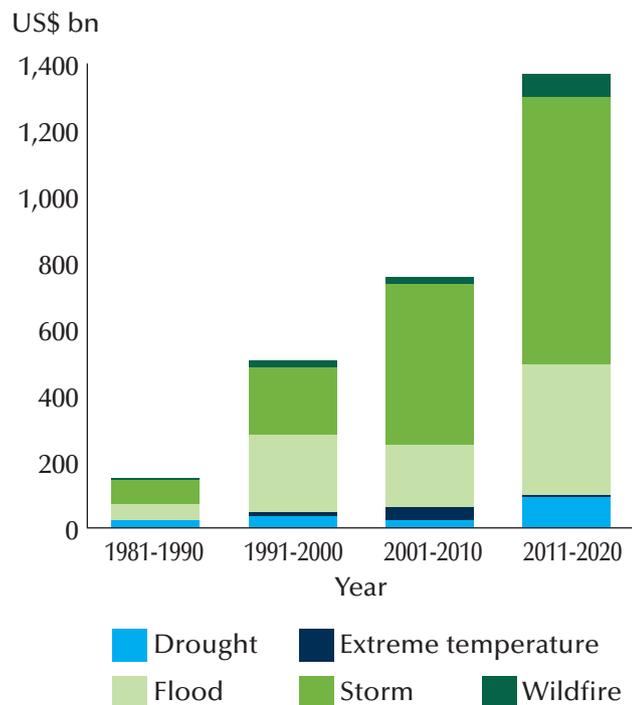
¹ IPCC (2021) provides a comprehensive and up-to-date assessment of climate change based on physical science evidence. See Box 1.1 for more details.

² For example, see, SSF (2019), UNEP-FI (2019), and BCBS (2021b).

³ For example, see, WMO (2021) and NOAA (2021).

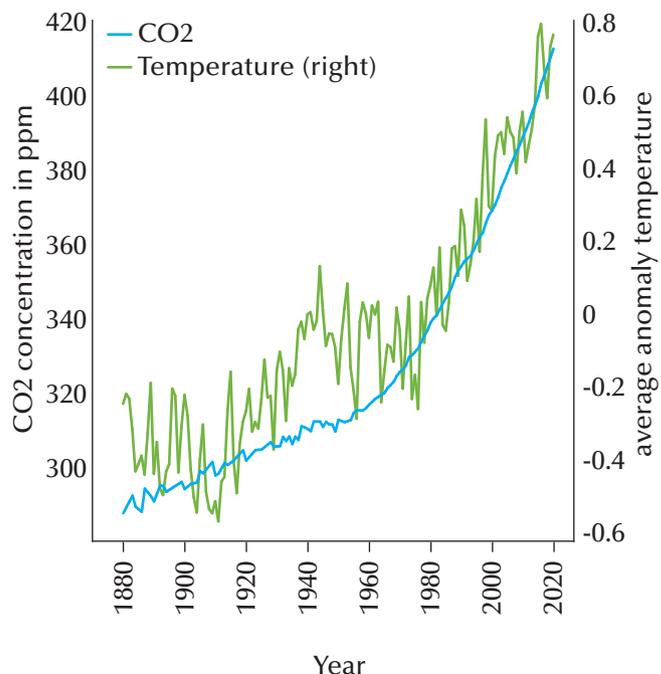
⁴ IPCC (2021).

Figure 1.2 Estimated economic losses from natural disasters (1981-2020)



Sources: The Emergency Events Database⁵ and HKIMR staff compilation.

Figure 1.3 Global CO₂ concentrations and anomalous temperatures (1875-2020)



Sources: National Oceanic and Atmospheric Administration,⁶ Met Office Hadley Centre (Morice et al., 2012), and HKIMR staff compilation.

Transition risk arises primarily from developments in regulation, technology, and consumer preferences in the process of moving to a low-carbon and sustainable economy.

First, the implementation of climate policies and the litigation related to climate change creates **compliance risk**. For example, countries around the world, including eight from Asia, are developing and implementing carbon pricing policies to induce reductions in GHG emissions. By 2021, 21.5% of global GHG emissions are covered by various carbon pricing schemes.⁷ With the increasing

implementation of carbon pricing policies, carbon-intensive companies may be exposed to increased risks of profit decline and asset devaluation.

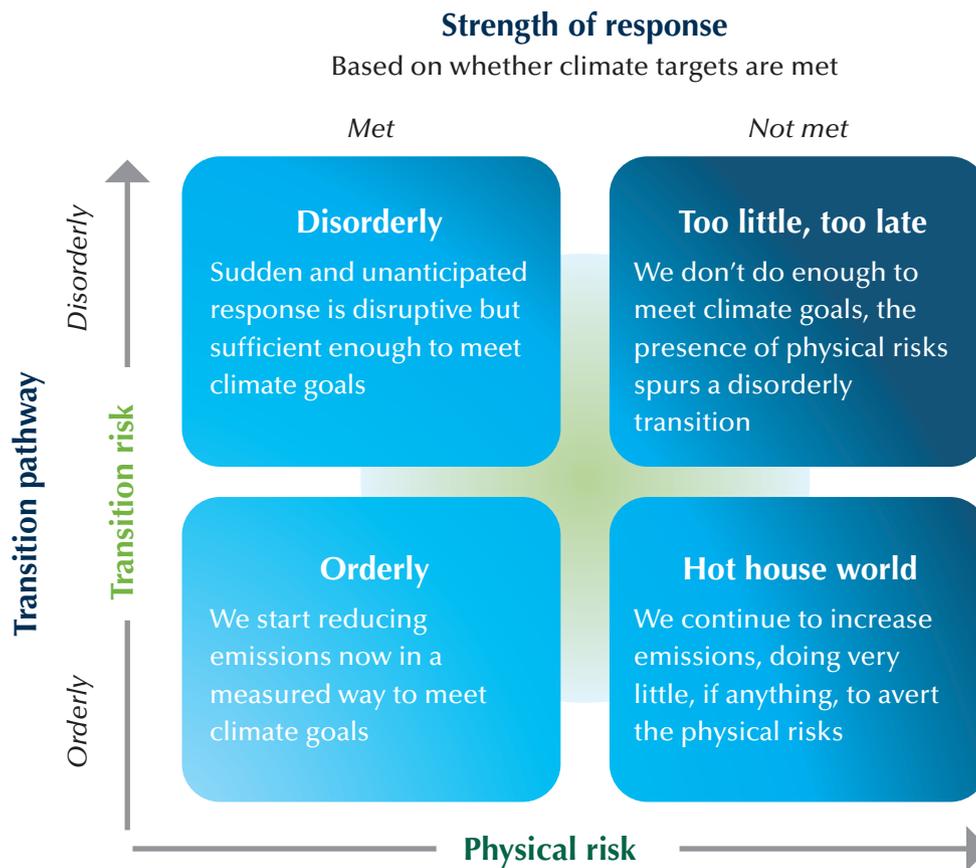
With the implementation of carbon pricing policies, carbon-intensive companies may be exposed to increased risks of profit decline and asset devaluation.

⁵ Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters, Université catholique de Louvain, Brussels, Belgium (www.emdat.be).
⁶ Ed Dlugokencky and Pieter Tans, NOAA/GML (gml.noaa.gov/ccgg/trends/).
⁷ World Bank (2021a).

Second, **technology risk** arises from the adoption of new low-carbon and energy-saving technologies, the abolition of inferior technologies, and the introduction of technological innovations that improve economic resilience to climate change. The development of the electric vehicle (EV) industry is a case in point. After a decade of rapid growth, the number of EVs on the world’s roads has reached 10 million by 2020, which is projected to increase more than tenfold to 145 million by 2030.⁸ While this transition creates opportunities for EV manufacturers, automakers producing fossil fuel vehicles may see a decrease in their profits.

Third, changes in consumer behaviours, investor sentiments, and social conventions result in **preference risk**. According to a recent survey of 9,000 citizens from East and South-East Asia, 75% of respondents expressed a desire to significantly reduce their environmental footprint. Besides, they ranked climate change and air pollution as two of the three most serious global concerns.⁹ These trends demonstrate a clear embrace of sustainability in consumer preferences. If companies do not adopt sustainable strategies accordingly, there is an increasing danger of being left behind.

Figure 1.4 High-level framework for the analysis of physical and transition risks



Source: NGFS (2021a).

⁸ IEA (2021).

⁹ Green Queen Media. Health and Sustainability a Priority for Asian Consumers but Cost and Ease Remain Still a Barrier (<https://www.greenqueen.com.hk/health-sustainability-a-priority-for-asian-consumers-but-cost-ease-remain-still-a-barrier/>).

Other forms of climate risk include **reputation risk**, which arises as a result of changes in consumer preferences and stakeholder expectations, and **liability risk**, which refers to the compensation that a company must pay should it be found responsible for the adverse effects of climate change. This report considers reputation and liability concerns as subsets of transition risk.

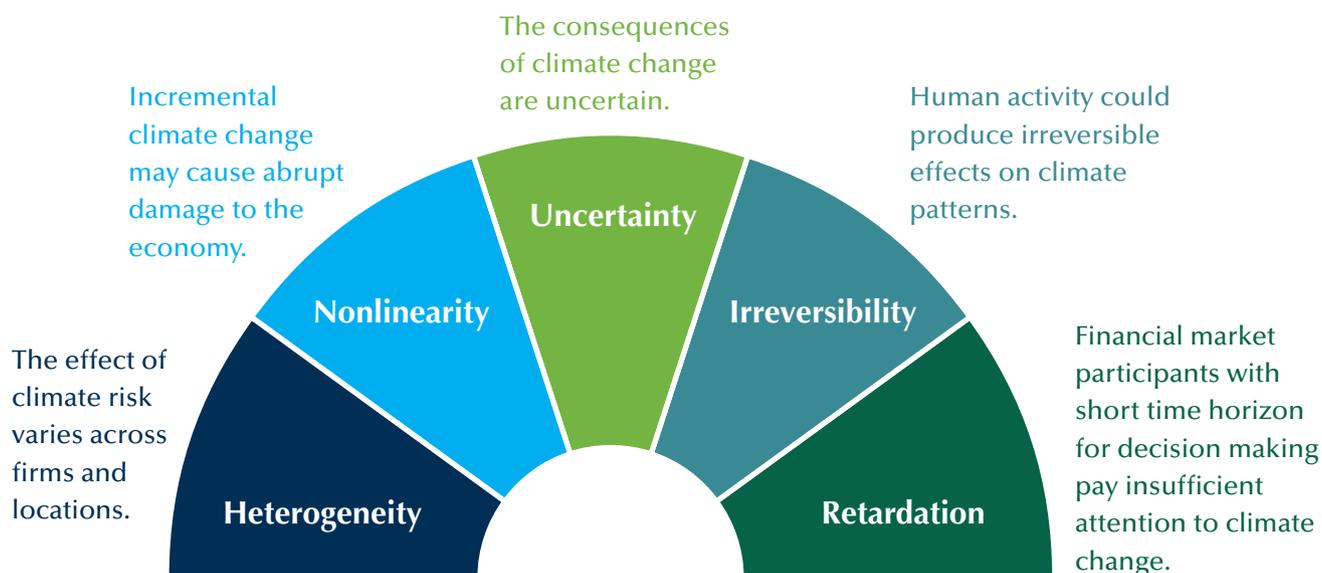
Physical and transition risks have complex relationships depending on the roles that human activities play in them. The Network for Greening the Financial System (NGFS) identifies four primary scenarios of physical and transition risk outcomes based on how adequately and orderly humans respond to climate change (Figure 1.4). For example, orderly and timely actions (bottom left quadrant) help reduce physical risk without increasing transition risk. If little is done to address climate change (bottom right quadrant), the transition risk will be

minimal, but the physical risk will be high. If actions are insufficient and delayed (top left quadrant), it is possible that both heightened physical and transition risks will be faced.

There is also a trade-off in the use of resources to mitigate these two types of risk.¹⁰ For example, focusing exclusively on accelerating the transition to a low-carbon economy could divert resources away from mitigating the negative impacts of climate change, thereby increasing physical risk. This underscores the importance of appropriate resource allocation to manage both types of climate risk.

Climate risk has several distinguishing characteristics that separate it from traditional financial risks. These include heterogeneity, nonlinearity, uncertainty, irreversibility, and retardation (Figure 1.5).

Figure 1.5 Distinguishing characteristics of climate risk



Source: HKIMR staff compilation.

¹⁰ CFTC (2020).

Heterogeneity: The effect of climate risk varies across locations. For example, while rising sea levels pose an existential threat to island nations, the impact on landlocked nations is relatively small. Climate risk also has varying effects on firms from different industries. For example, physical risk is more likely to affect the agriculture sector, while transition risk is more likely to influence the energy sector. The effect of climate risk must therefore be understood within its geographic and economic context.

Nonlinearity: Scientific studies show that small and incremental developments in climate may lead to large and abrupt changes in the ecological system, which may subsequently cause serious and unexpected damage to the economy. For example, once a threshold is reached, melting glaciers will greatly weaken and perhaps even stop ocean circulations that drive the Asian monsoon,¹¹ which could significantly affect food production in the region.

Uncertainty: The consequences of climate change are highly uncertain and little historical experience can be relied upon to estimate their magnitude. For instance, the significant decline in corn production due to climate change across Asia was once a one-in-100-year event between 1990 and 2017, but will become a one-in-20-year event by 2050.¹² The uncertainties surrounding climate policy, technological progress, and social transition make the impact of climate change even more difficult to predict. This suggests that conventional measurement methods that rely on mean forecasts may no longer be suitable for examining the impact of climate risk.

Irreversibility: Scientific evidence shows that human activity has the potential to permanently alter long-term climate patterns,¹³ which may lead to structural transformations in the economy and financial system. It is therefore important for the affected parties to consider how to adjust their risk management frameworks to reflect these structural transformations.

Retardation: Climate risk may fully unfold over several decades, but the timeframe that financial market participants usually consider is only a few years. This mismatched time horizon may lead to insufficient attention and response to climate risk. Thus, financial institutions and regulators may need to extend the time horizon of their decision-making process when addressing climate risk.

