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Allianz Research

The global economic ripple effect of cyclones

Executive Summary

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Tropical cyclones (TCs), are among the most destructive extreme weather events globally, causing an average of 43 deaths and USD78mn in economic damages daily. In the US, the economic costs have escalated dramatically, with the decade from 2010 to 2019 witnessing USD731bn in losses due to super-hurricanes Harvey, Irma and Maria. The current decade has already incurred USD460bn in damages, double the total losses from 1980 to 1999.

Global warming, increasing urbanization and the concentration of residents in densely populated coastal areas are set to worsen the impacts of tropical cyclones. Under most emission scenarios, except for the low-emission pathway (RCP2.6), the population exposed to tropical cyclones is expected to rise significantly by 2100. In a „hothouse world," the number of affected people could increase by 23% by 2050 and 84.2% by 2100.

While immediate economic losses from tropical cyclones are evident, the ripple effects on global supply chains and maritime trade often go unnoticed. Ports, which handle about 80% of global trade, face significant disruptions due to extreme weather, leading to costly downtime and widespread economic consequences. Major events such as Hurricane Katrina in 2005 shut down the Port of New Orleans for nearly four months, causing global grain shortages and spiking commodity prices. For instance, in 2023, tropical cyclones caused 117 days of port downtime globally. As climate change intensifies, these ripple effects are projected to worsen, with port-related export value at risk increasing by up to +38% to USD312bn.

Taiwan serves as a valuable case study due to its critical role in global supply chains and its high susceptibility to tropical cyclones (typhoons). Situated in the Western Pacific, Taiwan experiences three to four typhoons annually, with its mountainous terrain intensifying the impacts through severe rainfall, flooding and landslides. As the producer of over 60% of the world's microchips, disruptions in Taiwan due to cyclones have significant ripple effects on global supply chains. Estimates suggest that cumulative external economic damages from TC-induced shocks could range from USD84.7bn to USD94.6bn by 2050. China, Taiwan's largest trading partner, faces the highest potential losses, followed by the US, Japan and South Korea. The primary sectors affected are computers, electronics and optical equipment. While Taiwanese companies bear two-thirds of the total TC-related damages on average, in some sectors such as electrical equipment and motor vehicles, the external damage share is above 50%.

From 2040 to 2050, the supply-chain disruptions caused by cyclones could halve future return expectations for the stocks of Taiwanese semiconductor companies, with cascading effects on global equity markets. Under the most severe climate scenario, annual growth rates for these stocks could drop from +8% to around +4%. Despite Taiwan's small economy, its dominant role in the semiconductor sector means that disruptions can ripple through global equity markets. The S&P500, for example, could see its returns reduced by 2pps due to cyclones, lowering long-term expectations to around +6% per year.

Without improved adaptation measures and enhanced resilience, the economic consequences of tropical cyclones are likely to escalate as these events become more frequent and intense. As climate change intensifies, more countries will surpass their resilience thresholds, leading to severe economic damage and weakened capacity to cope with future hazards. Investing in adaptation measures, such as improved infrastructure, early warning systems, financial safety nets and nature-based solutions, can mitigate the economic costs of tropical cyclones and raise a country's resilience threshold. National Adaptation Plans (NAPs) under the UNFCCC are critical tools for adapting to climate change, with 140 countries engaged as of 2023. These plans are central to COP negotiations, particularly regarding financing, as developing countries seek significant funds for adaptation efforts.

While adaptation helps reduce the impacts of extreme events, it is not enough on its own. Limiting global warming to 1.5°C can significantly reduce the severity of tropical cyclones, thereby safeguarding economic stability. Key for effective climate-change mitigation is high carbon pricing that accurately reflects the true economic damage of carbon emissions and incentivizes emission reductions. Accounting for tropical cyclone damages would increase carbon pricing by +44% in cyclone-prone countries and by +22% globally.

Tropical cyclones: A looming threat

Storms, including tropical cyclones (TCs), rank among the most devastating extreme weather events globally, causing an average of 43 deaths and USD78mn in economic damages daily over the last 50 years[1], and posing significant threats to both human populations and economic stability. On average, severe storms directly impact 32.2mn people each year (2003-2022 average), leading to widespread displacement, loss of life and disruption of livelihoods. Despite the adaptation efforts, the economic toll of tropical cyclones is equally staggering, with average annual insured damages amounting to USD54.9bn over the period 2017-2022, and average annual uninsured damages almost double that at USD126bn. These figures underscore the severe and far-reaching consequences of TCs.

