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Integrating Climate Adaptation into Physical Risk Models

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Executive summary

The impacts of climate change are already beginning to materialise into financial risks. According to the World Meteorological Organization (WMO), climate change-related events over the past five decades have resulted in US$4.3 trillion in reported economic losses.[1]

In this report, GIC and S&P Global Sustainable1 analyse the projected increase in physical climate hazards for global real estate properties held by companies in the S&P Global REIT Index [2] and highlight the following takeaways:

- **Physical risks have tangible impacts on real assets.** Cumulative projected costs of changing climate physical risk exposure could reach US$536 billion, or 26% of the total real estate asset value of the index, by 2050 under the low (SSP1-2.6) climate change scenario. Under a medium-high climate change scenario (SSP3-7.0), the projected cumulative exposure could reach US$559bn, or 28% of the total real estate asset value of the index, by 2050. As we move beyond mid-century, future climate change scenarios diverge sharply, with climate physical risks becoming significantly more onerous in high warming scenarios compared to low warming scenarios. Regardless of the climate scenario used, the warming that is already embedded in the climate system means that physical risks are likely to increase over time, raising costs across the broader economy for customers, tenants, building operators, owners, and investors.
- **Existing risk assessment models often overlook the impact of adaptation, offering an incomplete picture of actual investment risks from climate events.** This omission can lead to an incomplete

[1] World Meteorological Organization (2023). *Atlas of Mortality and Economic Losses from Weather, Climate and Water-related Hazards (1970-2021)*.
[2] A REIT is a company that owns, operates, or finances real estate assets such as office buildings, hotels, shopping malls, and apartment complexes. Global REITs assessed in this report include real assets across over a dozen different categories including shopping centres, industrial, office, hotels, healthcare facilities etc.

view of the net costs of physical risks and create challenges for investors in prioritising risk management efforts.

- **Climate change creates opportunities for adaptation solution providers and for asset owners to invest in adaptation.** Our study examines some readily available climate adaptation solutions for non-residential real estate, such as green or cool roofs and wet or dry floodproofing, and estimates the annual demand for these solutions to reach approximately US$29bn globally through 2050 (or US$726bn in total). Coupled with strong policy support and timely deployment, these solutions could reduce the costs of climate physical risks. Wet and dry floodproofing, for example, could offset physical hazard costs by US$3.55 for every US$1 invested.

Introduction

Floods, hurricanes, cyclones, heatwaves, wildfires, rising sea levels, and erratic rainfall are increasing with climate change. In April 2024, a normally dry Dubai experienced 12 months' worth of rain in 12 hours,[3] the heaviest rainfall in 75 years, causing almost US$1bn in damages in one day. Globally, the WMO estimates that climate change-induced events have resulted in US$4.3tn in financial losses over the last 50 years.[4] While these losses are not fully borne by investors and property owners, their indirect impact materialises through damages across the broader economic system. The effects of climate change are increasingly felt here and now, with a tangible impact on the real economy and the value of assets.

However, investors struggle to quantify the financial impact of climate physical risks on their assets. In recent years, climate-related physical risk analytics have proliferated in the financial industry, from providing physical risk scores of locations to estimating valuation impacts on assets.

A key gap in these analytical models is the absence of adaptation measures that can mitigate the impact of the physical risk event, especially if the asset owner is proactive in implementing physical adaptation measures. When screening a portfolio of assets for physical risks, overlooking adaptation may also lead to inaccurate conclusions about the ranking of risky assets in one's portfolio and divert attention from where investors most need to focus.

With this publication, GIC and S&P Global Sustainable1 aim to advance the financial industry's approach to climate risk assessments by considering how adaptation analysis alters an assessment of physical risks for assets in the S&P Global REIT Index. Rather than focusing on downside risks alone, we also explore the potential upside opportunities associated with select climate adaptation solutions.

[3] CNN (2024). *A year's worth of rain plunges normally dry Dubai underwater.*
[4] WMO (2021). *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019).*

While the scope of the analysis is limited to readily accessible adaptation solutions for building operators, owners, and investors, we acknowledge that adaptation can also occur through government investments in public infrastructure, technological innovation, and behavioural shifts. Further research is needed across the financial industry to incorporate these variables into physical risk assessments.

This analysis serves as an initial prototype and catalyst for discussing how investors can improve physical risk assessments to better reflect the operating realities of the assets they invest in and the potential opportunities in climate adaptation solutions. We provide a more detailed explanation of our methodology and key limitations in the Appendix of this report.

Coordinated efforts by private and public sector actors will be needed to avoid the worst impacts of climate change. This analysis focuses on a selection of adaptations that are readily available to business owners and investors and which can deliver substantial cost reductions, but it also demonstrates that building-scale adaptations are likely not enough to avoid the worst costs of climate physical risk. Cumulative net benefits of the four adaptation measures studied in this paper (accounting for costs of implementation) are projected to total US$45bn by 2050 under the medium-high scenario, and while substantial in absolute terms, this represents just 8% of the total projected cumulative costs of climate hazard exposure. A coordinated approach combining private sector investments in building-scale adaptation and public investments in large-scale adaptation projects (such as sea walls, levees and other adaptations) will be needed to maximise the protection of communities, assets, and economies.