1.2 Transmission of climate risk in the financial system

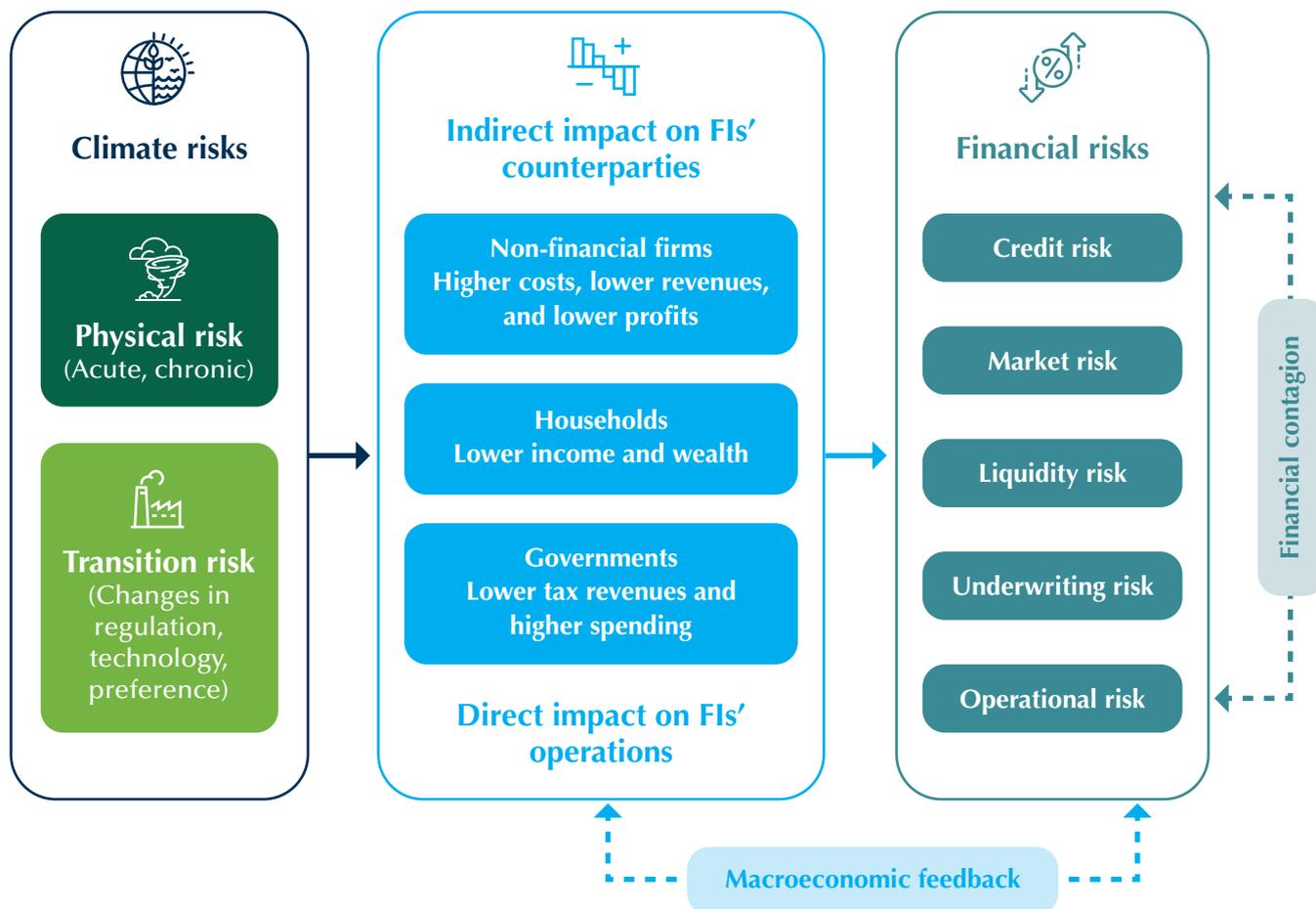
Climate risk mainly affects financial institutions (FIs) through their lending activities (banks), underwriting activities (insurers), and investments in affected securities (asset managers). Climate risk can also disrupt FIs' operations. It can be amplified from FIs with direct exposure to climate risk to those without such exposure through the two mechanisms of financial contagion and macroeconomic feedback. Figure 1.6 summarises the transmission channels of climate risk in the financial system.

¹¹ Lenton et al. (2019)

¹² MGI (2020).

¹³ IPCC (2021)

Figure 1.6 Transmission of climate risk in the financial system



Sources: NGFS (2020d), BCBS (2021a) and HKIMR staff compilation.

(1) Credit risk

Climate risk maps to credit risk when it affects borrowers to whom FIs provide lending services, such as non-financial firms, households, and governments. It can weaken borrowers' ability to service debt, resulting in a higher probability of default. It can also depreciate borrowers' collateralised assets, resulting in a lower recovery value for the collateral in case of default.

Physical risk may affect firms by damaging properties, disturbing operations, and disrupting supply chains, thereby reducing their ability to repay debt. It may also affect the value of homes that households have purchased using mortgages, which increases the credit risk for banks

holding the mortgage loans. For governments, physical risk may affect their tax and spending, because lower tax revenues may result from companies and households being affected by climate change, while higher government spending may be required to offset the negative effects of climate change. Both reduce the government's ability to repay debt, which leads to increased default risk.

Transition risk can also develop into credit risk. For instance, as consumer preferences shift towards environmentally friendly products, sales of carbon-intensive products may decline, restricting their producers' ability to repay loans. In addition, policies to restrict the extraction of fossil fuels may create *stranded assets* that no longer yield economic returns. As a result, firms owning

the right to exploit fossil fuel reserves may face an increased risk of default.

(2) Market risk

Market risk arises when climate risk depresses asset prices or increases asset price volatility and the risk premium. FIs that own the associated assets may suffer losses as a result of adverse price movements.

For instance, an increase in the frequency and severity of droughts may substantially reduce revenues for agricultural companies. Their investors may demand a higher risk premium because of this unanticipated change, which will depress the equity and bond prices of the affected firms.

Municipal bonds, as a type of debt security issued by local governments, offer another example. Physical risk may disturb publicly financed infrastructure projects and subsequently lower the value of municipal bonds tied to those projects. Transition risk may also have an impact: If local governments in regions with a high concentration of carbon-intensive industries fail to rebalance their economies, the transition towards a low-carbon economy may reduce their tax income, thus decreasing the value of the associated municipal bonds.

(3) Liquidity risk

Climate risk may manifest as *funding liquidity risk* if it impairs asset managers' ability to raise capital or prevents banks and insurers from meeting their obligations on time. It may also translate into *market liquidity risk* if it impairs FIs' ability to trade financial assets at a fair price in a timely manner.

Physical risk can have a detrimental effect on both funding and market liquidity. For instance, a wildfire may prompt affected households and firms to withdraw their savings from commercial banks, which puts banks' short-term funding liquidity under pressure. Dealers may also face increased funding liquidity risk after a wildfire, as a result

of liquidity shortages in the repo market. Furthermore, to settle the increasing number of claims following a wildfire, insurers may need to liquidate assets under unfavourable conditions, thereby introducing market liquidity risk.

Transition risk can lead to liquidity risk as well. Increased carbon taxes, for example, could shift market preference away from equities and bonds of carbon-intensive companies, making it more difficult for FIs holding these assets to liquidate them.

(4) Underwriting risk

Climate risk may translate into insurers' underwriting risk by incurring higher-than-expected insurance claim payouts, because the nonlinearity and uncertainty of climate risk increase the difficulty for insurers to predict the magnitude of losses when the risk materialises.

Physical risk can translate into underwriting risk. For property insurers, climate change may lead to an unforeseen increase in weather-related claims. For life insurers, the adverse impact of climate change on morbidity and mortality may increase their burden. Transition risk can create underwriting risk as well. For example, property insurers that service the carbon-intensive industries may face increased costs after the implementation of carbon pricing policies.

For property insurers, climate change may lead to an unforeseen increase in weather-related claims. For life insurers, the adverse impact of climate change on morbidity and mortality may increase their burden.

As climate hazards intensify over time, insurers may raise premiums to cover their claims. This could increase the

cost for the insured and deter them from purchasing insurance, resulting in more severe consequences if a contingency occurs. Alternatively, insurers may transfer risk through reinsurance or insurance-linked securities such as catastrophe bonds. However, if actual losses significantly exceed expectations, especially when climate risk becomes systematic and cannot be diversified, insurers may have to declare insolvency or exit the market, leaving the risk to the government and other unprotected market participants.

(5) Operational risk

Operational risk arises when climate events induce losses from inadequate or failed internal processes, people, and systems. Physical risk can lead to operational risk. For instance, acute weather events can damage transportation and telecommunication infrastructure, thus impairing FIs' operational capability. Chronic climate change, such as global warming, also threatens the operational efficiency of FIs by reducing labour supply and productivity.

Transition risk can translate into operational risk as well. For example, FIs that lend to and invest in carbon-intensive businesses may face increased litigation and liability costs. They may also be exposed to reputation risk if they fund companies that are then held responsible for negative climate impacts.¹⁴

(6) Amplification mechanisms

Climate risk can be amplified from those FIs with direct exposure to those without such exposure through the two mechanisms of financial contagion and macroeconomic feedback.

Financial contagion is the first mechanism. When FIs' balance sheets are negatively affected by climate risk, they may be forced to fire sell financial assets at discounted prices. This would erode the net worth of other market participants in a highly connected financial network, triggering further rounds of fire sales and asset devaluations. As a consequence, financial contagion may induce large-scale simultaneous asset sales, thereby amplifying climate risk in the financial markets.

The indirect effect of climate risk caused by financial contagion can be substantial compared with the direct impact of climate risk. According to a recent study,¹⁵ the second-round effects of climate risk due to banks' cross-exposure on the interbank credit market can be twice as large as the first-round effects due to banks' direct exposure to climate risk.

Macroeconomic feedback is the second mechanism. It arises from the interaction between the financial markets and the macroeconomy. For example, chronic physical risk, such as intensifying heatwaves, may increase the credit risk of commercial banks that lend to agricultural companies. It limits banks' lending capacity and weakens their support for the economy. The resulting decline in economic activity may create even higher credit risk, thereby amplifying the original disturbance.

This macroeconomic feedback can be qualitatively important. As demonstrated in another recent study,¹⁶ when the linkage between the financial markets and macroeconomy is ignored, the introduction of a carbon tax merely reallocates production from environmentally harmful to environmentally friendly industries. However, when this linkage is accounted for, the carbon tax will

¹⁴ BCBS (2021b).

¹⁵ Battiston et al. (2017).

¹⁶ Carattini et al. (2021).

cause a decline in the price of carbon-intensive assets, which reduces FIs' net worth, forcing them to scale back support for the economy and leading to a fall in production in both environmentally harmful and friendly industries.

1.3 Impact of climate risk on the financial market and financial institutions: Empirical findings

This section provides evidence on the impact of climate risk on the financial services industry by reviewing the latest findings from the academic literature on (1) whether climate risk is reflected in the prices of real estate, equities, and bonds, and (2) how climate risk affects the businesses of banks, insurers, and institutional investors.

There is evidence pointing to the pricing of climate risk in the real estate and bond markets, while the evidence from the equity market is more mixed. Moreover, studies

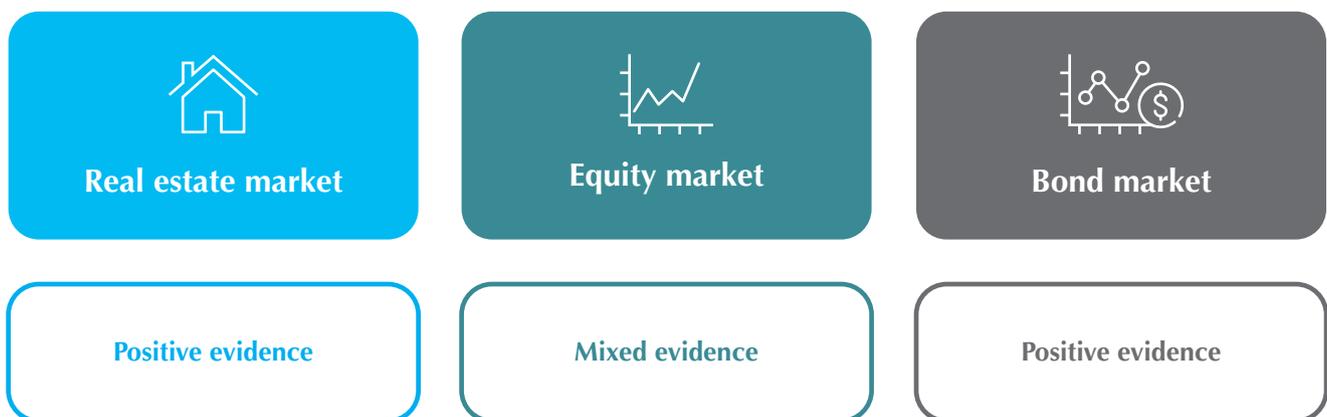
show that climate risk impacts FIs' decision-making behaviour. Banks respond by reducing lending and tightening lending policies to firms facing increased climate risk. Insurers affected by natural disasters raise premiums and rebalance their investments. Institutional investors reduce their holding of securities affected by elevated climate risk.¹⁷

There is evidence pointing to the pricing of climate risk in the real estate and bond markets, while the evidence from the equity market is more mixed.

1.3.1 Effect of climate risk on financial asset prices

Figure 1.7 summarises the evidence from the academic research on the pricing of climate risk in the real estate, equity, and bond markets.

Figure 1.7 Evidence on the pricing of climate risk in financial markets



Source: HKIMR staff compilation.

¹⁷ Most studies focus on the impacts of climate risk on the US financial markets and financial services industry in due to their importance and data availability. Other studies that focus on similar impacts in other regions of the world are also discussed in this section.

(1) Real estate market

Research on the real estate market shows that both physical risk (such as tropical cyclones) and transition risk (such as mitigating policies) have significant impacts on real estate prices. For instance, one study finds that hurricane Sandy, which struck the east coast of the United States in 2012, led to a persistent reduction in the prices of properties located in the affected areas, regardless of the degree of damage caused by the hurricane. Another study finds that, after England and Wales began penalising property owners for low energy efficiency, the prices of affected homes decreased by about £5,000 to £9,000 relative to unaffected ones.¹⁸

Some evidence suggests that, in climate-concerned communities, houses affected by chronic physical risk (such as sea level rises) also sell at a discount. For example, a study on the housing market of the United States shows that a one-standard-deviation increase above the national mean in the percentage of climate change believers is associated with an approximate 7% decrease in house prices for homes projected to be underwater.¹⁹

(2) Equity market

There is mixed evidence on whether climate risk is factored in equity prices. Several studies find that firms with higher carbon emissions generate higher returns. Known as the carbon premium, it suggests that investors demand compensation for the higher transition risk that these equities carry. A study on the US equity market finds

that a one-standard-deviation increase in carbon emissions of a listed company leads to a 1.8% increase in its annualised return. The sharp increase of the carbon premium is also observed in Asian equity markets across different economic sectors after the signing of the Paris Agreement.^{20, 21}

However, this finding is not yet conclusive, partly because investors have only recently begun to pay attention to climate risk, so that the data available for researchers to explore the effect of climate risk on expected stock returns is relatively limited. For example, a study finds that US green stocks in fact outperformed brown stocks as climate concerns strengthened in recent years.²²

Moreover, evidence suggests that equity prices do not *fully* factor in climate risk. For example, several studies find that a firm's *current* exposure to climate risk can predict its *future* equity returns. This implies that the response of equity prices to changes in climate risk is slow and insufficient, as investors do not make use of all publicly available information when pricing equities.²³

(3) Bond market

Studies on the bond market offer a clearer picture of the expected effects of climate risk because a bond's yield to maturity is a direct measure of its expected return. Evidence suggests that both physical and transition risks are beginning to be priced in corporate, municipal, and sovereign bonds. For instance, as demonstrated in a study, yield spreads between the corporate bonds issued by high-

¹⁸ Ortega and Taspinar (2018) and Ferentinos et al. (2021).

¹⁹ Baldauf et al. (2020).

²⁰ The Paris Agreement is an international treaty on climate change that was adopted by 196 Parties in December 2015. One of the main goals of the Agreement is to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels. Visit the following URL for more information: <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>.

²¹ Bolton and Kacperczyk (2020, 2021).

²² Choi et al. (2020), Pastor et al. (2020, 2021).

²³ Hong et al. (2019) and Kumar et al. (2019).

emitting firms and the risk-free bond increased by 0.37% after the signing of the Paris Agreement, suggesting that investors require a higher expected return in the face of greater transition risk.²⁴ In addition, evidence suggests that the sovereign bonds issued by countries that are more vulnerable to climate risk have lower credit ratings, higher bond yields, and higher bond spreads. These effects are especially large in developing countries with a weaker ability to adapt to and mitigate the consequences of climate change.²⁵

Several studies examine the performance of green bonds, which differ from conventional bonds in that they finance environmentally friendly projects. Although no conclusive evidence has emerged,²⁶ a study highlights that when a green bond is verified or certified, its yield at the issuance date is significantly lower than that for conventional bonds.²⁷ One interpretation of this finding is that investors are willing to accept a lower yield in exchange for a better hedge against climate risk.

1.3.2 Effect of climate risk on financial institutions

A growing body of literature explores how banks, insurers, and institutional investors respond to climate risk. Figure 1.8 outlines the main findings.

(1) Banking industry

Most discussions in the banking sector centre on the impact of acute physical risk. Extreme weather events impair the stability of banks by raising loan delinquency, increasing non-performing loans, and drying up banks' funding liquidity. For example, during the 1980s US Farm Debt Crisis, every 1% reduction in crop yields due to extreme weather leads to a 3% increase in loan defaults and a 0.32% increase in the probability of bank failure.²⁸ Another study confirms that natural disasters increase commercial banks' default risk using data from more than 160 countries in the period 1997-2010.²⁹

Figure 1.8 Financial institutions' responses to climate risk



Source: HKIMR staff compilation.