The damages caused by tropical cyclones are driven by several destructive forces, each contributing to the overall impact in different ways. Storm surges are among the most devastating, accounting for approximately 50% of cyclone-related fatalities globally. These surges, which occur when strong winds push seawater onto land, can inundate coastal areas, causing extensive flooding and erosion. Heavy rainfall accompanying tropical cyclones often leads to catastrophic inland flooding, which is responsible for nearly 25% of cyclone-related deaths and significant property damage. Additionally, the intense winds generated by these storms can lead to widespread structural damage, downing power lines, damaging buildings etc. Landslides are another critical driver of damage, particularly in hilly regions where saturated

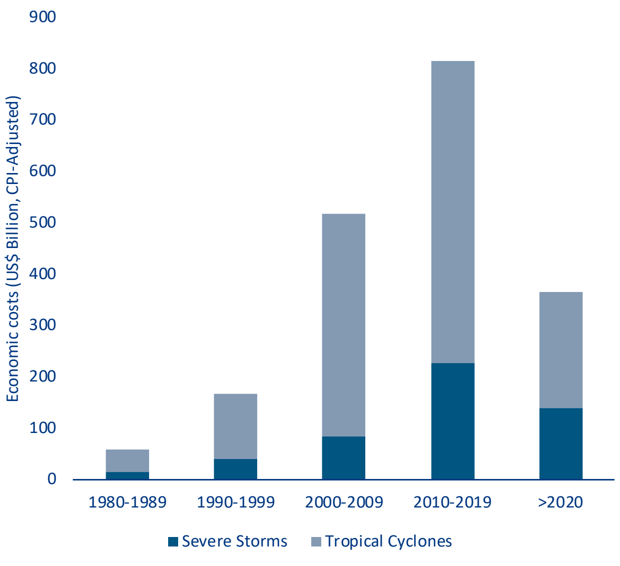
[1] https://wmo.int/topics/tropical-cyclone

soils can give way, causing loss of life and destruction of infrastructure. The recent tropical cyclone Yagi offers an example of the destructive power of landslides and inland flooding in Vietnam[2].

Moreover, climate change is intensifying tropical cyclones by creating marine heatwaves[3], i.e. prolonged periods of unusually high sea surface temperatures. These provide an abundant source of heat and moisture, enhancing evaporation rates and injecting more latent heat into the atmosphere, which fuels the strength of cyclones. Additionally, marine heatwaves expand the geographic regions where tropical cyclones can form, exposing new areas to storm risks, and they amplify cyclone intensity, often leading to rapid intensification, which complicates forecasting and preparation and adaptation efforts[4].

As a result, and amplified by rapid socio-economic developments, such as increasing urbanization and the concentration of populations in densely populated coastal areas, the direct economic damages associated with tropical cyclones (TCs) have surged dramatically since 1980. Figure 1 highlights the trend of escalating costs in the US, revealing a consistent increase in TC-related economic damages with each passing decade. For example, the decade from 2010 to 2019 witnessed the highest recorded economic losses, amounting to approximately USD731bn, largely driven by the catastrophic impacts of super-Hurricanes Harvey, Irma and Maria. Remarkably, the current decade, beginning in 2020, has already incurred USD460bn in damages, a figure that is double the total losses recorded over the entire two-decade period from 1980 to 1999, which saw USD225bn in damages. This sharp increase underscores the growing financial toll of tropical cyclones, exacerbated by both climate change and the increasing vulnerability of coastal regions.

Figure 1: Trends in direct economic damages caused by severe storms and tropical cyclones in the US (1980 – 2023)

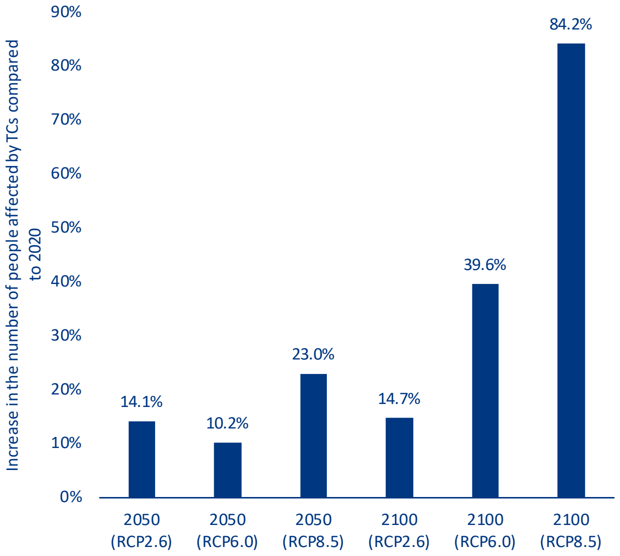


Sources: NOAA, Allianz Research

[2] https://www.reuters.com/world/asia-pacific/vietnams-death-toll-typhoon-yagi-rises-24-govt-says-2024-09-09/
[3] Sustainable ocean (allianz.com)
[4] https://www.nature.com/articles/s43247-024-01578-2