Section I: Analysis overview

Climate-related events and hazards are growing in severity, duration, and frequency, posing risks to the assets and operations of companies worldwide.[5] These risks are likely to worsen as the world warms further due to climate change. Three important pathways through which climate hazards can create direct costs for asset owners and investors include:

1. Loss of revenue due to business interruption;
2. Excess operating expenses (opex) such as higher cooling costs and productivity impacts;
3. And higher capital expenditure (capex) associated with cleanup and repair, accelerated asset degradation, and asset replacement.

In this study, we assess the physical risk impacts across these three dimensions and examine the risk reduction potential of select adaptation measures for real estate assets owned by S&P Global REIT Index constituents. Our analysis is based on a medium-high climate change scenario, which references the Intergovernmental Panel on Climate Change (IPCC)'s SSP3-7.0 climate change scenario. In the medium-high scenario, global warming levels are ultimately higher than the future projected temperature currently implied by Nationally Determined Contributions (NDCs). We believe it is reasonable to select this scenario as the latest UN Emissions Gap Report[6] concludes that the NDCs are unlikely to be met by current national policies. Nonetheless, we acknowledge that the assumption that climate policies do not materially strengthen over time may be debateable.

[5] IPCC (2022). *Summary for Policymakers.*
[6] UNEP (2023). *Emissions Gap Report 2023.*

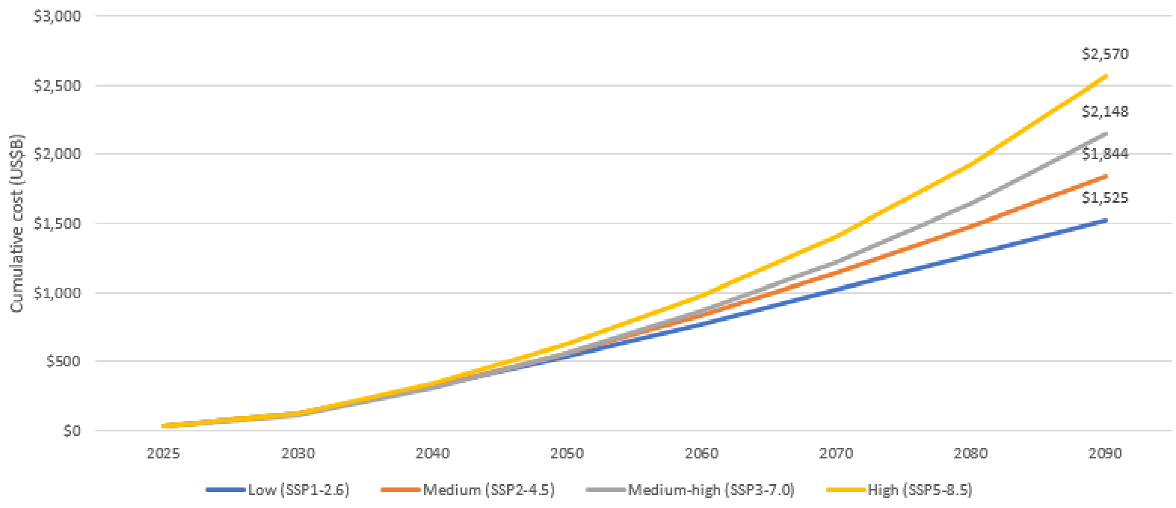
Section II: Impact of physical climate hazards on real assets

Our analysis suggests that under a medium-high warming scenario without adaptation investment, properties represented in the S&P Global REIT Index could incur US$110bn by 2030, US$310bn by 2040, and US$559bn by 2050 in cumulative excess costs from climate hazard exposure. This implies that by 2050, the cumulative costs (nominal prices) of physical climate risks could reach the equivalent of 28% of the total real estate asset value of the index constituents as of July 2024. The actual costs of physical risks may not directly translate into valuation impairments, as not all costs are borne directly by investors or property owners. However, the data highlights the value of incorporating physical risks into investment processes, as damages can spread across the broader economic system. Importantly, physical risks are estimated to drive financial impacts across all climate scenarios, whereby cumulative projected costs reach US$536bn to US$559bn, or 26% to 28% of the total real estate asset value of the index, by 2050 under the low (SSP1-2.6) and medium-high (SSP3-7.0) scenarios, respectively. For more details, please see Figure 1.

Some hazards, such as extreme heat, will be more widespread across regions, while others, such as tropical cyclones and flood, are more limited to certain regions and geographic conditions. We estimate that 89% of S&P REIT Index constituent assets will be materially exposed to extreme heat by the 2050s, whereas only 1%, 9%, and 13% of assets will be exposed to coastal flood, pluvial flood, and fluvial flood, respectively. Managing physical risks will require investors to take a bottom-up approach to account for the different exposures each property can have to different hazards. Additionally, the skills required to implement the adaptation measures that address more widespread physical impacts may need to become core to real asset management. For further details on our calculation methodology, please see the Appendix.