²⁴ Seltzer et al. (2021)

²⁵ Cevik and Jalles (2020a, 2020b)

²⁶ For a review of the green bond premium literature, see Lau et al. (2020).

²⁷ HKIMR (2020).

²⁸ Bergman et al. (2020).

²⁹ Klomp (2014).

Following natural disasters, banks charge higher lending rates and offer less favourable lending policies when they originate new mortgage and commercial loans in the affected areas. They also transfer existing risk through loan sales and securitisation. Furthermore, studies examining the consequences of earthquakes in Japan find that, as the lending capacity of affected banks deteriorates, it adversely impacts borrowers even outside the affected areas.³⁰

While some studies suggest that banks temporarily increase lending in the short run to meet increased credit demand after natural disasters, evidence also suggests that banks reduce lending to areas or firms with high exposure to climate risk in the long run.

Finally, evidence reveals that banks experience increased financial risks when there is a risk of their loans being affected by climate policies. As a result, they charge higher lending rates to less environmentally sustainable firms. For example, a study finds that, after the signing of the Paris Agreement, the lending rate for brown firms is on average 0.23% higher than that for non-brown firms in the Asia-Pacific syndicated loan markets.³¹ Further evidence suggests that banks' financial risks decrease when climate policies are already in place. For example, a study shows that Chinese banks' green practices have reduced the credit risk they face after the introduction of a series of green credit policies in China.³²

(2) Insurance industry

Studies of the insurance industry find that extreme weather events incur substantial losses to insurers, who respond by raising insurance premiums. However, the total premium earned in the affected areas declines, which is not only because of falling demand, but also because some insurers have exited the market. Insurers also adjust other insurance policies to cover the losses. A study finds that, following losses in an insurer's property insurance division caused by unusual weather, its life insurance division adjusts policies to generate more immediate revenue and increase transfers to support the property insurance division.³³

Insurers also rebalance their investment portfolios to address increased underwriting and liquidity risks. This includes selling risky assets and shifting towards liquid securities. For instance, a study shows that insurers are more likely to purchase safer and more liquid bonds after unusual weather events.³⁴

(3) Institutional investors

Climate risk can influence the decision-making behaviour of institutional investors. Adverse weather events affect investors' performance by changing their mood and distracting their attention. A study finds that fund managers located near disaster regions underweight the equities of firms from disaster areas. This is due to asset managers' irrational behaviour rather than any superior information they may possess.³⁵

³⁰ Hosono et al. (2016) and Uesugi et al. (2018).

³¹ Ho and Wong (2021).

³² Cui et al. (2018)

³³ Ge (2021).

³⁴ Ge and Weisbach (2021)

³⁵ Alok et al. (2020).

Most institutional investors are aware of the threat that climate risk poses to their portfolios. Accordingly, divestment is a widely adopted strategy to address heightened climate risk. A study shows that mutual funds reduce their exposure to GHG emissions by 7.5% in one year after signing an initiative that commits to responsible investment.³⁶

Most institutional investors are aware of the threat that climate risk poses to their portfolios, and divestment is a widely adopted strategy to address heightened climate risk.

Box 1.1 Scientific evidence for climate change

The Intergovernmental Panel on Climate Change (IPCC) released its Sixth Assessment Report in August 2021. The 4000-page report presents the most comprehensive and up-to-date physical science understanding of climate change. According to the report, human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes across the climate system have occurred. These changes are unprecedented and already affecting many weather and climate extremes in every region across the globe.

Under all emissions scenarios considered in the report, global surface temperature will continue to increase until at least the middle of 21st century. Global warming of 1.5°C and 2°C will be exceeded during this century unless deep reductions in greenhouse gas emissions occur in the coming decades. Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost. Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events.

Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, but they will have little effect on long-term global warming. With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers.

From a physical science perspective, limiting human-induced global warming to a specific level requires reaching at least net zero carbon dioxide emissions along with strong reductions in other greenhouse gas emissions.

The effect of climate change discussed in the IPCC report may create climate risk, which could subsequently translate into financial risks and affect the financial services industry.

Source: IPCC (2021) and HKIMR staff compilation.

³⁶ Humphrey and Li (2021).

2

Measuring Climate Risk: Methods and Ongoing Issues

HIGHLIGHTS:

- Climate risk indicators are used to measure financial institutions' exposure to climate risk. Carbon emission indicators are often used as benchmark measures for transition risk. Physical risk indicators are constructed from geographic data using various sources. Recently developed indicators based on textual and capital market data offer a broader picture of financial institutions' exposure to climate risk.
- Scenario-based measurement methods are used to explore a range of plausible impacts of climate risk on financial institutions that might occur under different climate scenarios. Stress testing and sensitivity analysis are two major applications of scenario-based methods.
- The primary challenge in climate risk measurement is the lack of available data. Besides, the reliability and comparability of different methods and data sources are also issues to be explored and their implication better understood.



2.1 Overview

Climate risk measurement is an essential component of effective climate risk management. As climate risk is distinguished from traditional financial risks, a new set of methods is required to measure its magnitude and quantify its impact on financial institutions (FIs).

A general framework for climate risk measurement with three stages is outlined in Figure 2.1. The first stage **defines the objectives**, where FIs specify the goals to achieve, consider the types of climate risks to be assessed, and identify the channels through which climate risk translates into financial risks. The discussion in the previous chapter can serve as a reference point. The next stage is to **calculate climate risk metrics**, where FIs collect relevant data and use measurement methods that suit their objectives to make calculations. Finally, FIs **utilise the results** from the previous stage, which can be communicated to stakeholders, used to guide decision-making, and incorporated into risk assessment frameworks for further investigation.³⁷

This chapter summarises the main methods that FIs apply to measure climate risk (Figure 2.2). It first

introduces **climate risk indicators**, which estimate the magnitude of climate risk that FIs are exposed to. These include risk measures that are widely adopted in the financial services industry, such as carbon emission indicators, as well as novel metrics that offer a broader picture of FIs' exposure to climate risk, such as capital market-based indicators.

Scenario-based methods are then discussed. They translate climate risk exposure into financial performance metrics, such as the expected return of an investment and the default probability of a loan. These methods do not aim to make precise predictions, but rather to explore a range of plausible impacts of climate risk that might be realised under alternative climate scenarios. Two main applications of the scenario-based methods, stress testing and sensitivity analysis, are introduced.

This chapter concludes by discussing the ongoing issues in climate risk measurement, with a focus on the availability, reliability, and comparability of data and methods. An essential approach to solving these issues is to implement mandatory and consistent climate risk disclosure frameworks, which is discussed in the next chapter.

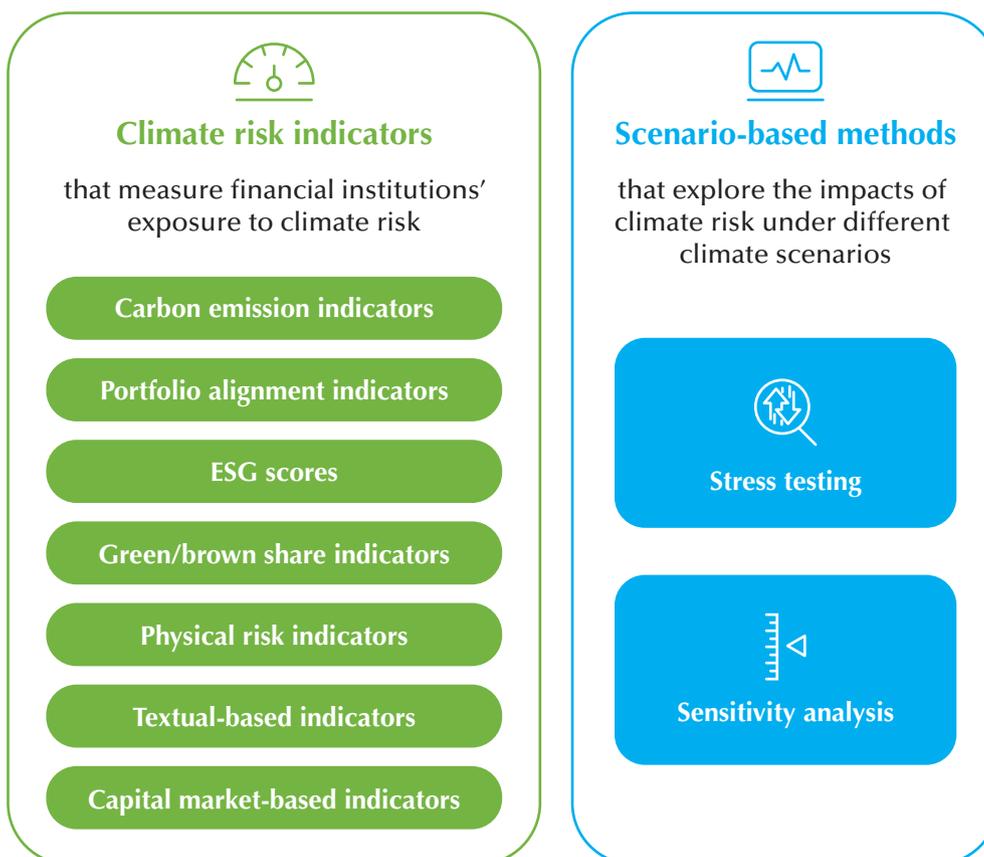
Figure 2.1 Climate risk measurement framework



Source: HKIMR staff compilation.

³⁷ This high-level framework encompasses more detailed procedures for climate risk measurement. For example, in the last stage, the results can be used to assess the financial impact of climate risk and then for strategy and target setting.

Figure 2.2 Overview of climate risk measurement methods



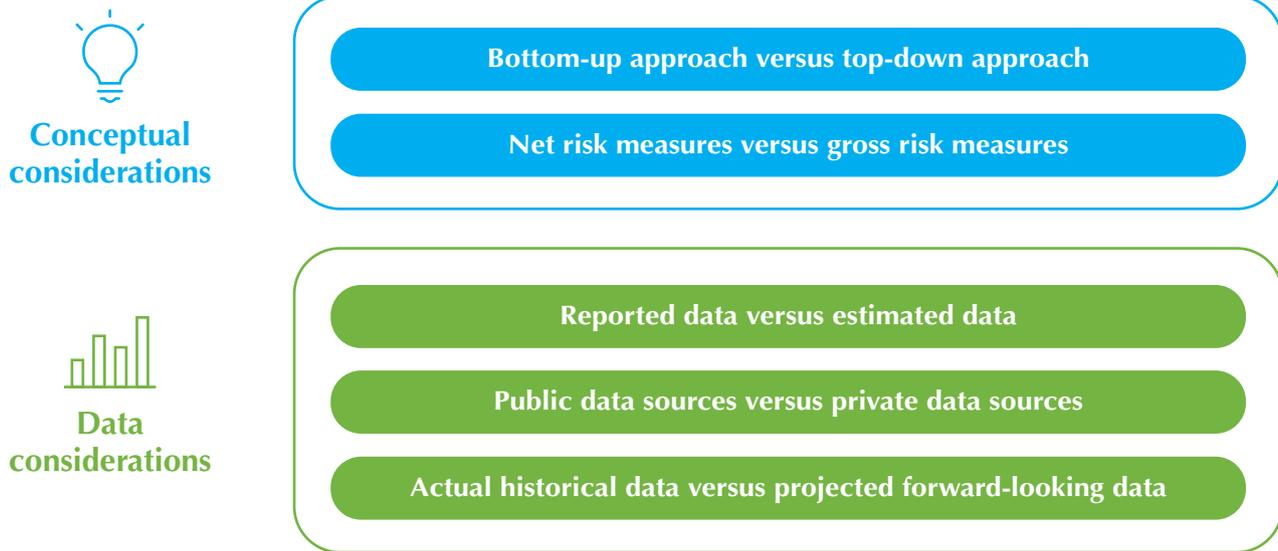
Sources: HKIMR staff compilation. Appendix A provides more details on climate risk indicators.

Figure 2.3 summarises several important conceptual and data considerations for climate risk measurement.

The first conceptual consideration is whether to take a top-down or bottom-up approach in climate risk measurement. The **top-down approach** starts with an estimation of climate risk at an aggregate level and then works its way down to the individual components. In comparison, the **bottom-up approach** begins by assessing the climate risk associated with individual components, and then sums these risks to reach a holistic view. Adopting a top-down strategy is more cost effective and is likely to yield more comparable results, while adopting a bottom-up strategy can produce more granular results by accounting for the characteristics of individual firms and locations.

The second conceptual consideration is whether to employ gross or net measures of climate risk. Methods that do not account for adaptation and mitigation efforts produce **gross risk** measures, whereas those that do account for these efforts generate **net risk measures**. For instance, when assessing how much damage a hurricane could potentially cause to an insured property, an insurer can compute the gross loss, assuming no protective measures are implemented, or the net loss, assuming precautionary measures, such as roof reinforcement, are taken by the property owner. Net risk measures incorporate active climate risk management into the calculation, but mitigation efforts considered in the calculation may become less effective as the environment changes. As a result, deriving gross risk measures is equally important for FIs to understand the magnitude of damage that climate risk may cause.

Figure 2.3 Methodological considerations of climate risk measurement



Sources: BCBS (2021a) and HKIMR staff compilation.

Three data concerns also need to be addressed. First, either **reported data** or **estimated data** can be used. Reported data are collected from a variety of sources, while estimated data are derived from models. Reported data typically provide more detailed information about the climate risk exposure of individual firms and locations, but are subject to biases, especially when there is a lack of mandatory and standardised frameworks outlining how climate-related data should be reported. When reported data are not available, estimated data from models that are built on several assumptions can be used. In this case, it is crucial to ensure that the underlying assumptions of the chosen model are compatible with the climate risk measurement objectives.

Second, the data used to calculate climate risk measures come from **public data providers** or **private data suppliers**. One of the main advantages of private data is its high granularity, but there is no guarantee of its reliability, as different data suppliers use different methods to collect data, process data, and calculate metrics. Besides, for proprietary reasons, private data suppliers are not transparent about how their data are

produced, thereby reducing the comparability of the measures.

Finally, climate risk measures can be calculated using either **actual historical data** or **projected forward-looking data**. Using historical data to quantify climate risk presumes that past patterns will persist in the future, but the uncertainty and non-linearity associated with climate risk may nullify this premise. From this perspective, forward-looking data that account for future climate change and socio-economic transitions may be more suitable for calculating climate risk metrics. Even so, measures built on forward-looking data can at best provide a range of possible outcomes, but not precise forecasts. Caution should be exercised when using forward-looking data to avoid creating misleading interpretations.

2.2 Climate risk indicators

This section introduces indicators that FIs use to measure climate risk. These indicators provide an estimate of the magnitude of climate risk that FIs carry through the

exposure of their counterparties whom they lend to, underwrite for, and invest in. Table 2.1 presents an overview of climate risk indicators. Depending on the granularity of the data available, these indicators can quantify the magnitude of climate risk associated with an economy, an industry, a company, a region, a property, a project, or an investment portfolio. Appendix A provides more details on these climate risk indicators, including their construction, merits and drawbacks, applicability, and related data issues.

A range of indicators is used to measure the transition risk arising from developments in regulations, technologies, and consumer preferences that are associated with the transition to a low-carbon economy. Given the important role of GHG emissions in contributing to global warming, **carbon emission indicators** are frequently used as benchmark measures for transition risk.³⁸ A higher level of carbon emissions implies a greater vulnerability to changes in regulations, technologies, and preferences, and consequently a higher exposure to transition risk. FIs can employ these indicators to measure their counterparties' exposure to transition risk and avoid engaging in high-emission projects.

Portfolio alignment indicators also measure transition risk. They gauge how closely the carbon emission path of an entity, usually a firm or an investment portfolio, aligns with a climate target, such as limiting global warming to below 2°C. A closer alignment indicates a lower exposure to transition risk. In addition, these indicators can be communicated to FIs' counterparties, in order to prompt them to align their businesses with climate targets.