The impacts of tropical cyclones are expected to worsen due to ongoing global warming and as more people are exposed to their effects. Figure 2 shows that the population exposed to low, moderate and severe tropical cyclones will increase in almost every scenario[5], with the exception of an orderly transition with stringent mitigation (Representative Concentration Pathway 2.6). In a hothouse world, the number of people affected by TCs is projected to increase by +23.0% by 2050 and by +84.2% by 2100, compared to 2020. In contrast, under the low-emissions scenario (RCP2.6), the increase is more modest, with only a +14.7% rise in those affected by 2100.

Figure 2: Global trends in the number of people affected by low, moderate and severe tropical cyclones for different transition scenarios



Sources: Geiger et al. (2021)[6], Allianz Research

Direct damages can be the tree that hides the forest. While the immediate economic losses from storms and tropical cyclones are easily visible, the gradual and long-term economic consequences are often less apparent. But these ripple effects can disrupt global supply chains and maritime trade (Boxes 1 and 2), hinder economic growth and exacerbate poverty in vulnerable communities. For instance, a severe tropical cyclone (in the 90th percentile) can lead to a -7.4% reduction in per capita incomes two decades later, effectively erasing 3.7 years of average development progress[7]. TCs also have a significant impact on price stability, particularly in the short term, with food prices often seeing the most immediate increases. This price volatility exacerbates the financial strain on affected households, especially among the poorer segments of the population. For instance, after a severe storm, the cost of basic groceries tends to rise, disproportionately burdening lower-income communities in the impacted areas. These already vulnerable communities may find themselves paying between 1-5% more for essential food and goods compared to their higher-income counterparts[8]. In low-income areas, limited infrastructure, lower-quality construction and fewer grocery store options can lead to supply shortages in the aftermath of severe TCs. As products run out, families are forced to buy higher-priced alternatives, further straining their budgets. As a result, the economic shock of a tropical cyclone extends beyond immediate damages, deepening inequality and making recovery more challenging for developing nations.

5 Assuming constant demographic conditions based on the 2015 population.
6 https://www.nature.com/articles/s41558-021-01157-9
7 https://www.nber.org/papers/w20352
8 https://www.emorybusiness.com/2023/12/08/hurricanes-and-natural-disasters-linked-to-grocery-tax-for-lower-income-americans/

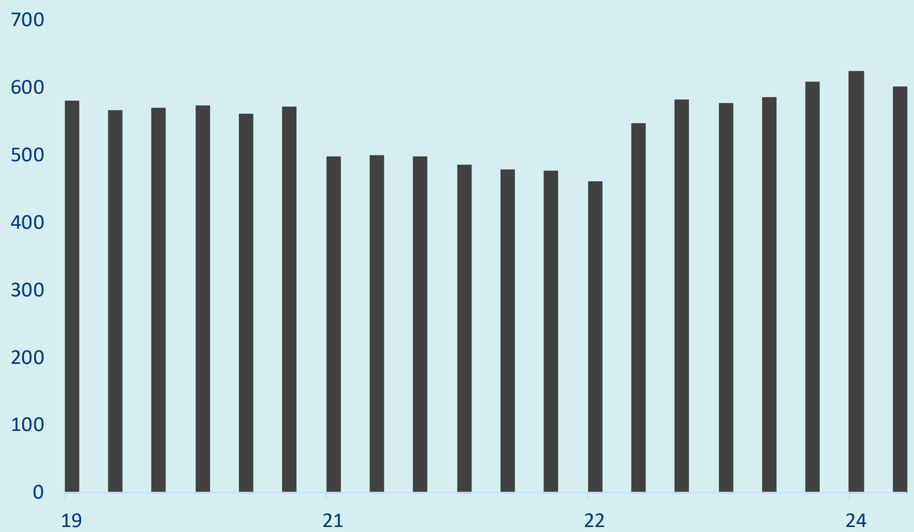
Box 1: Local disaster with global impact: Spruce Pine quartz mines