Figure 1: Cumulative costs of physical hazard exposure are significant even under a low climate change scenario

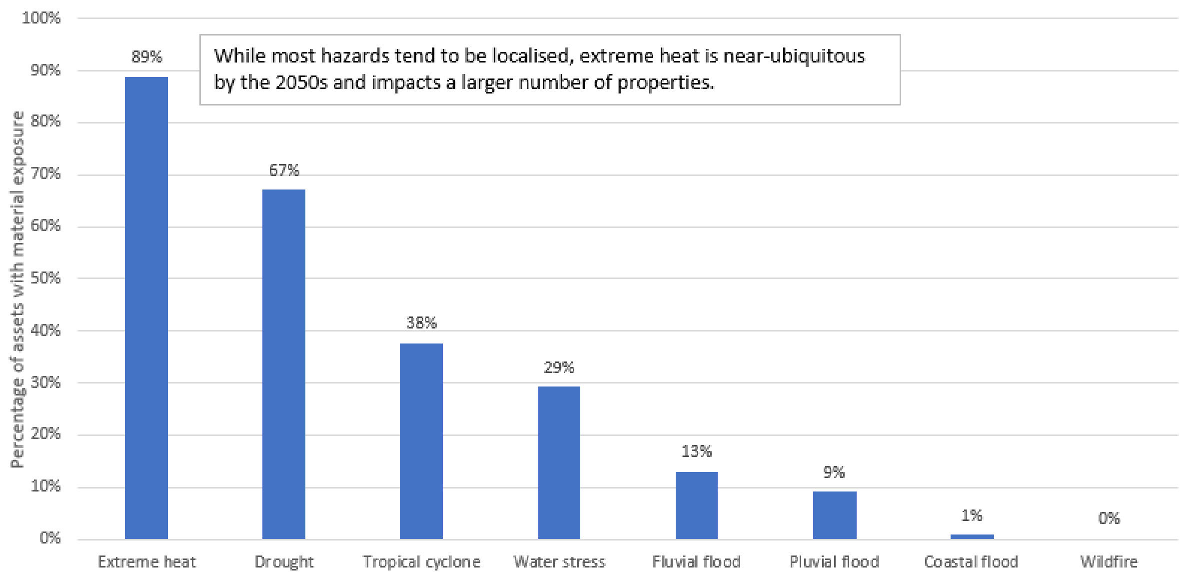
Cumulative cost of climate physical hazard exposure for S&P Global REIT Index assets by climate change scenario



Source: S&P Global Sustainable1, S&P Global Market Intelligence, 8 August 2024

Figure 2: Real estate asset exposure varies widely by physical hazard

Percentage of S&P Global REIT Index assets materially exposed to physical hazards in the 2050s under the medium-high climate change scenario



Source: S&P Global Sustainable1, S&P Global Market Intelligence, 8 August 2024

Section III: The financial benefits of investing in adaptation

Property owners or managers could better manage the increasing financial impacts from climate change by incorporating adaptation measures into their asset valuation and maintenance work. While climate adaptation measures may take various forms, including government investments into public infrastructure, technological innovation, and behavioural change, we identify a subset of readily available solutions to investors and real asset owners that can be implemented at the property level. These include green or cool roofs to adapt to extreme heat and wet or dry floodproofing solutions to manage flooding risks.

The projected increase in physical hazards worldwide over the next 25 years presents an opportunity for property owners to invest in adaptation measures where benefits outweigh implementation costs. We find that implementing these measures for assets represented in the S&P Global REIT Index could reduce the cumulative cost of climate hazard risks by $45bn on a net basis by 2050, including the cost to deploy the adaptation solutions. This includes reducing the cost of coastal, fluvial, and pluvial flood events by an average of 59% and the cost of extreme heat by 5% compared a scenario with no adaptation measures. If implemented in a timely manner, wet and dry floodproofing could save US$3.55 for every US$1 invested, while green and cool roofs could save US$7.45 for every US$1 invested. From a bottom-up perspective, the relationship between the costs and benefits of deploying various adaptation solutions will vary by asset, depending on their overall commercial viability and the intensity of relevant climate hazards. Below, we provide a non-exhaustive list of solutions that property owners and investors can deploy, assuming these solutions are economical.

While the total benefits of green and cool roof and wet and dry floodproofing adaptations are large and the return on each dollar invested is high, these selected adaptation measures alone are not able to eliminate the majority of the projected costs of climate hazard exposures leading up to 2050. This is due to several reasons. This study does not consider adaptations for other hazards such as wildfire, tropical cyclone, drought, and water stress, and both wet and dry floodproofing adaptations can only reduce, but not fully eliminate, the costs associated with flood events. The impact of flooding could be further reduced through broader infrastructure investments by governments to prevent flood waters from reaching properties, such as sea walls, levees, drainage, and other flood mitigation infrastructure. Furthermore, while green and cool roofs can reduce cooling costs and HVAC degradation caused by extreme heat, these adaptations do not address the largest driver of the cost of extreme heat — impacts on employee productivity and wellbeing. There is room for more ambitious action by governments on climate adaptation at the local, regional, and national scale, in addition to investors' own bottom-up investments in property-level adaptation.