As a measure of a company's **environmental performance**, the **environmental, social, and governance (ESG) score** is also commonly applied as a proxy for transition risk. The ESG score is usually calculated by rating agencies to assess a company's exposure to ESG risks and its ability to manage these risks. The environmental (E) dimension of the ESG score reflects the environmental profile of a company, such as its energy efficiency, climate strategy, and waste disposal, which are related to its exposure to climate risk. ESG scores are mainly used by asset managers, especially those with sustainable mandates, to weigh their portfolios towards sustainable assets. Banks and insurers also use them in due diligence.³⁹

Green/brown share indicators are another set of transition risk measures, which quantify a company's environmentally friendly or harmful activities (corresponding to green or brown share). For example, the fraction of expenditure on environmentally related research and development is a green share indicator, while the percentage of revenue from petroleum-based products is a brown share indicator. A higher green share suggests lower transition risk, while a higher brown share suggests higher risk.

Based on geographic data, numerous **physical risk indicators** are developed to quantify the magnitude of physical risk rising from extreme weather events and chronic climate changes. For example, banks can use floodplain maps to determine how likely it is that properties subject to their mortgage loans will be affected by flooding. Insurers can use historical wildfire data to estimate the probability that insured assets will be damaged in forest fires. Asset managers can use rice yield data to predict the market performance of agriculture companies.

³⁸ A company's total emissions can be divided into three scopes (GGP, 2004). See Appendix A for a brief introduction to these three scopes.

³⁹ Several data issues on ESG scores, including its reliability and comparability, are discussed in Chapter 2.4.

Two novel sets of indicators provide a more comprehensive view of how climate risk can be quantified. **Textual-based indicators** are constructed using textual data gathered from different sources, such as company filings, government releases, newspapers, and social media, while **capital market-based indicators** are developed based on the prices of publicly traded financial assets. These indicators can be used to measure transition risk, physical risk, or both, depending on the information contained in the raw data. As both types of

indicators are built on publicly available data, especially that of listed companies, they are most useful for asset managers to gauge their investment portfolio's exposure to climate risk. Banks and insurers can also use these indicators to assess the climate risk that their counterparties carry. Due to the high technicality in deriving these novel indicators, FIs may obtain them directly from readily available tools provided by public organisations and private institutions.

Table 2.1 Climate risk indicators

Indicators	Risk coverage	Description	Examples
Carbon emission indicators	Transition	The amount of GHG emissions from an entity	Carbon emission, carbon footprint, carbon intensity
Portfolio alignment indicators	Transition	How closely an entity's future emission path matches a climate target	Carbon budget overshoot, implied temperature rise
ESG scores	Transition (mainly)	The ESG performance of an entity	ESG scores, E scores
Green/brown share indicators	Transition	An entity's activity that helps or obstructs the transition to a low-carbon economy	Fraction of environmentally related R&D expenditure, share of revenue from petroleum product
Physical risk indicators	Physical	The magnitude of physical risk that an entity carries	Rice yield, precipitation
Textual-based indicators	Physical, Transition	The exposure to climate risk obtained from textual data	Wall Street Journal climate change news index ⁴⁰
Capital-market based indicators	Physical, Transition	The exposure to climate risk obtained from capital market data	Carbon beta

Source: HKIMR staff compilation. Appendix A provides more details.

⁴⁰ Engle et al. (2020)

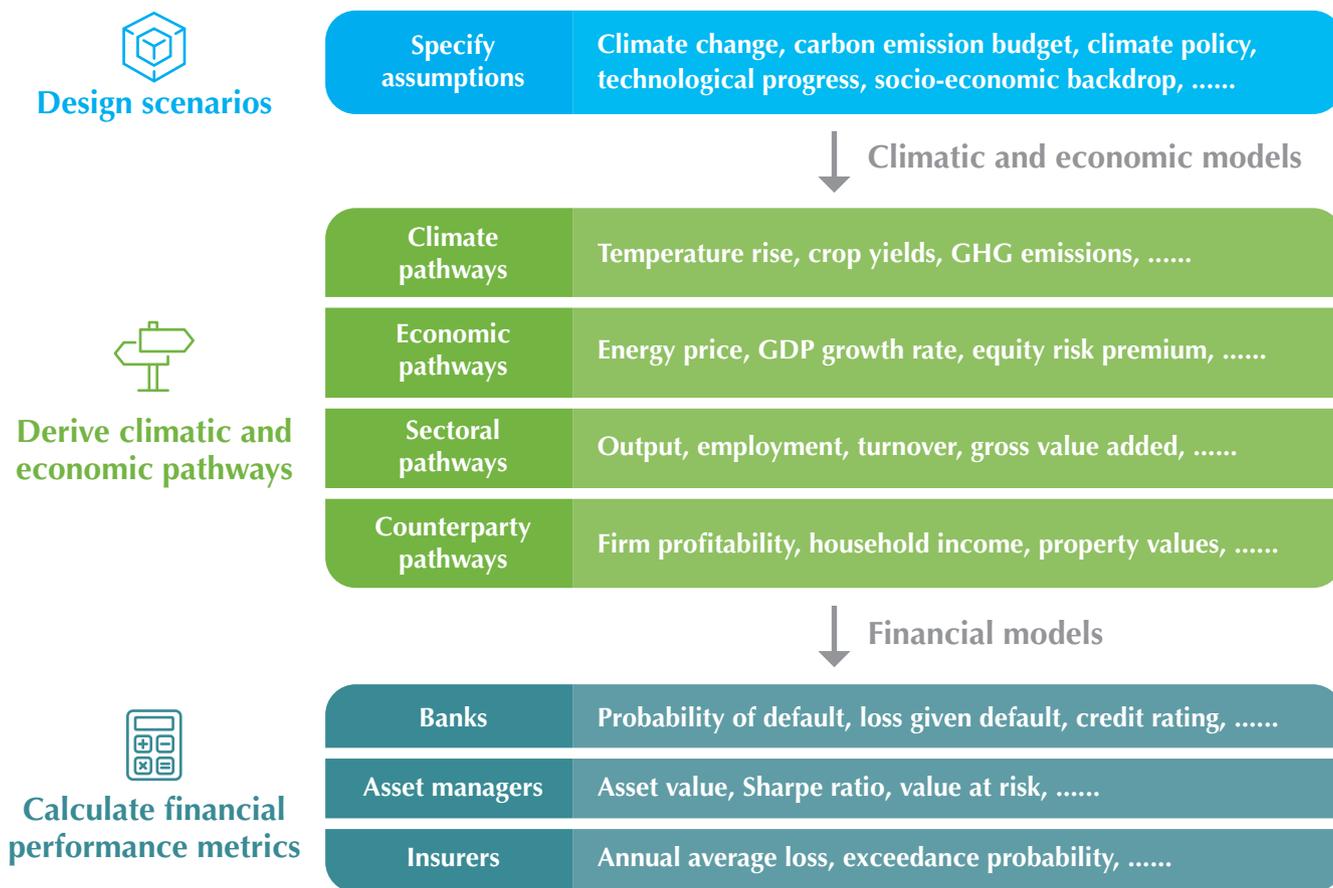
2.3 Scenario-based methods

While the indicators discussed in the previous section measure FIs' exposure to climate risk, the scenario-based methods introduced in this section quantify the impact of climate risk on FIs' businesses using commonly adopted financial performance metrics, such as the default probability of a loan, the value-at-risk (VaR) of an investment, and the exceedance probability of an insurance loss. Given the substantial uncertainty and nonlinearity associated with climate risk, the scenario-based methods do not aim to make precise predictions, but rather to explore a range of plausible impacts of climate

risk under alternative assumptions, which better prepare FIs for different possibilities that may occur in the future.⁴¹

The scenario-based methods explore a range of plausible impacts of climate risk under alternative assumptions, which better prepare financial institutions for different possibilities that may occur in the future.

Figure 2.4 General framework for scenario analysis



Source: HKIMR staff compilation.

⁴¹ Scenario-based methods are still rapidly evolving and there is still much research work that needs to be carried out. For example, the consideration of model calibration and the elicitation of input assumptions, which are only few topics of interest that will be left as future research agendas.

This section serves as a high-level overview of scenario-based methods. More technical details and practical guidelines can be found in the reports released by the United Nations Environment Programme Finance Initiative (UNEP-FI).⁴² In addition, several public organisations and private institutions provide climate risk measurement tools that embed scenario-based assessment methods. FIs can employ these tools to measure the impact of climate risk on their business. An introduction of these tools can be found in the reports published by the UNEP-FI, Centre of Economic Research, and Swiss Sustainable Finance.⁴³

Figure 2.4 presents the general framework for scenario analysis.⁴⁴ The first stage is to design climate scenarios. Each scenario features a set of assumptions describing how climate risk will evolve. Based on these scenario assumptions, the next stage uses various models to derive the transition pathways that show how climatic and economic conditions will develop over time. The final stage feeds the transition pathways into financial models to obtain financial performance metrics that measure the impacts of climate risk on FIs' businesses under different climate scenarios.

As an illustrative example, suppose that an asset manager intends to quantify the market risk of an investment in a fossil fuel company, assuming that the economy will achieve the net-zero emission target by 2050. The manager could begin by choosing the NGFS's Net Zero 2050 scenario as the benchmark. Next, the pathways for GHG emissions and carbon prices can be derived based on the assumptions of the Net Zero 2050 scenario, which

are in turn used to obtain the pathways for the revenue and cost of the fossil fuel company. The final step feeds these revenue and cost pathways into an asset valuation model to determine the change in the market value of the investment.

(1) Design scenarios

Scenario analysis starts with scenario design, which involves specifying assumptions related to climate risk. Key assumptions should be made on how climate, policies, technologies, and socio-economic conditions will develop over a specified time horizon. For example, the NGFS's Net Zero 2050 scenario posits that carbon emissions will limit global warming to below 2°C, climate policies will react in an orderly and timely manner, technologies will advance at a relatively rapid pace, and socio-economic transitions will be modest.

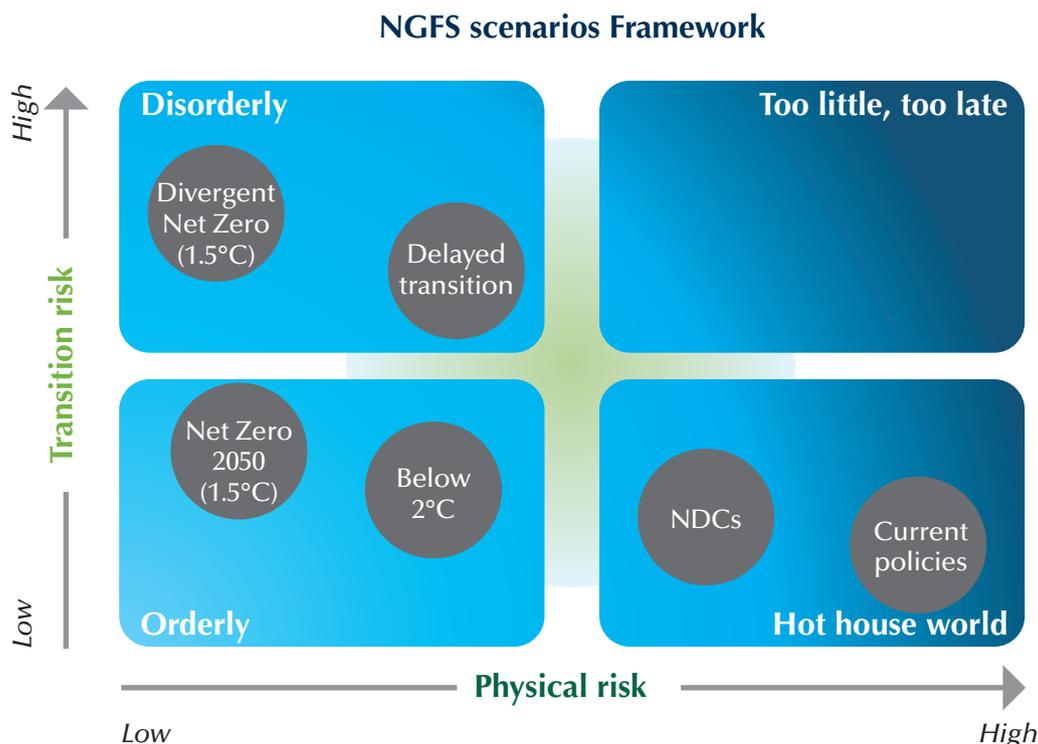
FIs can employ the widely adopted scenarios developed by the NGFS, International Energy Agency, and other public organisations, or they can develop their own scenarios. The former approach is generally preferred because it saves time and resources and requires less human capacity. Moreover, it facilitates the comparison of the scenario analysis results across different FIs employing common scenarios. However, the downside is that these common scenarios are typically designed on a global scale, which may omit some types of climate risk to which local FIs may be especially vulnerable. Against this background, several regulatory authorities have tailored common scenarios to make them more usable for FIs in their region.

⁴² UNEP-FI. *TCFD – Task force on climate-related financial disclosures* (<https://www.unepfi.org/climate-change/tcfd/>).

⁴³ CER (2020), SSF (2019), and UNEP-FI (2019, 2020, 2021a).

⁴⁴ Before beginning a scenario analysis, it is essential to clarify the objectives, identify the types of risks to be considered, and specify the transmission channels through which climate risk translates into financial risks. These guarantee that the scenario analysis will be focused on the most important concerns of FIs and that the results will be used in accordance with FIs' needs.

Figure 2.5 Climate scenarios designed by the NGFS



Note: NDC is an acronym for Nationally Determined Contribution. It represents the commitment of a country to reduce GHG emissions submitted under the Paris Agreement. The NDCs scenario in the bottom right quadrant assumes that governments implement climate policies consistent with NDCs.

Source: NGFS (2021c).

Figure 2.5 presents the six main climate scenarios designed by the NGFS, each reflecting a combination of physical and transition risks that is likely to materialise over the next few decades. A number of regulators have adapted these scenarios locally and used them in climate stress tests.

Further important considerations in scenario design include the choice of time horizons and the number of scenarios. Selecting shorter horizons (1-20 years) is useful for examining climate risk that is likely to materialise in the near future, while selecting longer horizons (20-50 years) is essential for exploring how the

full impact of climate risk that will gradually unfold over time. Using fewer scenarios reduces the calculation and communication costs, while employing more scenarios can prepare FIs for a wider range of possible outcomes that may occur in the future.

(2) Derive climatic and economic pathways

The scenario assumptions are then combined with collected data in a modelling framework to generate transition pathways. These pathways illustrate how climatic and economic conditions will evolve over time.⁴⁵

⁴⁵ Appendix B provides more details on the models used in scenario analysis.

The modelling frameworks used by FIs typically consist of a climatic module and an economic module. The climate module computes the pathways of climate-related variables, such as rice yield, humidity, and air temperature. The economic module derives the pathways of economic and financial variables, such as energy prices, economic growth rates, and equity risk premium.

These climatic and economic pathways derived at the aggregate level can then be decomposed into more granular pathways at the sectoral- and counterparty-levels using additional economic models. For example, the counterparty-level pathways typically detail how firm profitability, household income, or property value will develop over time.

The preceding description mainly applies to a top-down exercise, in which transition pathways are calculated at the aggregate level and then disaggregated to the sub-components. To conduct a bottom-up exercise, FIs can directly calculate the pathways of their counterparties that are in line with the scenario assumptions, without examining how the aggregate pathways will evolve.

(3) Calculate financial performance metrics

The final step is to use financial models to convert climatic and economic pathways to financial performance metrics. For instance, banks can feed the pathways of their borrowers' financial conditions into a credit risk model to derive the default probabilities of loans. Asset managers can incorporate the profitability pathways of their invested companies into a valuation model to calculate changes in asset returns. Insurers can use the pathways of insured property values to determine the probable maximum losses of insurance contracts.

It is worth mentioning that the transition pathways deduced from climate scenarios are deterministic. However, many financial metrics can only be constructed on outcomes that are uncertain. To calculate these metrics, randomness can be introduced to scenario analysis to reflect the uncertainty associated with climate risk.

One approach is to select multiple scenarios and assign each scenario a probability. For example, to obtain the expected loss of an investment, an asset manager can select two climate scenarios and assume that these two scenarios may have an equal chance to be realised. The expected return will then be the average of the losses under the two scenarios.