Since Covid-19, we have been learning about pinch points and choke points that underpin our modern economies. From surgical masks to semiconductors, from the Suez Canal to the Panama Canal, they have been making the headlines in turn since 2020. Another recent example is the flooding of Spruce Pine, North Carolina, caused by Hurricane Helene which might have severe consequences for the global semiconductor supply chain. Spruce Pine is the source of the world's highest-purity quartz, which is essential for producing silicon wafers used in semiconductors. The quartz mined in Spruce Pine is a critical input for a variety of tech products, including smartphones, computers, solar panels, and automotive systems. The disruption of mining activities in this region, which supplies 80-90% of the global demand for high-purity quartz, poses significant challenges to the semiconductor industry. Silicon wafers, the foundational material for microchips, are produced using quartz crucibles made from the ultra-pure quartz mined in Spruce Pine. This purity is vital because even the smallest impurity can affect the performance and efficiency of the semiconductor wafers. The quartz must be of such high quality that only Spruce Pine and a few other locations globally meet the standards needed for semiconductor manufacturing. This makes the area critical to the supply chain of semiconductors.

The recent devastation caused by Hurricane Helene has put this vital resource in jeopardy. Over a week after the hurricane Helene hit, Spruce Pine remains without basic services like water and electricity. Local infrastructure has suffered significant damage, with roads and railways severely impacted, isolating the town and halting operations. The two main firms operating the mines have halted production, and it remains uncertain when they will resume. Even though the companies have established safety stocks and secondary purification sites in places like Norway, these reserves are limited and cannot sustain global demand indefinitely. Substitution of this critical material is not straightforward. While other regions produce quartz, none offer the same purity levels as Spruce Pine's deposits. The industry has historically experimented with synthetic quartz, but it remains costlier and less efficient compared to the natural, ultra-pure quartz mined in North Carolina.

While companies involved in the mining operations have activated contingency plans, the immediate focus is on restoring local infrastructure and safety conditions. There has been alarming news on potential large disruptions in the global supply chain of the semiconductor industry, but they are probably overblown. Indeed, the combined inventories of the largest listed wafer manufacturers stood at close to 2 years of DIO (days inventories outstanding – see Figure 3). Will Spruce Pine resume activity in a few months? Mostly likely so.

Figure 3: DIO of largest wafer manufacturers



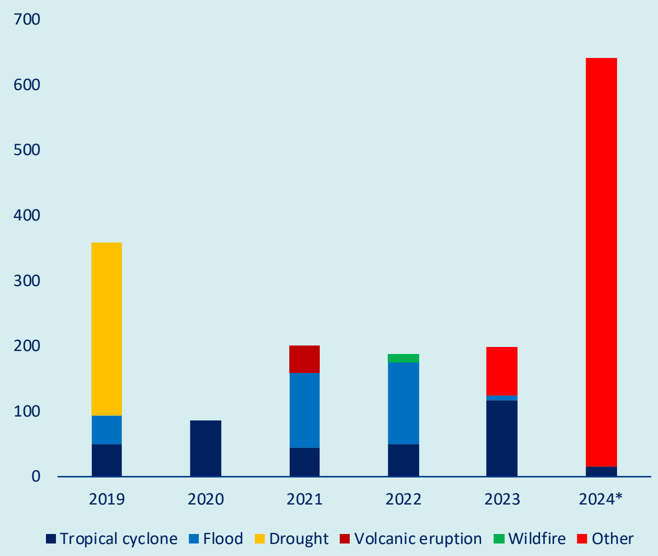
Sources: LSGE Eikon, Allianz Research

The Spruce Pine flood illustrates the fragility of global supply chains, which depend heavily on a few key geographic locations for critical materials. This situation is not unique. For example, the Democratic Republic of Congo (DRC), present similar risks. DRC produces over 70% of the world's cobalt, crucial for batteries in electric vehicles (EVs) and other electronics while it only has one major road connecting its mines to neighbouring Zambia before going onwards to ports in Durban or Walvis Bay. Any political or environmental disruption in the DRC can therefore have a cascading effect on EV supply chains and battery manufacturing globally. The risk of these disruptions reinforces the need for diversification in sourcing and greater resilience planning within companies.