We also note that rising physical risks offer an opportunity for companies that provide solutions to help the world adapt to a new environment. We estimate global non-residential demand for green or cool roofs and floodproofing adaptation measures could present a **US$726bn** revenue opportunity through 2050, or about **US$29bn each year** under a medium-high warming scenario.

For a more detailed description of extreme heat and floodproofing adaptation measures, as well as our calculation methodology, please see the Appendix.

Figure 3: Examples of adaptation measures that building owners can implement

Hazard	Adaptation response for existing building owners	
Coastal flood Fluvial flood Pluvial flood	• Floodwalls • Dry/wet floodproofing • Raising of structures	• Changes in building use • Water resilient building materials
Extreme heat	• Cool/green roofs • Insulation	• HVAC • Heat pumps
Tropical cyclones	• Impact resistant glass	• Reinforced concrete foundation
Wildfire	• Non-combustible building envelope	• Sprinkler systems with dedicated power/water supply
Drought Water stress	• Rainwater harvesting	• Greywater recycling

Factors that impact adaptation for property owners include:

- Costs of adaptation
- Local infra resilience
- Magnitude of hazards

Source: UN, US FEMA, US EPA, S&P Global Sustainable1, S&P Global Market Intelligence and GIC

Conclusion

The effects of climate change are already translating into financial losses for real estate assets globally. This trend will likely accelerate as the window of opportunity to curb global warming narrows each year. Under a medium-high warming scenario, the cumulative costs (as a % of asset value) arising from physical climate risks could reach 28% of the total real estate asset value held in the S&P Global REIT Index, or US$559bn, by 2050 based on our analysis.

However, adaptation can partially offset these risks in a cost-effective manner, creating opportunities for solution providers. As the focus on adaptation grows, we estimate the annual demand for select adaptation solutions, including non-residential green or cool roofs and wet or dry floodproofing, could reach approximately US$29bn globally through 2050 or US$726bn in cumulative terms. Combined with strong policy support and timely deployment, wet and dry floodproofing could save US$3.55, and green and cool roofs US$7.45, for every US$1 invested in the non-residential real estate sector. These measures only represent a small subset of adaptation solutions, and there are other cost-effective solutions across different industries that governments, investors, and asset owners can leverage to enhance global resilience against climate-related physical risks.

While climate risk assessment models are expanding in scope and sophistication across the financial industry, the lack of adaptation considerations creates challenges in providing holistic datapoints to help investors and asset owners prioritise risk management efforts. Looking ahead, climate-related physical risk assessment models need to evolve to capture a wider category of adaptation solutions. Further work is required to increase the granularity of models on region- and asset-specific marginal adaptation cost curves to produce more actionable insights for investors and asset owners.

In addition, national and local adaptation plans by governments, advancements in new climate adaptation technologies, and behavioural shifts are important areas to consider, as these can materially increase the resilience of real assets against the impacts of climate change.

This report aims to provide an initial analysis to prototype and catalyse the financial industry's efforts in incorporating adaptation measures into risk assessment models. We invite industry participants to contribute their perspectives on how to enhance existing climate assessment approaches and advance the industry's response to growing climate-related physical risks.

Appendix I: Methodology to estimate climate physical hazard impacts

This analysis is based on an assessment of the climate physical hazard exposure, asset-level vulnerability, and resultant financial impact of climate change for 54,948 global real estate assets held by real estate investment trusts.

The S&P Global REIT Index was used to provide a global sample of real estate assets, providing insight into the climate-related financial impact exposure of real estate investors globally, as well as the potential for a variety of adaptation measures to reduce these risks. As of July 2024, this index had 416 constituents with a total market capitalisation of US$1.7tn and a total real estate asset value of US$2.3tn. Real estate asset data was acquired from the S&P Global Market Intelligence REIT database, covering 96.5% of the index weight. For companies where asset data was not available, results were scaled based on the assumption that the costs for the non-covered companies would be comparable to the ones for covered companies.

Our research is based on a medium-high climate change scenario that references the IPCC's SSP3-7.0 scenario. In this scenario, efforts to reduce global greenhouse gas emissions are limited and total emissions double by 2100. This scenario was chosen to represent a plausible climate change outcome if efforts to reduce global emissions are not accelerated in line with the goals of the Paris Agreement on climate change. The other three climate scenarios include the low warming scenario, which corresponds to SSP1-2.6; a medium scenario, which references SSP2-4.5; and a high scenario, which is linked to SSP5-8.5.

Using the S&P Global Climanomics platform, we analysed the exposure of each property to eight physical hazards: extreme heat, drought, wildfire, water stress, coastal flooding, fluvial flooding, pluvial flooding, and tropical cyclone.