Another approach is to keep most of the assumptions in a scenario constant while changing a few crucial assumptions with some probabilities. This approach is used in computing the climate value-at-risk (VaR) of an investment, which is an estimate of the potential investment loss caused by climate risk at low probabilities, such as 1% or 5%. To derive the climate VaR, it is assumed that key scenario assumptions, such as the rate of technological growth, are uncertain. By conducting repeated simulations, one can obtain the distribution of investment loss and consequently the climate VaR.

The climate value-at-risk is an estimate of the potential investment loss caused by climate risk at low probabilities.

(4) Stress testing and sensitivity analysis

Stress testing and sensitivity analysis are two types of scenario-based methods often used in climate risk measurement (Figure 2.6).

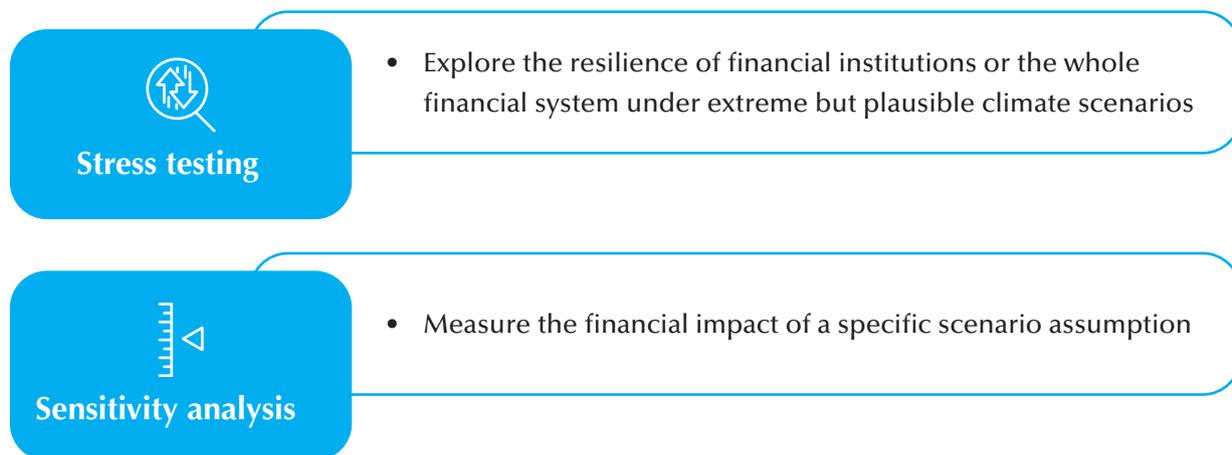
Stress testing evaluates the resilience of individual FIs or the whole financial system in the face of extreme but plausible climate scenarios. A climate stress test is distinct from a traditional stress test in three aspects. First, the time horizon of a climate stress test is sometimes extended to several decades to account for the length of time required for climate risk to fully materialise. Second, a larger number of scenarios are considered in a climate stress test, reflecting the high uncertainty and non-linearity associated with climate risk. Finally, the results of climate risk stress test conducted by financial regulators have not yet been used to set capital requirements, as the relationship between the two needs to be further explored.⁴⁶

Sensitivity analysis measures the financial impact of a specific scenario assumption. To perform a sensitivity analysis, a single scenario assumption is changed across multiple simulations to obtain the range of outcomes caused by variations in that assumption. It is a valuable tool for assessing the potential impact of a particular policy action. For example, it can be used to examine the impact of a 1% increase in the carbon tax on the default probability of corporate bonds.

2.4 Ongoing issues in climate risk measurement

Despite significant progress in climate risk measurement, several challenges remain. The lack of available data is the primary obstacle facing many measurement methods. The reliability and comparability of different methods and data sources are also issues to be explored and their implication better understood.⁴⁷

Figure 2.6 Two main applications of scenario analysis



Source: HKIMR staff compilation.

⁴⁶ For example, increasing capital requirements may prevent FIs from financing carbon-intensive companies, thereby protecting them from suffering losses when transition risk materialises. However, stop financing carbon-intensive companies may also delay their green transition and eventually increase physical risk. See more discussions in, for example, BPI (2021).

⁴⁷ For example, see, discussions in FSB (2021) and NGFS (2020c, 2021b).

The availability of data is the fundamental issue in measuring climate risk. There is a shortage of data to measure the transmission and amplification of climate risk within the financial sector. Data on mitigation and adaptation measures taken to address climate risk are also scarce. As a result, existing methods may underestimate or exaggerate the magnitude of climate risk. Moreover, it is challenging to collect data on the climate risk facing emerging markets and developing economies, which results in difficulties in quantifying the risk exposure of firms operating in these markets.

Some data availability issues are associated with particular measurement methods. For instance, there is a lack of forward-looking data on the projected carbon emission pathways of companies. As a result, portfolio alignment indicators, which reflect how closely the carbon emission path of a firm will align with a climate target, cannot be calculated in a straightforward way.

Additional challenges are associated with the accessibility of public data sources. First, due to the limited availability of public data sources, FIs may not be able to find public data that meet their needs. Furthermore, although fetching data from public sources is free of charge, FIs may need to devote significant human resources in researching, collecting, and processing these data, especially those unstructured and high-dimensional data that can only be managed with cutting-edge digital technologies by experienced analysts. This high resource cost could be a burden particularly for small FIs with limited financial resources and little access to climate risk specialists.

The second issue relates to the reliability of measurement methods. Due to the lack of historical data as a reference, it is difficult to judge the accuracy or relevance of their climate risk measurement. While reported data are usually unaudited and sometimes incomplete, estimated data are subject to more concerns, as there are no standards to determine whether the assumptions used in the derivation of estimated data are reasonable. For

instance, capital market-based indicators are calculated based on the assumption that a firm's asset price reflects its underlying value. When the relationship between asset prices and fundamental values is weak, as may be the case in developing countries, capital-market-based indicators may be unable to accurately reflect a firm's actual exposure to climate risk.

A lack of transparency in the construction of climate risk indicators creates another reliability issue. The proprietary nature of private data sources implies that there is limited transparency on how raw data are collected and processed, as well as how climate risk indicators are defined and calculated, which puts the reliability of their outputs into question. The ESG score is a typical example. Many rating agencies are opaque about how their ESG scores are derived, and therefore end-users may have difficulty understanding what these scores really measure.

Further reliability issues may result from the ambiguous interpretation of climate risk indicators. For example, high carbon emissions are usually considered an indication of high exposure to transition risk; however, they may reflect only a company's historical environmental profiles but not its future action and commitment, as these are not reflected in carbon emission indicators. Considering these reliability concerns, the role of expertise becomes especially important, as in most situations, FIs can only rely on expertise to determine the reliability of a measure.

The third issue arises from the comparability of climate risk measures with different meanings. Even for metrics that encompass similar concepts, a direct comparison may be difficult if data sources or measurement methods are not identical. For instance, green/brown share indicators are developed based on taxonomies that define which activities are sustainable and which are not. When different taxonomies are used in their construction, the resulting measures may not be comparable. The divergence of ESG scores from different rating agencies

for the same company has also attracted attention in academia and industry.⁴⁸ This ambiguity leads to questions about whether the ESG score can fully reflect a company's environmental performance, and it may cause under-investment in sustainable assets. Identifying and resolving inconsistencies in ESG scores may require considerable human resources.

Building human capacity is critical for improving climate risk measurement, as financial institutions rely on expertise to process data, calculate metrics, and make judgements on the reliability and comparability of those metrics.

Many of these issues discussed above could be alleviated by introducing mandatory and standardised frameworks for climate-related financial disclosure across sectors and borders. As is explored in the next chapter, financial regulators worldwide are working towards this direction. Building human capacity is also critical for improving climate risk measurement, as FIs rely on expertise to process data, calculate metrics, and make judgements on the reliability and comparability of those metrics.

⁴⁸ For example, see, discussions in Berg et al. (2021) and Christensen et al. (2022).

3

Evolving Global Landscape of Current Practices and Regulatory Oversight

HIGHLIGHTS:

- According to the findings from more than ten international surveys conducted between 2019 and 2021, financial institutions have begun engaging in climate risk management and have developed action plans to address increased climate risk.
- Financial institutions have started to use transition risk indicators and scenario-based methods to measure climate risk, and many have included climate-related disclosures in their financial reports.
- Regulators worldwide have begun enacting mandatory regulations on climate-related financial disclosure. In addition, they are working towards standardised disclosure frameworks and green taxonomies.
- A growing number of supervisory bodies have conducted climate stress tests. Available findings suggest that, without timely and effective mitigating policies, some financial institutions may face potentially sizeable losses as a result of materialising climate risk.



This chapter begins by reviewing the current practices of financial institutions (FIs) in addressing climate risk based on the findings from recent international surveys. It then examines the regulatory oversight of climate risk, including trends in implementing mandatory and standardised climate risk disclosure requirements, as well as regulators' experiences in conducting climate stress tests.

3.1 Financial institutions' current practices

Several private and public institutions have conducted surveys on climate risk management practices in the financial services industry. Based on the results from these surveys, this section summarises the current practices of FIs in climate risk governance, strategy, management, measurement, and disclosure, sketching out the evolving landscape of FIs' current practices in addressing climate risk (Figure 3.1). In addition, this section shares some good practices that are observed among FIs in tackling climate risk.

The discussion is based on the outcomes of more than ten surveys and case studies conducted between 2019 and 2021, covering major banks, insurers, and asset managers worldwide.⁴⁹ The findings of most surveys show the growing awareness and increasing sophistication across FIs in dealing

with climate risk. These trends reflect FIs' expectations of the strong impact that climate risk may have on their business, as well as their needs to comply with regulatory requirements. Survey participants also cited associated challenges, including the lack of available data, reliable methods, consistent standards, and adequate resources.

(1) Governance

Effective climate risk management starts with executive board involvement in overseeing climate-related issues. The main functions of the board in climate risk governance are (1) developing and implementing climate strategies, (2) setting and monitoring climate risk targets, and (3) integrating climate risk into their overall risk assessment frameworks.

Many FIs have started to oversee climate risk at the board level. In terms of the contents of board discussions, Global Association of Risk Professionals (2021b) finds that the primary focus is climate change itself, followed by the consideration of how to align their business with climate targets. FIs also discuss transition risk, which relates to developments in regulations, technologies, and consumer preferences during the transition to a low-carbon economy (Figure 3.2). Physical risk that arises from changes in weather and climate has received relatively less attention.

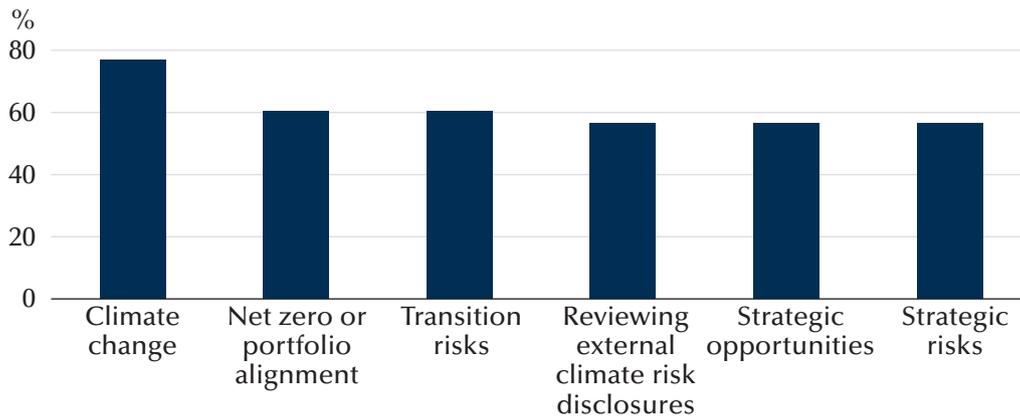
Figure 3.1 Five dimensions of financial institutions' practices



Source: HKIMR staff compilation.

⁴⁹ See AIGCC (2021), AMF (2020), BCS Consulting (2021), DNB (2020), Bresnahan et al., (2020), GARP (2021a, 2021b), IIF and EBF (2020), NGFS (2020b), SFC (2019), ShareAction (2020), Stroebel and Wurgler (2021), and TCFD (2021b, 2021c, 2021d).

Figure 3.2 Most common topics discussed by boards



Source: GARP (2021b)

Regarding executive-level responsibilities, many FIs appoint a designated board member to oversee climate-related issues, and several also establish a dedicated climate risk team. As for working-level responsibilities, climate risk specialists engage with climate-related issues in addition to general managers and analysts who are increasingly involved. This implies that the analysis of climate risk has been integrated into the daily work of many FIs.

The findings from various surveys suggest that it is constructive for FIs to have a well-defined governance framework to address climate risk. It ensures a better understanding of the potential impact of climate risk, and it also lays the foundation for adaptation and mitigation actions.

(2) Strategy

According to the results of several surveys, more than half of FIs have adopted a comprehensive and long-term view of climate risk, and most of the remaining FIs also intend to embrace this strategic approach within the next few years.

Many FIs have developed plans and deployed resources to address climate-related risks and opportunities. Major adaptation activities include providing green loans and

mortgages, issuing and investing in sustainable assets, and underwriting low-emission projects.

Financial institutions have developed adaptation plans to address climate risk, including providing green loans and mortgages, issuing and investing in sustainable assets, and underwriting low-emission projects.

Moreover, some FIs enhanced their staff’s understanding and awareness of climate risk by providing training programmes, recruiting climate experts, and increasing their communications with other institutions. A sizeable proportion of FIs seeks assistance from external sources to address climate risk, such as academic institutes and consulting firms, which provide an alternative approach to building human capacity.

The most salient strategic challenge is the difficulty of applying reliable methods to measure climate risk. Other significant impediments are the lack of data, expertise, green taxonomy, and regulatory guidance. However, FIs expect these issues to become less of a problem in the future.

It is observed that leading FIs have considered climate-related risks and opportunities throughout their formulation and implementation of strategies. Their experience implies that clear adaptation measures must be anticipated in their planning. Another good practice is to specify a climate risk appetite level that defines the extent of climate risk that FIs are willing to accept. This enables them to embark on proactive risk adaptation and mitigation efforts. This practice can be adopted for internal decision-making processes. Besides, FIs may also communicate their current climate risk appetite to stakeholders and build metrics to evaluate any misalignment from their desired appetite for climate risk.

(3) Management

Strategic insights are incorporated into FIs’ business operations through risk management frameworks, which specify how climate risk should be measured, monitored, addressed, and reported.

Figure 3.3 shows how finance professionals rank the relative importance of climate-related risks over short and long time horizons. The transition risk arising from regulatory developments is ranked to be the top concern in the next 5 years. Although most of financial professionals do not consider physical risk as the most imminent

climate risk, they predict that its impact will become more salient when the time horizon is extended to 30 years.

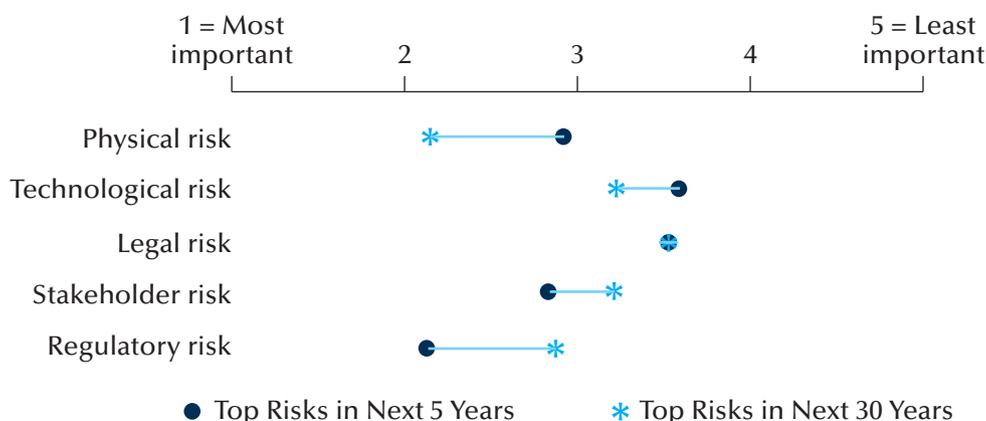
Most FIs have incorporated climate risk considerations in their overall risk management framework, at least to some extent. As evidence of this incorporation, many FIs have examined the impacts of transition and physical risks on their counterparties as a part of their due diligence.

The findings from several surveys indicate that FIs benefit from recognising the importance of incorporating climate risk into their overall risk management framework. Additionally, as climate risk mainly affects FIs’ businesses through its impacts on their counterparties, it is important for FIs to actively engage with their counterparties to not only communicate their climate concerns, but also identify the channels through which climate risk translates into financial risks.

(4) Measurement

The results from several surveys indicate that the majority of FIs now use a variety of indicators and methods, most of which were discussed in the preceding chapter, to measure climate risk. The outputs of the measurement are mainly used for risk management, strategic planning, decision making, engagement with counterparties, and communication with stakeholders.

Figure 3.3 Ranking of the importance of climate-related risks according to finance professionals



Source: HKIMR staff compilation on Stroebel and Wurgler (2020).

Many FIs have measured the transition risk they carry. The transition risk metrics that FIs use most frequently are carbon emission indicators and green/brown share indicators. Some recently developed metrics, such as portfolio alignment indicators, are also gaining popularity. In the calculation of green/brown share indicators, FIs have applied various methods to define green and brown activities. These include applying the definitions from third-party data providers, adopting national or international green taxonomies, as well as developing internal classification standards.

By contrast, relatively few FIs have measured the physical risk they face, which indicates the lack of a systematic approach to identifying and assessing physical risks within the financial services industry.

Scenario-based methods are becoming increasingly prevalent in climate risk measurement, though FIs still use them in an ad hoc manner rather than on a regular basis. Besides, most scenario analyses focus only on the impacts of a few types of climate risks. For example, many FIs analyse only transition risk but not physical risk, which may limit their understanding of the full impact of climate risk on their operations and businesses.⁵⁰

FIs also mention several challenges associated with climate risk measurement. These include concerns with underlying assumptions, the scarcity of high-quality data, and the difficulty of deciphering complicated calculation methodologies, which highlight the importance of increasing the availability, transparency, and comparability of climate-related data and methods in climate risk measurement.

Increasing the availability, transparency, and comparability of climate-related data and methods is key to improving climate risk measurement.

As developing a coherent set of climate risk indicators requires time and resources, it is therefore important for FIs to act early to build their capability for climate risk measurement now. In addition, the practices of leading FIs suggest the benefits of combining qualitative and quantitative assessment tools to gain a more holistic view of the impact of climate risk.

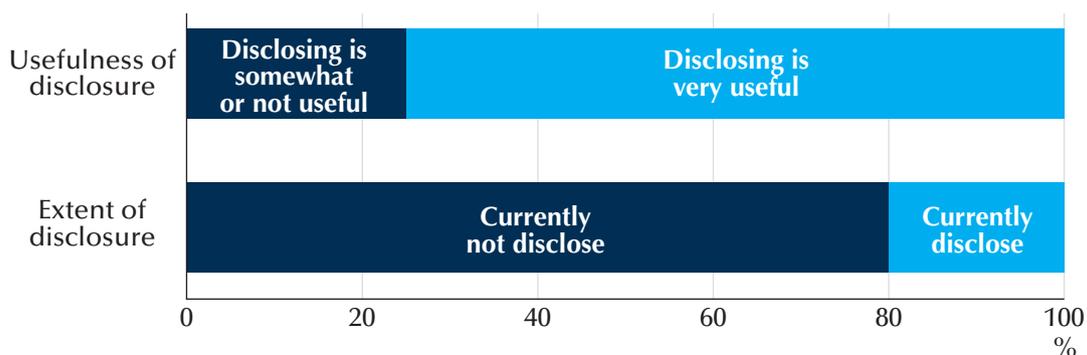
(5) Disclosure

Climate risk disclosure provides a measure of accountability by allowing stakeholders to have a better understanding of FIs' risk profiles and their response to climate risk.

One important issue is whether FIs' disclosure adheres to the Task Force on Climate-Related Financial Disclosures (TCFD) framework on the reporting of climate risk metrics, targets, and transition plans. The TCFD framework provides a consistent guideline for disclosing climate-related financial risks and is supported by many international organisations and regulatory authorities. Survey findings reveal that the adoption varies across regions. A growing number of FIs in developed economies, and some in emerging economies, have disclosed or plan to disclose climate-related information in line with the TCFD framework. This demonstrates the convergence in the application of standardised disclosure framework among FIs.

⁵⁰ It is worthwhile mentioning the importance of understanding how FIs apply different financial models in scenario analysis to assess the impact of climate risk on their businesses. This topic represents a useful starting point for future research works.

Figure 3.4 Disclosure of climate-related financial performance by financial institutions



Source: TCFD (2021b) and HKIMR staff compilation.

While FIs agree that climate risk disclosures are useful for decision-making processes from an end-user perspective, they find it difficult to disclose such information themselves from a preparer perspective. Figure 3.4 shows the proportion of FIs who think that disclosing financial impacts of climate risk is useful, compared to the proportion of FIs who disclose such impacts. The stark difference between the two types suggests the need for the implementation of mandatory disclosure requirements.

In order to enhance transparency and accountability, it is crucial to develop a comprehensive and standardised framework for disclosing climate-related information, and such disclosures should keep FIs’ stakeholders informed of the climate risk to which the FIs are actually exposed.

3.2 Regulatory oversight: Climate risk disclosure

This section discusses the regulatory oversight of climate risk by examining global trends in implementing mandatory disclosure regulations, as well as the convergence of risk disclosure frameworks and green taxonomies. Promoting climate-related financial disclosure

is not only critical for solving various issues in climate risk measurement discussed in the previous chapter but also key for alleviating the problem of the mismatched horizon between long-term climate consequences and short-term economic incentives. This is because, when financial market participants can learn about a firm’s future climate risk exposure through its financial disclosures, they will influence the current prices of the firm’s financial assets. Through this channel, the financial markets can reward or penalise a firm for its environmentally friendly or harmful activities, even if these activities have not yet generated immediate benefits or damage.⁵¹

(1) Mandatory climate risk disclosure

To date, many regulators have issued guidelines and recommendations to encourage FIs to voluntarily disclose climate-related financial information. However, evidence suggests that firms do not significantly increase their disclosure and prefer reporting non-fundamental information under a voluntary disclosure regime.⁵² Against this background, regulators have begun to implement mandatory disclosure regimes.

In October 2021, New Zealand became the first jurisdiction in the world to pass a government bill on

⁵¹ Institute for the Environment. Fireside chat with Dr. MA Jun: Sustainable finance taxonomies and green finance (<https://ienv.ust.hk/events/fireside-chat-dr-ma-jun-sustainable-finance-taxonomies-and-green-finance>).

⁵² For example, see, Bingler et al. (2021).

mandatory climate risk disclosure. Under this bill, approximately 200 organisations, including the insurers, banks, and managers of investment schemes, are required to make mandatory climate-related financial disclosures.⁵³ One month later, the United Kingdom also announced a new legislation that requires over 1,300 UK-registered companies and FIs to disclose climate-related financial information on a mandatory basis beginning in 2022.⁵⁴

Additionally, several Asian regulators have indicated their intent to enact mandatory disclosure regulations in the near future. For example, the People's Bank of China will consider introducing mandatory environment-related disclosure requirements for FIs.⁵⁵ In Hong Kong, the Hong Kong Exchanges and Clearing Limited has incorporated elements of the TCFD recommendations in its ESG Reporting Guide since 2020,⁵⁶ and the Green and Sustainable Finance Cross-Agency Steering Group is making progress towards mandating climate-related disclosures aligned with the TCFD framework by 2025 across relevant sectors.⁵⁷ Singapore Exchange announced that climate reporting will be mandatory for issuers in the financial and several other sectors from the fiscal year commencing 2023.⁵⁸

(2) The TCFD disclosure framework

One key step to enhance climate risk disclosure is the adoption of a standardised disclosure framework. Among the approximately 400 frameworks available, the TCFD disclosure framework has emerged to be the most widely

accepted one. The framework covers four core elements demonstrating an organisation's approach to addressing climate risk: governance, strategy, risk management, and metrics and targets. It is highly adaptable and applicable to companies and institutions operating in different sectors and regions. Figure 3.5 shows that the TCFD framework is currently supported by 2,616 organisations worldwide, including more than 1,000 FIs managing assets of over 194 trillion US dollars.

Apart from being used by a growing number of FIs as a guideline for voluntary disclosures, the TCFD framework is also becoming the building block for mandatory disclosure regulations, including those that have been or will soon be implemented in the European Union (EU), Hong Kong, Singapore, Japan, and the UK. Besides, it forms the basis for global climate risk disclosure frameworks developed by international organisations. For example, an alliance of five global standard-setting bodies⁵⁹ released a prototype for developing global standards for climate-related financial disclosures based on the TCFD framework. In addition, the International Financial Reporting Standards (IFRS) Foundation has established the International Sustainability Standards Board (ISSB) under its governance structure, with the aim of developing global baseline sustainability disclosure standards that build on the TCFD framework. Furthermore, the UNEP-FI has developed numerous tools, frameworks, and guides under its TCFD pilot projects to empower the financial services industry to better assess, manage, and disclose climate risk aligned with the TCFD framework.⁶⁰

⁵³ Ministry of Business, Innovation and Employment of New Zealand. *Mandatory climate-related disclosures* (<https://www.mbie.govt.nz/business-and-employment/business/regulating-entities/mandatory-climate-related-disclosures/>).

⁵⁴ Department for Business, Energy and Industrial Strategy of the United Kingdom. *UK to enshrine mandatory climate disclosures for largest companies in law* (<https://www.gov.uk/government/news/uk-to-enshrine-mandatory-climate-disclosures-for-largest-companies-in-law>).

⁵⁵ Yi (2020).

⁵⁶ HKEX (2021).

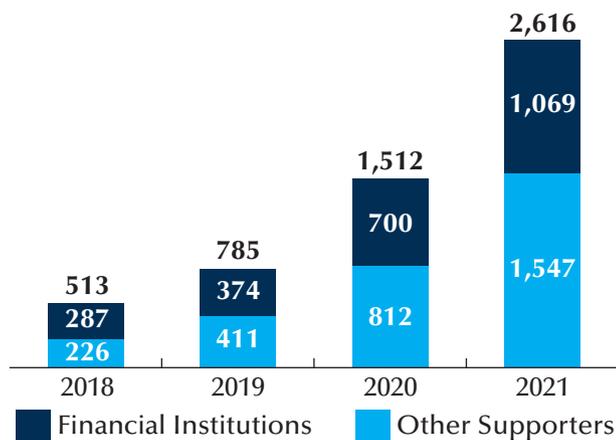
⁵⁷ The Government of Hong Kong Special Administrative Region. *Cross-Agency Steering Group announces progress and way forward to advance Hong Kong's green and sustainable finance development* (<https://www.info.gov.hk/gia/general/202112/16/P2021121600553.htm>).

⁵⁸ Singapore Exchange. *SGX mandates climate and board diversity disclosures* (<https://www.sgx.com/media-centre/20211215-sgx-mandates-climate-and-board-diversity-disclosures>).

⁵⁹ The Carbon Disclosure Project (CDP), the Climate Disclosure Standards Board (CDSB), the Global Reporting Initiative (GRI), the International Integrated Reporting Council (IIRC), and the Sustainability Accounting Standards Board (SASB).

⁶⁰ UNEP-FI. *TCFD – Task force on climate-related financial disclosures* (<https://www.unepfi.org/climate-change/tcfd/>).

Figure 3.5 Organisations supporting the TCFD framework



Source: TCFD (2021a) and HKIMR staff compilation.

(3) Green taxonomies

Another important aspect of climate risk disclosure is the choice of green taxonomies. A green taxonomy refers to a set of classification standards that identifies environmentally sustainable economic activities, financial assets, and project categories. Choosing a suitable green taxonomy is not only fundamental for climate risk measurement and disclosure but also helpful for FIs to align their businesses with sustainability criteria. To date, many regulators, international organisations, and private institutions have developed their green taxonomies. However, the existence of a wide variety of taxonomies reduces the comparability of climate risk disclosure across borders and sectors, and it also increases the compliance costs for companies that must adhere to multiple taxonomies concurrently. Additionally, by shifting cross-border investment from countries adopting stricter green taxonomies to those adopting looser green taxonomies, environmentally harmful projects may continue to be funded.

Several jurisdictions have sought multilateral co-operation to develop internationally recognised green taxonomies. For instance, the International Platform on Sustainable Finance (IPSF) has published its initial phase of work on the Common Ground Taxonomy (CGT) in November 2021. The CGT is a milestone work resulting from an in-depth comparison of commonality and differences between the EU and China’s green taxonomies.⁶¹ It paves the way for the improvement in the comparability and future interoperability of taxonomies around the world. Several members of the IPSF, including Hong Kong, will explore developing a green classification framework aligning with the CGT.⁶² The Association of Southeast Asian Nations (ASEAN) has also released its first version of Taxonomy for Sustainable Finance in November 2021, which will serve as a reference point to guide capital and funding towards green activities in Southeast Asia.⁶³

3.3 Regulatory oversight: Climate stress test

Following increasing concerns about climate risk and the rapid development of scenario-based methods, a number of regulatory authorities have completed, are conducting, or plan to perform climate stress tests. The International Monetary Fund (IMF) and the World Bank have also conducted climate stress tests for several countries. At the time of writing, the results of 13 climate stress tests covering 11 regions have become publicly available, nine of which are for developed economies and four for developing countries (Table 3.1). The Hong Kong Monetary Authority (HKMA) is the first regulator in Asia that has released the results of its climate risk stress test (Box 3.1). In addition, at least four other Asian regulators are conducting climate stress tests or sensitivity analyses for their economies.⁶⁴

⁶¹ IPSF (2021).

⁶² The Government of Hong Kong Special Administrative Region. Cross-Agency Steering Group announces progress and way forward to advance Hong Kong’s green and sustainable finance development (<https://www.info.gov.hk/gia/general/202112/16/P2021121600553.htm>).

⁶³ ASEAN. ASEAN sectoral bodies release ASEAN Taxonomy for Sustainable Finance – Version 1 (<https://asean.org/asean-sectoral-bodies-release-asean-taxonomy-for-sustainable-finance-version-1/>).

⁶⁴ These include the Bank of Japan, Bank of Korea, Monetary Authority of Singapore, and People’s Bank of China (ECB, 2021a).

Table 3.1 Comparison of climate stress tests with publicly available results

Institution	Region	Publication date	Approach	Risk coverage	Institution coverage	Balance sheet assumption	Granularity	Time horizon
Bank of France	France	May 2021	Bottom-up	Physical, transition	Banks, insurers	Hybrid	Sector	30 years
Bank of Italy	Italy	Oct 2021	Top-down	Transition	Households, firms	–	Sector	–
Der Nederlandsche Bank	The Netherlands	Oct 2017	Top-down	Physical	Banks, insurers, pension funds	–	–	–
Der Nederlandsche Bank	The Netherlands	Oct 2018	Top-down	Transition	Banks, insurers, pension funds	Static	Counterparty	5 years
European Banking Authority	The Euro Area	May 2021	Top-down	Physical, transition	Banks	Static	Counterparty	30 years
European Central Bank	The Euro Area	Sep 2021	Top-down	Physical, transition	Banks	Static	Counterparty	30 years
Hong Kong Monetary Authority	Hong Kong	Dec 2021	Bottom-up	Physical, transition	Banks	Static	Counterparty, sector	1 year, 5 years, 30 years
IMF	The Bahamas	Jul 2019	Top-down	Physical	Banks, credit unions	Static	Sector	3 years
IMF	Chile	Dec 2021	Top-down	Physical, transition	Banks	Static	Sector	3 years
IMF	Denmark	Aug 2020	Top-down	Transition	Households, firms	–	Sector	10 years
IMF	Norway	Nov 2020	Top-down	Transition	Households, firms, financial institutions	Static	Sector	3 years
IMF	The Philippines	Apr 2021	Top-down	Physical	Banks	Static	Sector	3 years
World Bank	Colombia	Nov 2021	Top-down	Physical, transition	Banks	Hybrid	Sector, municipal	2 years

Sources: NGFS (2021c), ACPR (2021), Bdl (2021), DNB (2017, 2018), EBA (2021), ECB (2021b), HKMA (2021), IMF (2019, 2020a, 2020b, 2021a, 2021b), World Bank (2021b), and HKIMR staff compilation.