2.1 Analysis

The analysis was conducted as follows:

1. All real estate assets owned by companies in the S&P Global REIT Index were compiled from the S&P Market Intelligence REIT database.
2. Each asset was processed using the S&P Global Climanomics platform to calculate the projected relative modelled average annual loss (MAAL) as a percentage by impact pathway across eight hazards, four scenarios, and eight time periods, assuming:
   a. No adaptation applied to any assets (no adaptation scenario)
   b. Adaptation applied to all assets exposed to each hazard (adaptation scenario)[7]
3. Each asset was assigned an estimated asset value by apportioning the total real estate asset value for each company in the index to each asset owned by that company.
4. The relative MAAL (%) for each asset was multiplied by the estimated asset value to calculate the absolute MAAL (US$) associated with each hazard, scenario, and time period. This process was repeated for the "no adaptation" baseline scenario and the "adaptation" scenario.
5. The absolute MAAL (US$) results were summed to the company level and then summed to the index level.
6. The index-level absolute MAAL (US$) was scaled to account for the proportion of index constituents for which asset data was not available (less than 4%), assuming that the costs for the non-covered companies are comparable to those of the covered companies.
7. The financial benefits of adaptation were calculated by subtracting the MAAL results for the "adaptation" scenario from the "no adaptation" scenario.
8. Benefit/cost ratios were calculated by dividing the financial benefit for each adaptation type by the cost of implementation for all assets owned by companies in the

[7] Flood adaptations were assumed to be adopted by all properties with nonzero exposure to fluvial flood and coastal flood, or with modeled annual average loss of greater than 1% for pluvial flood.

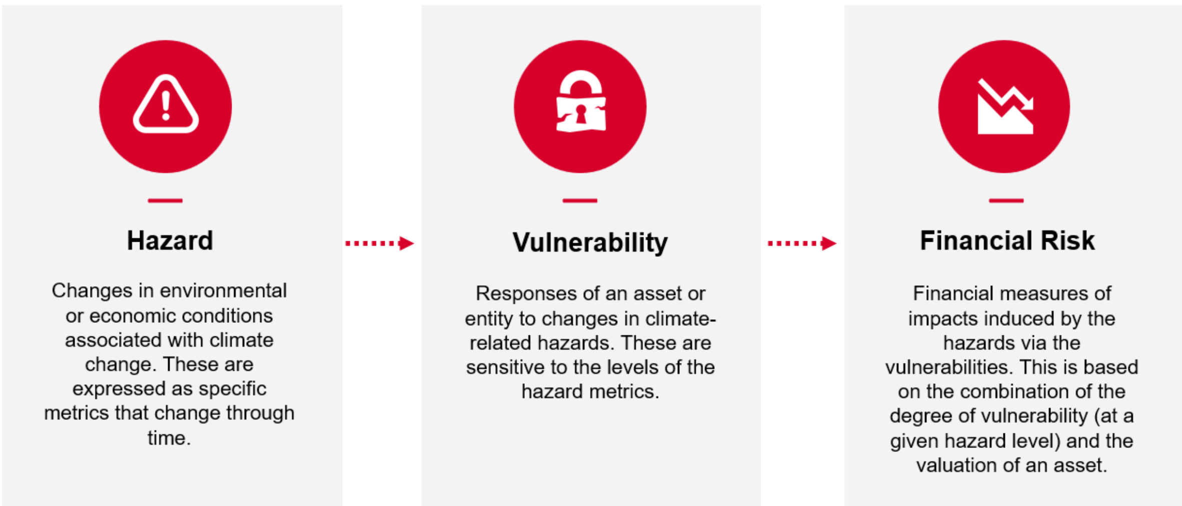
index. Adaptation costs were estimated by applying global average cost estimates to all assets, scaling by property size and value.

9. Cumulative costs and benefits were calculated by summing the costs and benefits for all years for a given scenario. No assumptions are made about growth in real estate asset values in future years and no discount rate is applied. The results are presented in nominal prices.

2.2 Vulnerability and financial risk modelling for climate physical hazards

The financial impact of a climate physical hazard can vary based on how vulnerable a given asset is to different hazards.

Figure 4: Modelling direct financial impacts of physical hazards on various asset types