Most of these exercises are based on the scenario analysis framework introduced in the previous chapter.⁶⁵ Drawing on the experience of completed and ongoing climate stress tests, this section reviews their objectives, main characteristics, key findings, and associated challenges.⁶⁶

The primary objectives of many climate stress tests are to explore FIs' exposure to climate risk and assess the impact of climate risk on the financial system. In addition, they may serve as means to raise the awareness and improve the understanding of climate risk within the financial services industry. Moreover, some climate stress tests aim to help FIs and regulators to identify data gaps and facilitate capacity building. For example, the Bank of England describes three objectives of its climate stress test: (1) to size the exposure of financial institutions and the financial system to climate risk, (2) to understand how climate risk challenges FIs' business models, and (3) to assist FIs in enhancing climate risk management. In contrast to conventional stress tests, regulators have not yet used the results of climate stress tests to set capital requirements.⁶⁷

Top-down or bottom-up approaches or a combination of the two may be adopted in a climate stress test. In a top-down approach, the supervisory body runs the exercise without FIs' involvement. This approach requires fewer resources and ensures that consistent measurement methods are applied in the assessment. For example, the European Central Bank (ECB)'s top-down exercise leveraged its internal datasets and models to calculate the extent to which banks from different European countries are exposed to climate risk. By contrast, in a bottom-up approach, the supervisory body aggregates the stress test

results submitted by individual FIs, which offers more insights into FIs' own assessment of climate risk. For instance, in the Bank of France's bottom-up exercise, the participating FIs submitted their own risk projections before the results were aggregated at the country level.

As for risk coverage, transition risk is assessed in more climate stress tests than physical risk. It is important to note, however, that physical risk is often considered in countries that may suffer considerable losses as a result of climate change. This applies to the Netherlands, which is highly exposed to the risk of sea level rises, and the Philippines, which is highly exposed to the typhoon risk. Some climate stress tests conducted by the IMF and the World Bank assess the resilience of the financial system when it is exposed to both climate risk and macroeconomic risk.

Concerning institution coverage, all climate stress tests with a financial perspective examine the performance of banks under extreme scenarios, and some also examine the performance of insurers, credit unions, and pension funds. In terms of financial risk types, many climate stress tests explore how FIs are affected by credit and market risks created by climate change and associated transitional developments. Covering a wider range of financial risk types and institutions requires more resources, but it may achieve a more fine-grained understanding of how climate risk affects the financial system.

In scenario design, a critical assumption is whether FIs' balance sheets are static or dynamic. Both static and dynamic balance sheets change when FIs' businesses are passively affected by climate risk. Additionally, a dynamic balance sheet may also change when FIs take proactive measures, such as ceasing to fund carbon-intensive

⁶⁵ The stress tests for the Italian and Danish economies are two exceptions because they focus on the impact of climate risk on households and firms in the real economy, rather than banks and other financial institutions in the financial system.

⁶⁶ For more information on completed climate stress tests, refer to ACPR (2021), BdI (2021), DNB (2017, 2018), EBA (2021), ECB (2021b), HKMA (2021), IMF (2019, 2020a, 2020b, 2021a, 2021b), and World Bank (2021b). For more information on ongoing climate stress tests, refer to APRA (2021) and BoE (2021a, 2021b). For overview of climate stress tests, refer to BCBS (2021d), NGFS (2021c), and UNEP-FI (2021b).

⁶⁷ Some regulators are exploring the relationship between capital requirements and climate risk. See, for example, PRA (2021).

projects, to tackle climate risk. Assuming balance sheets are static can diminish the possibility of underestimating the impact of climate risk, while assuming balance sheets are dynamic can better capture the full impact of climate risk on FIs’ businesses. Some climate stress tests assume hybrid balance sheets. For example, in the World Bank’s stress test for the Colombian banking system, it is assumed that banks’ balance sheets evolve with socio-economic developments but otherwise stay static.

In terms of the granularity of analysis, most climate stress tests focus on the sectoral-level effects of climate risk. In addition, the aggregate-level effects of climate risk are usually examined in a top-down stress test, which shows how climate risk affects GDP growth, inflation, and other macroeconomic variables. The counterparty-level effects of climate risk are sometimes examined in a bottom-up stress test, which demonstrates how climate risk affects the counterparties of FIs to which they provide services, such as households, firms, and governments.

Many supervisory bodies conduct climate stress tests over a 30-year time horizon. This timeline is consistent with the climate targets set in many regions. For example, both the European Banking Authority and ECB chose a 30-year

time horizon for their climate stress tests conducted in 2021, which corresponds to the EU’s target of achieving net-zero GHG emissions in 2050.⁶⁸ Some climate stress tests are conducted over a shorter time horizon to explore the impact of extreme weather events that have already caused substantial losses in the past and may occur again in the near future. For example, the climate stress test for the Bahamas replicates the severe consequences caused by two hurricanes in 2004, which inflicted a combined damage of 22% of the country’s GDP.

The NGFS scenarios are widely applied in climate stress tests. The three most popular scenarios are: (1) Net zero 2050, featuring a smooth transition with minimal physical risk and low transition risk; (2) Delayed transition, featuring low physical risk and high transition risk; and (3) Current policies, featuring minimal transition risk and high physical risk. Table 3.2 summarises the core assumptions of these scenarios. The scale of physical risk is indicated by the temperature goal, where a more ambitious goal implies less physical risk caused by global warming. The scale of transition risk is determined by the adequacy of policy reaction, the swiftness of technology change, the use of carbon dioxide removal technology, and the development of the socio-economic backdrop in these scenarios.⁶⁹

Table 3.2 NGFS scenarios most commonly used in climate stress tests

Scenario	Category	Temperature goal	Policy reaction	Technology change	Carbon dioxide removal technology	Socio-economic backdrop
Net zero 2050	Orderly	1.5°C	Immediate and smooth	Fast	Medium use	Does not shift markedly from historical patterns
Delayed transition	Disorderly	1.8°C	Immediate but divergent	First slow then fast	Low use	
Current policies	Hot house world	3°C+	None – current policies	Slow	Low use	

Sources: NGFS (2021a, 2021c), and HKIMR staff compilation.

⁶⁸ The European Green Deal (EC, 2019).

⁶⁹ For more information, see NGFS (2021a, 2021c), and the NGFS Scenarios Portal (<https://www.ngfs.net/ngfs-scenarios-portal/>).

Rather than apply these scenarios directly, some supervisory bodies customise them locally to study the types of climate risk to which their region may be particularly vulnerable. Some others take a step further and create their own scenarios. The South African Reserve Bank, for example, designs a scenario to examine the impact of severe drought, as the ongoing drought started in 2018 has already led to a serious water crisis in Southern Africa.

Table 3.3 summarises the main findings of 13 concluded climate stress tests for which results are publicly available. Overall, these findings indicate that some FIs may face potentially sizeable losses as a result of materialising climate risk. Such losses are especially large for FIs that are closely connected to carbon-intensive industries or highly vulnerable to extreme weather events. The implementation of timely and effective mitigating policies is key to minimising these losses. Sufficient capital buffers are also important to maintain the resilience of the financial system.

Table 3.3 Main findings from completed climate stress tests

Institution	Region	Year of completion	Main findings
Banque de France	France	2020	The exposure of French institutions to the sectors most impacted by transition risk is relatively low, but their vulnerabilities associated with physical risk are far from negligible.
Banca d'Italia	Italy	2021	Introducing carbon taxation would raise the vulnerability of both households and firms. However, even in the extreme case, it would remain below the peak reached during the sovereign debt crisis.
Der Nederlandsche Bank	The Netherlands	2017	Insurers are likely to experience a rise in claims burdens as a result of changing weather patterns. Financial institutions may incur losses through their exposure to uninsured parties.
Der Nederlandsche Bank	The Netherlands	2018	The losses for financial institutions in the event of a disruptive energy transition could be sizeable, but also manageable. Policy makers can help to avoid unnecessary losses by implementing timely, reliable and effective climate policies.
European Banking Authority	The Euro Area	2021	The impact of climate-related risks across banks has different magnitudes and is concentrated in some particular sectors.
European Central Bank	The Euro Area	2021	There are clear benefits to acting early: the short-term transition costs pale in comparison to the unfettered climate change costs in the medium to long term. For banks most exposed to climate risks, the impact would potentially be very significant, particularly in the absence of further climate mitigating actions.

Institution	Region	Year of completion	Main findings
Hong Kong Monetary Authority	Hong Kong	2021	Climate risk can give rise to significant adverse impact on the banks' profitability, capital positions and operations. Nevertheless, the Hong Kong banking sector remains resilient to climate-related shocks given the strong capital buffers built up over the years.
IMF	The Bahamas	2019	Hurricanes could negatively impact bank credit quality through degradation and closure of large resorts and key infrastructure, although the overall banking system is resilient to hurricane shocks given large aggregate capital and liquidity buffers.
IMF	Chile	2021	Physical risks are relatively contained, which is reflected in a relatively small impact on banking system capitalization. Transition risks could be material for some banks, but not sizable enough to compromise financial stability.
IMF	Denmark	2020	The paper introduces various climate mitigation policies that Denmark develops, which can be good prototypes for others to follow. It particularly recommends the use of revenue-neutral feebate schemes to strengthen mitigation incentives.
IMF	Norway	2020	A sharp increase in carbon prices would have a significant but manageable impact on banks. Banks that concentrate lending to sectors that are highly affected see more of their exposure at risk.
IMF	The Philippines	2021	Physical risks from typhoons can be relevant for banks' solvency, though they may not be necessarily systemic except for extreme tail events.
World Bank	Colombia	2021	The banking sector is vulnerable to gradual and more acute risks – stemming from both transition and physical risks. This vulnerability differs between banks and a few are substantially more vulnerable than most others.

Sources: DNB (2017, 2018), ACPR (2021), Bdl (2021), EBA (2021), ECB (2021b), HKMA (2021), IMF (2019, 2020a, 2020b, 2021a, 2021b), World Bank (2021b), and HKIMR staff compilation.

In addition to common difficulties in climate risk measurement such as the lack of available and comparable data, regulatory authorities observe some distinctive challenges associated with climate stress tests. These include difficulties in (1) adapting commonly used climate scenarios to the domestic economy's unique characteristics, (2) downscaling the impact of climate risk to sectoral or

more granular levels, and (3) applying shorter-term risk assessment frameworks used in conventional stress tests to investigate climate risk that may materialise in longer time horizons. These issues once again underscore the importance of capacity building and the necessity of implementing mandatory and standardised climate risk disclosure frameworks.

Box 3.1: Hong Kong Monetary Authority's climate risk stress test

The HKMA completed a pilot exercise for a climate risk stress test in 2021. Twenty major retail banks and seven branches of international banking groups participated, accounting for 80% of the banking sector's total lending in Hong Kong. The exercise aims to assess the climate resilience of the Hong Kong banking sector as a whole and to facilitate the capability building of participating banks with respect to climate risk management.

The climate risk stress test comprises three scenarios: (1) a physical scenario featuring extreme weather events, including increasing temperature, rising sea level, and more intense tropical cyclones; (2) an orderly transition scenario, which assumes that authorities will take early and progressive actions to reduce GHG emission with the availability of new technology; and (3) a disorderly transition scenario, which assumes that authorities will not introduce climate policies until 2030, leading to an abrupt reduction in GHG emission afterwards. It is assumed that the participating banks will not change their business strategies over the horizon of assessment and will maintain a static balance sheet.

Most of the participating banks assess the physical risk impact over a 1-year horizon by assuming an instant switch from the current climate situation of Hong Kong to that in the middle of the 21st century. Emphases of the assessment are placed on the vulnerabilities of residential mortgages and other property-related lending in Hong Kong. The participating banks project that the expected credit losses (ECLs) of their property-related lending in Hong Kong are estimated to be three times more than those in Q4 2020. The banks also anticipate a higher level of operational losses arising from damages to office premises and disruptions to business operations.

All the participating banks have assessed the 5-year impact between 2031 and 2035 under the disorderly transition scenario while the domestic systemically important authorized institutions (D-SIBs) have additionally conducted a 30-year assessment between 2021 and 2050 for the orderly transition scenario. Under both scenarios, the participating banks have assessed the potential transition impact on their exposures to the property development sector and six high-emitting industries. The results indicate that transition risk will manifest itself in terms of increased credit risk exposures of the banks. The impact is particularly conspicuous under the disorderly transition scenario. D-SIBs' capital adequacy ratios (CARs), for instance, will on average drop by 3 percentage points over the 5-year horizon under this scenario.

The assessment results indicate that, under the extreme scenarios assumed in the exercise, climate risks can potentially give rise to significant adverse impacts on the banks' profitability, capital positions and operations. Notwithstanding the significant potential impacts of climate change, the Hong Kong banking sector should remain resilient to climate-related shocks given the strong capital buffers built up by the banks over the years.

Sources: HKMA (2021) and HKIMR staff compilation.

Conclusions

Climate risk has received widespread attention in the financial services industry in recent years. It has non-negligible effects on the prices of financial assets and a concrete impact on financial institutions' decision-making behaviour. Due to its distinctive characteristics, a new set of tools are being developed to measure climate risk and its financial impacts. Based on financial institutions' practices and financial regulators' experiences, a few considerations are in order.

The systemic nature of climate risk implies that **a holistic and coherent approach is needed to address the full range of its impact**. For financial institutions, this requires incorporating climate risk into their existing risk governance and management framework. It helps financial institutions to achieve a comprehensive identification and assessment of the impact of climate risk on all of their business areas over varying time horizons and different climate scenarios. It is also fundamental for an effective adoption of risk management and mitigation practices in line with their business strategies and risk appetite. For regulators, this requires embedding climate risk in their policy mandates and adjusting their supervisory strategies and oversight functions accordingly.

Consistent data collection and comparable data analyses are critical for effective climate risk management. Therefore, it is important to **promote convergence towards mandatory and standardised disclosure requirements** that evolve in line with international consensus. These include standardised climate risk disclosure frameworks, as well as green taxonomies that define green and brown activities. One encouraging development is the creation of the global baseline reporting standards by the ISSB under the IFRS

Foundation. In addition, a mandatory disclosure regime would ensure the quantity and quality of the reporting. Mandatory and standardised disclosure requirements help end users to better identify, monitor, and manage climate risk, while also allowing them to more clearly demonstrate the risks and opportunities that they face. Furthermore, they help avoid the problem of greenwashing.

The unique characteristics of climate risk create numerous challenges for its assessment and management. **Co-operation and sharing of best practices among different entities is the key** to managing climate risk, because it not only helps the convergence of methods, strategies, and policies, but is also fundamental to the formation of consistent expectations. Sharing best practices helps to overcome knowledge barriers, keep the information up to date, lower the possibility of repeating mistakes, and improve the financial system's overall resilience to climate risk. Co-operation may occur within organisations' various departments, across sectors and countries, between industry and academia, between regulators and the regulated, and between financial institutions and their counterparties.

An insufficient and incomplete understanding of climate risk can be costly for both financial institutions and the whole financial system. Therefore, it is useful to **raise regulators', financial institutions' and the general public's awareness** through a variety of approaches, including providing training opportunities, organising meetings, disseminating research, releasing guidance and regulations, and conducting system-wide evaluations (such as climate stress tests). In addition, it is essential for financial institutions and regulators to **develop capabilities** to better tackle climate risk, which involves

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building sufficient capacity, allocating enough resources, and acquiring specialised expertise in climate risk management.⁷⁰

As climate change becomes an increasingly pressing issue, **acting early** is the key to minimising its negative impact while capitalising on accompanying opportunities. As new climate-related data, methods, conditions, and policies are constantly emerging, financial institutions and regulators will benefit from **keeping an open mind** on further refinements to best practices to maintain their resilience against climate risk. This includes proactively identifying new risks and opportunities, continuously monitoring the impact of climate risk on business, and regularly reviewing and adjusting strategies to account for the changing conditions.