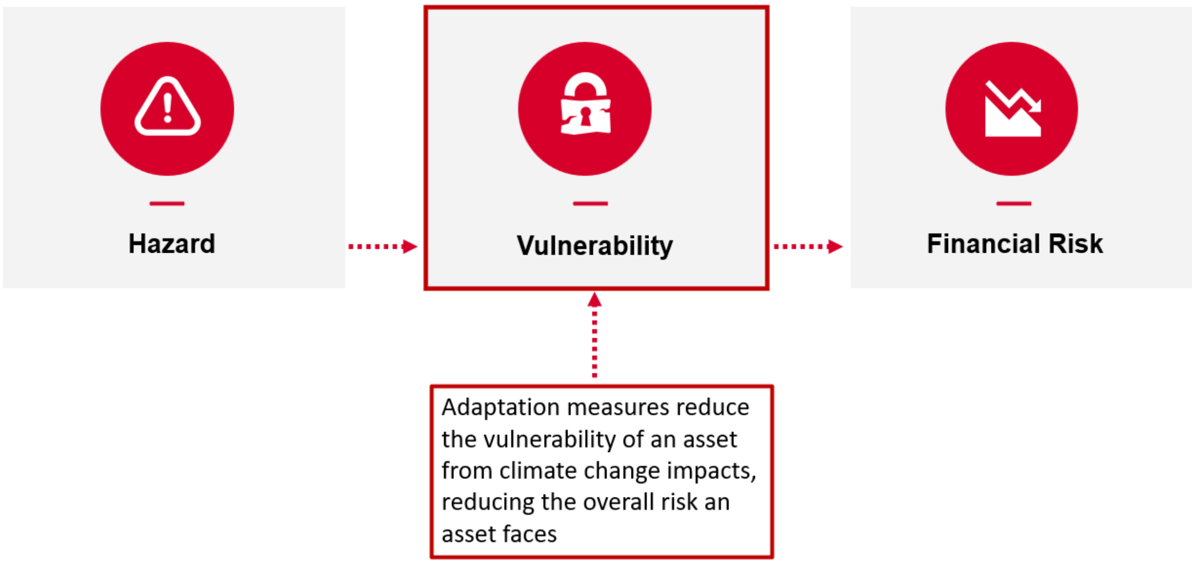
Source: S&P Global Sustainable1

S&P Global Sustainable1's vulnerability methodology models the direct financial impacts that each hazard is expected to have on each asset type. Each asset type's vulnerability is based on the specific ways that asset type is impacted by a given climate hazard. Finally, impact functions, composed of impact pathways, are assigned to model the risk based on the hazard and vulnerability. The S&P Global Climanomics library of impact functions are based on peer-reviewed published research and papers published by government and industry sources. Impact function whitepapers describing key methods and sources are maintained by S&P Global. Please contact S&P Global Sustainable1 for more information.

Impact functions estimate the financial losses, including revenue, operating expenses, and capital expenditures, that a hazard of varying intensity would cause to a specific type of asset. A single hazard might impact an asset in multiple ways requiring multiple impact pathways to adequately characterise risk. For example, high maximum daily temperatures at an office building could drive up cooling costs, degrade the HVAC system, and reduce employee productivity — each of which is a single impact pathway.

Adaptation or resilience can modify the vulnerability of an asset to the hazard it is exposed to. Overall, adaptation measures can take different forms, from **structural** (engineered, technological or services-based), to **social** (educational, informational, or behavioural) to **operational/institutional** (policy and programme changes or process changes). The current S&P Global Sustainable1 methodology focuses on **structural** adaptation measures.

Figure 5: Incorporating adaptation measures while modelling asset level physical risk



Source: S&P Global Sustainable1

2.3 Flood adaptation measures

This analysis focuses on two flood adaptation measures that can be implemented at the individual property scale. Other broader-scale adaptation infrastructure could further reduce flood impacts, such as sea walls, levees, and drainage systems, but these would typically be managed by local, regional or national governments.[8]

- **Wet floodproofing** involves the use of flood damage-resistant materials that do not need to be replaced if flooded, including pressure-treated plywood, concrete, and cement board. Flood vents are installed in the walls of the enclosure to let floodwaters enter and leave by gravity, which allows forces on either side of the structure's walls to equalize. This prevents the structure and foundation from collapsing in the event of a flood.[9]

  The current wet floodproofing adaptation analysis incorporates the most commonly used measures. These include making the basement or ground floor of the structure water-resistant by installing flood vents and other interior fittings, using flood-resistant materials such as concrete, metal or plastic for the walls and ceilings, opting for concrete instead of carpet for the floors, and installing utilities and mechanical systems at a higher elevation above the potential flood levels.
- **Dry floodproofing** includes measures that make a structure watertight below the level that needs flood protection to prevent floodwaters from entering. This can be done by sealing the outside of the building, assuming the walls are strong enough to handle the hydrostatic pressure from floodwaters. Dry floodproofing can also include closing the gaps or using shields to prevent water from entering a building

[8] Federal Emergency Management Agency (2012). *Engineering Principles and Practices for Retrofitting Flood-Prone Residential Structures.*
[9] Ibid.

through other openings such as under doors and around windows.

The dry floodproofing adaptation analysis is based on the most commonly used dry floodproofing strategy, which is making the structure watertight. This usually involves the following strategies:

1. Applying waterproof coatings on walls, foundations, and basements
2. Installing sealants to prevent seepage through walls
3. Installing plastic sheeting or waterproof membranes along the structure's exterior
4. Installing watertight doors and windows to minimise water entry

The cost of implementation for wet floodproofing is estimated at US$323 per square meter, based on data from Marin County Flood Control.[10] The cost of implementation for dry floodproofing is estimated at US$53 per square meter, based on data from the US Federal Emergency Management Agency.[11] Floodproofing is assumed to be applied only to the ground floor of a property. The proportion of the total floor area represented by the ground floor is estimated based on different assumptions by property type to account for differences in building design.

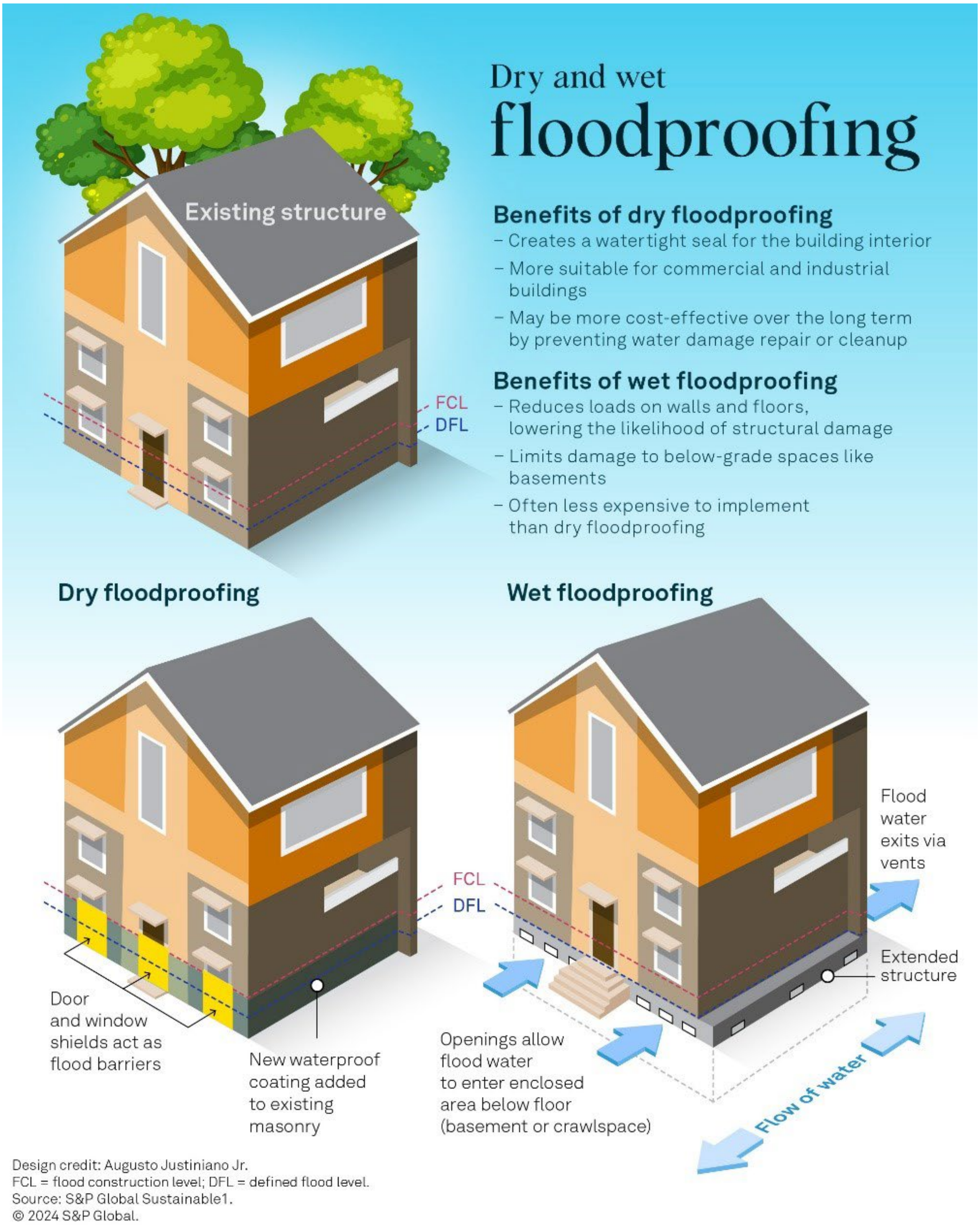
Wet and dry floodproofing is assumed to be implemented for properties exposed to either fluvial or coastal flood, or properties where the MAAL for pluvial flood is greater than or equal to 1%, and not to non-exposed properties.

Scaled to the total building area of all properties held by companies in the S&P Global REIT Index, the total cost of adopting wet and dry floodproofing adaptations is US$11bn, assuming wet floodproofing is implemented at

[10] Marin County. *An Overview of Retrofitting Residential and Commercial Buildings for Flood Mitigation.*
[11] Federal Emergency Management Administration (2014). *An Overview of the Retrofitting Methods.*

50% of the properties and dry floodproofing is implemented at the remaining 50%. Assuming a total useful life of 20 years for wet and dry floodproofing, the total cumulative benefits (avoided costs) associated with these adaptations equate to US$40bn by 2050 under the medium-high warming scenario. This produces an estimated benefit/cost ratio of 3.55 for wet and dry floodproofing adaptations.