⁷⁰ BCBS (2021c) discusses these aspects comprehensively.

Appendix A: Climate Risk Indicators

This Appendix summarises the climate risk indicators commonly used by financial institutions (FIs), including transition risk indicators, physical risk indicators, and novel indicators derived from textual and capital market data that are capable of measuring both types of risks.

Carbon emission indicators	
Meaning	Given the key role of greenhouse gas (GHG) emissions in contributing to global warming, carbon emission indicators are used frequently as the benchmark measures of transition risk. A higher emissions level implies a greater vulnerability to developments in regulations, technologies, and consumer preferences changes during a transition to a low-carbon economy.
Construction	Total carbon emissions are an absolute metric to gauge the total GHG emissions attributable to a particular entity, such as a sector, a firm, or an investment. Carbon footprints and carbon intensity are relative metrics that normalises the total emissions against the total market value or production of an entity.
Merits and drawbacks	Carbon emission indicators are commonly used as a proxy for transition risk; however, they only measure one source of risk, which may not fully reflect the overall level of climate risk that an entity carries. The absolute measures are straightforward to compute and understand, but cannot be compared across entities of varying sizes. By contrast, the relative measures are more appropriate for comparing the transition risks carried by entities with different sizes, although they require additional data for normalisation.
Applicability	FIs use carbon emission indicators for different purposes. Asset managers can use them to guide investment decisions, while banks and insurers can use them to avoid funding or underwriting projects that pose high transition risks.
Data issues	Many private data suppliers, such as Refinitiv and Trucost, provide highly granular carbon emission data for enterprises worldwide. Several public data sources, such as the Network for Greening the Financial System (NGFS) and Carbon Tracker, offer freely available data with a lower degree of granularity. The Partnership for Carbon Accounting Financials (PCAF) publishes standards for accounting and reporting carbon emission data in the financial industry. ⁷¹
Additional remarks	The GHG Protocol Corporate Standard ⁷² specifies three scopes, or categories, of carbon emission indicators. Scope 1 covers direct emissions from an entity's owned resources. Scope 2 covers indirect emissions from its purchased energy. Scope 3 covers any other indirect emissions in the value chain not included in Scope 2. Many firms have adopted the practice of disclosing Scope 1 and 2 emissions, but barriers to reporting Scope 3 emissions remain.

⁷¹ PCAF (2020).

⁷² GGP (2004).

Portfolio alignment indicators	
Meaning	Portfolio alignment indicators assess how closely the future carbon emission path of an entity aligns with a global climate target. A larger divergence indicates greater exposure to transition risk.
Construction	<p>To derive the alignment measures, a comparison is made between (1) the <i>projected</i> carbon emissions path of an entity with (2) the <i>required</i> emissions path in line with this entity's carbon budget under a climate target.</p> <p>The comparison yields two alignment indicators. Carbon budget overshoot (CBO) measures the discrepancy between <i>projected</i> and <i>required</i> carbon emissions. Implied temperature rise (ITR) measures the temperature rise that would occur if the entire world exceeded its carbon budget as the entity does. Box A.1 details the construction.</p>
Merits and drawbacks	CBO is conceptually simple. By contrast, ITR depends on additional assumptions, such as the entire world acting as a single entity, which may be unrealistic. However, ITR is more comparable to well-understood climate targets (e.g., below 2°C) and is more easily communicated to the general public.
Applicability	These alignment indicators help FIs to set decarbonisation goals and align their operations with climate targets. Moreover, FIs may communicate these indicators to their counterparties to prompt them to align their businesses with climate targets as well.
Data issues	The Task Force on Climate-Related Financial Disclosures (TCFD) has released a series of guidelines detailing the methodology for FIs to calculate and utilise portfolio alignment indicators. ⁷³ Alternatively, FIs can access these indicators directly from data providers, such as Morgan Stanley Capital International (MSCI). As with carbon emission indicators, PCAF's standards serve as a guide for accounting and reporting these alignment indicators.

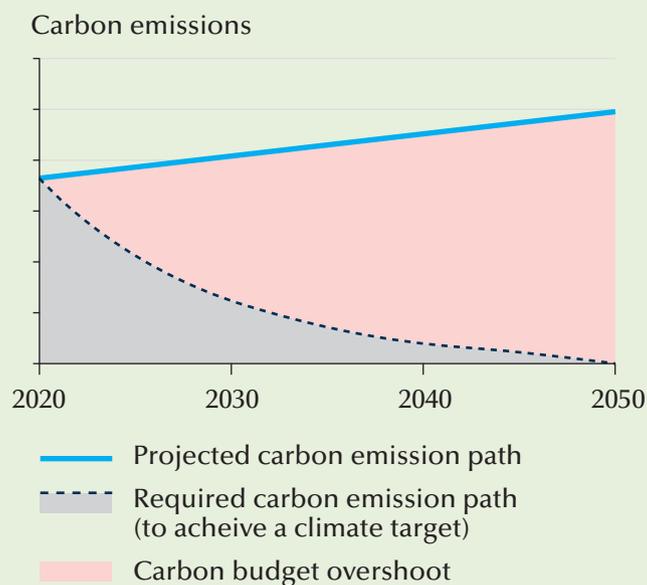
⁷³ For example, see TCFD (2021c).

Box A.1: Quantifying the portfolio alignment of a company

Figure A.1 shows how to quantify the portfolio alignment of a company with a specific global climate target. To obtain alignment measures, a comparison is made between the solid and dashed lines. The solid line represents the carbon emissions path that a company is *projected* to follow, while the dashed line represents the carbon emissions path that this company is *required* to follow in order to meet the climate target of limiting global warming to less than 2°C before 2050.

There are two ways to measure the difference between the two lines. **Carbon budget overshoot (CBO)** measures the size of the red region, which represents the amount of carbon emissions that exceed the company's carbon budget. Additionally, by imposing additional assumptions, one can convert CBO into the **implied temperature rise (ITR)**, which denotes the temperature increase that would occur if the entire world exceeded its carbon budget as this company does.

Figure A.1 Visualisation of portfolio alignment indicators



Sources: MSCI (2021) and HKIMR staff compilation.

ESG scores	
Meaning	The ESG score quantifies a company’s environmental, social, and governance performance. The overall ESG score, or more precisely the ‘E’ (Environmental) score, can be used as a proxy for the level of transition risk.
Construction	The ESG score is calculated based on raw data gathered from a variety of sources, including company filings, government publications, reports from various organisations, and many other public and proprietary datasets.
Merits and drawbacks	The ESG score is forward-looking because it measures a company’s exposure to potential risks (and opportunities), as well as its capacity to manage and mitigate these risks. The score is derived from diverse sources, each of which deals with different dimensions of climate risk. However, this also complicates the interpretation of ESG scores.
Applicability	As the ESG score reflects risks that may affect asset valuations, it is primarily used by asset managers to weight portfolios. Moreover, for asset managers with green or sustainable goals, the ESG score serves as a barometer showing how closely their investments adhere to their mandates. Banks and insurers can use ESG scores as a part of their due diligence in climate risk management.
Data issues	Several private data vendors, including Sustainalytics and MSCI, have created ESG datasets for publicly traded companies. ⁷⁴ However, the methods that rating agencies apply to calculate ESG scores are different and not fully public, which decreases the comparability and reliability of these scores. ⁷⁵ In consideration of this problem, some FIs have developed their own ESG scoring system.

⁷⁴ IOSCO (2021) provides an overview of these products.

⁷⁵ See, for example, discussions in Berg et al. (2021) and Christensen et al. (2022).

Green/brown share indicators	
Meaning	Green/brown share indicators distinguish between a company's activities that contribute to the transition to a low-carbon economy (green share) and those that obstruct the transition (brown share). A higher green share indicator suggests a lower transition risk, while a higher brown share indicator indicates the opposite.
Construction	Green/brown share indicators are quantitative measures of a firm's green and brown activities. For instance, the size of environmentally related research and development (R&D) expenditure is a green share indicator, while the percentage of revenue from petroleum products is a brown share indicator.
Merits and drawbacks	The advantage of green/brown share indicators is that they are capable of measuring the particular aspects of transition risk that a company faces. However, the data required to obtain these measures is relatively limited at this stage. In addition, the construction of these indicators depends on taxonomies that set out standards for which activities are classified as either green or brown. Because of the availability of numerous taxonomies, an indicator that is green to one taxonomy may not be green to another.
Applicability	Asset managers can use these indicators to reduce the transition risk of their investments by selecting securities with a high green share or low brown share. Similarly, banks and insurers can use them to strengthen risk surveillance and screen projects with high transition risk.
Data issues	Several private data vendors, such as MSCI and Trucost, offer some types of green/brown share indicators for companies operating in sectors that are vulnerable to transition risk. If certain green/brown share indicators that FIs need are not provided by private data suppliers, they must collect the relevant data and calculate these indicators themselves.

Physical risk indicators ⁷⁶	
Meaning	Physical risk indicators quantify the physical risks carried by the counterparties of FIs. These indicators can be used to measure acute physical risks, such as flooding and wildfires, as well as chronic physical risks, such as intensifying typhoons and rising sea levels.
Construction	These indicators are constructed using geographic data provided by governments, private companies, and public institutions. These data usually describe the vulnerability of certain locations to certain climate hazards. Location-level physical risk scores can be derived from these data, which can be subsequently translated to property-level indicators for assets that FIs hold, fund, or insure.
Merits and drawbacks	These indicators are useful for measuring a variety of physical risks, but due to the lack of standard data collection and indicator construction procedures, it is challenging to make comparisons between indicators calculated based on different data and methods.
Applicability	FIs can use physical risk indicators for different objectives. For example, banks can use floodplain maps to determine the likelihood that a residential property carrying a mortgage will be affected by flooding. Insurers can draw on historical wildfire data to estimate the risk of insured assets being destroyed in forest fires. Asset managers can rely on extreme heat forecasts to predict the market performance of agriculture companies.
Data issues	The NGFS Scenario Portal assembles a collection of frequently used physical risk indicators from a variety of public data sources. These indicators are available at national- and provincial-levels. Other public data providers include Climate Finance Alpha and ClimateWise, while private data providers such as Four Twenty Seven and MSCI also provide physical risk data at various granularity levels.

⁷⁶ A particular set of physical risk indicators can be derived from **natural capital risk analysis**. Developed by the Natural Capital Finance Alliance, it is a framework that considers water, soil, land, and other components of the eco-system as capital stock and assesses their dependences and impacts on FIs and their counterparties. The outcomes of the analysis can be used to inform FIs about their exposure to physical risk, or they can be integrated into a generic risk assessment framework for further investigation.

Textual-based indicators	
Meaning	Textual-based indicators are built on textual data and used to quantify a counterparty's exposure to transition risk, physical risk, or a combination of the two, depending on the data used in the construction.
Construction	These indicators are constructed based on textual data from a variety of publicly accessible sources, including corporate filings, government releases, newspapers, and social media. After collecting the data, various artificial intelligence and machine learning methods are employed to construct these indicators.
Merits and drawbacks	Textual-based indicators quantify information in unstructured textual data that is difficult to measure with standard risk metrics. They can be built on both historical and projected data and can be used to measure different types of climate risk at various degrees of granularity. One drawback is that the extent to which climate risk is reflected in texts may differ from the level of climate risk that a FI actually carries.
Applicability	These indicators are useful for asset managers to assess the climate risk of listed companies. For banks and insurers, their usefulness is relatively limited because there might not be publicly available textual data to quantify the climate risk that their counterparties carry.
Data issues	FIs may employ text analytics tools from Bloomberg and other commercial data providers to develop textual-based indicators.

Capital market-based indicators	
Meaning	Capital market-based indicators measure the exposure of publicly traded financial assets and the companies that issue them to climate risk. A larger indicator value suggests that the underlying asset or firm is more exposed to climate risk.
Construction	<p>These indicators are extracted from the asset prices on the capital market. The construction begins by generating a risk factor that represents the systematic climate risk to which all assets are exposed. The second step is to regress the risk factor against an asset's historical returns. The estimated slope coefficient is the capital market-based indicator for this asset.</p> <p>For the risk factor that only measures transition risk, the resulting capital market-based indicator is sometimes referred to as the carbon beta. Box A.2 describes how carbon beta is calculated for an investment portfolio.</p>
Merits and drawbacks	The advantage of this approach is that once the climate risk factor is generated, all that FIs need to calculate the capital market-based indicators are the historical asset prices, which saves FIs considerable time in gathering fundamental climate-related information for individual assets or firms. The drawback is that the indicator value may only reflect climate risk that market participants <i>expect</i> an asset or a firm to carry, but not necessarily the risk it <i>actually</i> carries.
Applicability	Capital market-based indicators benefit asset managers the most, as they provide guidance on how to monitor and hedge climate risk on the capital market. Banks and insurers may also use these indicators to measure the exposures of their listed counterparties to climate risk.
Data issues	FIs can combine the climate risk factor provided by the Carbon Risk Management project with the historical returns of assets in which they are interested in to obtain the corresponding capital market-based indicators. Alternatively, they can construct risk factors that are tailored to their specific needs using factor investing techniques.

Box A.2: Deriving the carbon beta of an investment portfolio

The carbon beta measures an investment portfolio's exposure to transition risk. The derivation of this indicator consists of two steps. First, a transition risk factor is constructed. This factor is a time series that represents the systematic transition risk to which all firms are exposed.⁷⁷ A larger factor value at a point in time indicates a greater systematic transition risk in that period.

Second, a regression analysis is performed, with the dependent variable being the investment portfolio's historical returns and the independent variable being the transition risk factor over the same time period. The estimated slope coefficient is the carbon beta of the portfolio. It quantifies the sensitivity of the portfolio's return to the transition risk factor. Based on the assumption that the equity price reflects market participants' expectations of the transition risk that the underlying company carries, this carbon beta can serve as an estimate of the portfolio's exposure to transition risk. A steeper slope suggests that this portfolio has greater exposure to transition risk.

⁷⁷ Chapter 34 of *NGFS (2020a)* provides further details on how to calculate this factor.

Appendix B: Models for Scenario Analysis

Table B.1 briefly describes the models that are commonly used to derive climatic and economic pathways in scenario analysis.

Table B.1 Models for scenario analysis

Model	Description
Integrated assessment model (IAM)	The IAM combines simplified climate and economic science models to derive climate and economic pathways based on a set of scenario assumptions.
Computable general equilibrium (CGE) model	The CGE model is used for deriving granular economic pathways. It describes the structure of the economy, capturing the linkages across sectors and economic agents, including firms, households, and governments.
Dynamic stochastic general equilibrium (DSGE) model	The DSGE model is used for deriving granular economic pathways. It describes the structure of the economy, emphasising the uncertainty in the economic environment and its influence on economic agents.
Input-output (IO) model	The IO model is used for deriving granular economic pathways. It captures the dependencies between different economic sectors and can be used to derive transition vulnerability factors, which measure the impact of climate risk at the sectoral level.
Econometric model	The econometric model is a statistical model used for studying the impact of climate risk on economic or financial pathways, based on data that show the historical relationship between climate risk and its economic or financial consequences.

Sources: NGFS (2020c) and HKIMR staff compilation.

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ABOUT THE ALLIANCE

The Alliance for Green Commercial Banks (the Alliance) is a new initiative that brings together financial institutions, research institutions and innovative technology providers to work together to develop a community across emerging markets and finance the infrastructure and business solutions needed to urgently address climate change.

For more information please visit our website (<https://www.allianceforgreencommercialbanks.org/>).

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The AoF is set up with full collaboration amongst the HKMA, the Securities and Futures Commission, the Insurance Authority and the Mandatory Provident Fund Schemes Authority. By bringing together the strengths of the industry, the regulatory community, professional bodies and the academia, it aims to serve as (i) a centre of excellence for developing financial leadership; and (ii) a repository of knowledge in monetary and financial research, including applied research.

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CONTACT US

Email: hkimr@hkma.gov.hk

Tel: +852 2878 1706

Website: <https://www.aof.org.hk/research/HKIMR>



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