Figure 6: Dry and wet floodproofing



2.4 Extreme heat adaptation measures

Companies can reduce the impacts of extreme heat on buildings in part by reducing how much heat is absorbed through their rooftops. The two common heat management strategies included in this analysis are cool roofs and green roofs.

- **Cool roofs** help reduce how much heat is absorbed into the building during the day by using materials that will reflect the sun away and take longer to heat up than conventional materials. They can be made from a variety of light-coloured materials, including coatings, asphalt shingles, metal, clay tiles, and concrete tiles. [12] Cool roofs can reduce cooling costs by decreasing air conditioning needs and thus energy bills. The US Environmental Protection Agency (EPA) estimates cool roofs can stay up to 60 degrees F (33 degrees C) cooler in the summer and can reduce building cooling needs by 11% to 27%. [13]

  The cool roof adaptation analysis uses data based on a broad definition of cool roof, independent of adaptation style or materials used, meaning any roof that is designed to reflect more sunlight than a traditional roof. The impact pathways for cooling costs and cost saving estimates are based on a broad definition of cool roofs across various building types.

  The cost of implementation for cool roofs is estimated at US$1 per square meter of total building area, based on data from the EPA. [14]
- **Green roofs**, sometimes also referred to as rooftop gardens or living roofs, are another adaptation measure for dealing with extreme heat conditions in the summer and can also insulate a building from the cold in winter. They are typically composed of multiple

[12] United States Environmental Protection Agency (2008). *Reducing Urban Heat Islands: Compendium of Strategies.*
[13] United States Environmental Protection Agency (2022). *Using Cool Roofs to Reduce Heat Islands.*
[14] Ibid.

layers starting with vegetation and its soil, followed by other layers that help filter and drain away water, provide structural support or waterproof the building's internal structure to prevent water from leaking into the building's interior.

Green roofs provide more energy savings than cool roofs as they act as an additional barrier between a building's interior and the exterior environment in both hot and cold weather. [15]

The cost of implementation of green roofs is estimated at US$4 per square meter of total building area, based on data from the EPA and Sproul et al. [16,17]

- Scaled to the total building area of all properties held by companies in the S&P Global REIT Index, the total cost of adding green and cool roofs is US$3bn, assuming green roofs are implemented at 50% of properties and cool roofs are implemented at the remaining 50%. Assuming a total useful life of 40 years for cool and green roofs, the total cumulative benefits (avoided costs) associated with these adaptations equate to US$22bn by 2050 under the moderately high warming scenario. This produces an estimated benefit/cost ratio of 7.45 for green and cool roof adaptations.

[15] United States Environmental Protection Agency (2008). *Reducing Urban Heat Islands: Compendium of Strategies.*
[16] United States Environmental Protection Agency (2022). *Using Cool Roofs to Reduce Heat Islands.*
[17] Energy and Buildings, Volume 71, pages 20-27 (2014). *Economic comparison of white, green, and black flat roofs in the United States.*

Figure 7: Cool and green roofs

Appendix II: Limitations

Noteworthy limitations and caveats for this analysis include:

- This study does not reflect adaptation measures taken at the municipal, state, or national level, such as urban tree planting projects or seawall construction, which could provide additional adaptation benefits to real estate assets.
- Adaptation measures that happen as a result of technological innovation, such as improvements in HVAC efficiency and cooling properties of new building materials, have not been taken into account. In addition, behavioural shifts, such as a decrease in effective office utilisation rates due to increasing work-from-home practices – which would impact cooling energy demand – have not been modelled in this study.
- This study focuses on the direct costs that the owners and operators of real estate assets may incur due to physical climate hazards. However, it does not account for indirect impacts on local real estate markets and vacancy rates in high-risk locations that have been repeatedly impacted by extreme or chronic climate events.
- This study does not consider the impact of insurance due to a lack of reliable data. The use of insurance would distribute the costs of climate physical hazards more widely across a broader group of market participants (premium holders, insurance companies, and investors) but would not reduce the costs projected in this study.
- The study assumed a useful life of 40 years for green and cool roof adaptations[18] and 20 years for wet and dry floodproofing adaptations.[19] As such, cool and green roofs are not assumed to be replaced in the

[18] Environmental Affairs Department, City of Los Angeles (2006). _Green Roofs – Cooling Los Angeles._
[19] Federal Emergency Management Administration (2015). _Reducing Flood Risk to Residential Buildings That Cannot Be Elevated._

time period leading up to 2050 and wet and dry floodproofing adaptations are assumed to be partially replaced in the 25 years until 2050. No maintenance cost assumptions are made due to lack of reliable data.

- There are many different adaptation measures a property owner could implement to offset the potential risks of climate physical hazards aside from the ones discussed in this study. We have chosen to examine the benefits of cool roofs, green roofs, dry floodproofing, and wet floodproofing to demonstrate the potential value of adaptation more broadly.
- Global warming will likely increase the intensity and frequency of climate change related hazards. Our analysis however is largely based on the expected changes in frequency of hazards and not their intensity (a gap common amongst climate risk models).

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