Box 2: Navigating troubled waters and the implications of natural disaster disruptions in maritime trade

Many ports face operational disruptions due to extreme weather events, leading to costly downtime. Maritime transport is widely regarded as the backbone of international trade and the global economy, with ports handling around 80% of global trade. But tropical cyclones can cause severe disruptions to port activity. For instance, operations at the ports of Shanghai and Ningbo are disrupted for five to six days each year on average because of tropical cyclones. Port disruptions alter both demand and supply patterns: Trade flows managed at ports serve supply chains in the hinterlands, either directly – when firms receive goods from ports – or indirectly – when firms rely on suppliers that do. For example, in 2005, Hurricane Katrina shut down the port of New Orleans for almost four months, as well as other major ports in Louisiana, causing substantial disruptions to global grain supply and resulting in export losses for the US. This had a cascading effect on dependent supply chains worldwide, resulting in increased commodity prices. In recent years, the number of interrupted days at ports due to extreme events has varied significantly, from 358 days in 2019 to just 87 days in 2020 (Figure 4). In 2023, tropical cyclones accounted for the largest downtime at ports, totaling 117 days. Other significant events, such as shipping limitations in the Panama Canal due to low water levels (73 days in 2023) and trade disruptions in the Red Sea due to conflicts, contributed to a total of 626 days of downtime across ports globally in 2024.

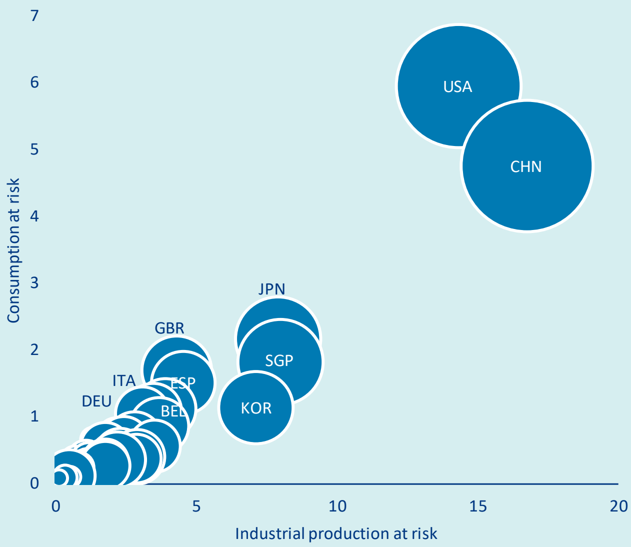
Figure 4: Number of accumulated interrupted days at ports due to extreme events, 2019-2024



Sources: University of Oxford, IMF PortWatch, Allianz Research. Notes: Latest data September 2024. Other includes the collapse of the Baltimore bridge, trade disruptions in the Red Sea and shipping limitations of the Panama Canal due to low water levels.

Disruptions to ports from weather events can have systemic impacts on global shipping and trade, and across supply chains. In July 2024, Port Houston closed for two days after Hurricane Beryl made landfall in Texas, disrupting a key gateway for energy commodities and their byproducts. Annually, port disruptions due to extreme weather put USD162bn in global exports at risk, along with USD 132bn in industry output and USD37bn in consumption. The exports of countries such as China, the US and Singapore face significant risks (Figure 5), equivalent to USD22bn, USD19bn and USD9bn, respectively. In terms of industrial production at risk, these countries account for USD17bn, USD14bn and USD8bn. On the consumption side, the US faces the highest risk at USD6bn, followed by China at USD4bn and Japan at USD2.2bn. The supply chains most at risk include wood and paper in Taiwan and South Korea, mining and quarrying in France and petroleum, chemicals and non-metallic mineral products in Macau and Aruba.

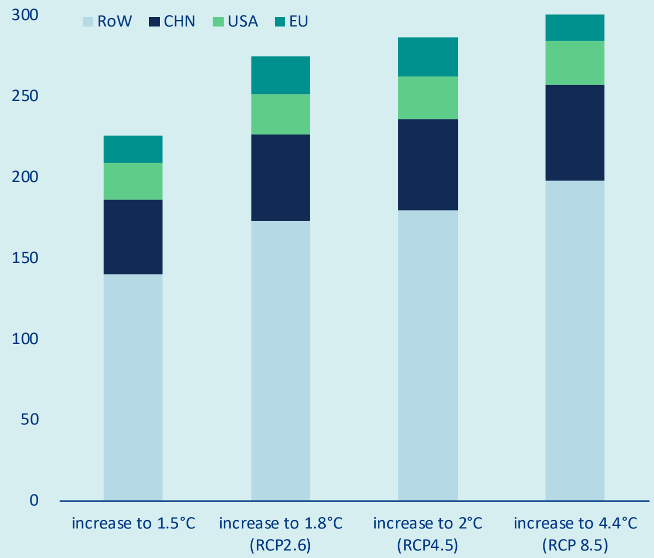
Figure 5: Industry output, consumption and exports at risk at ports due to extreme weather, in USD bn



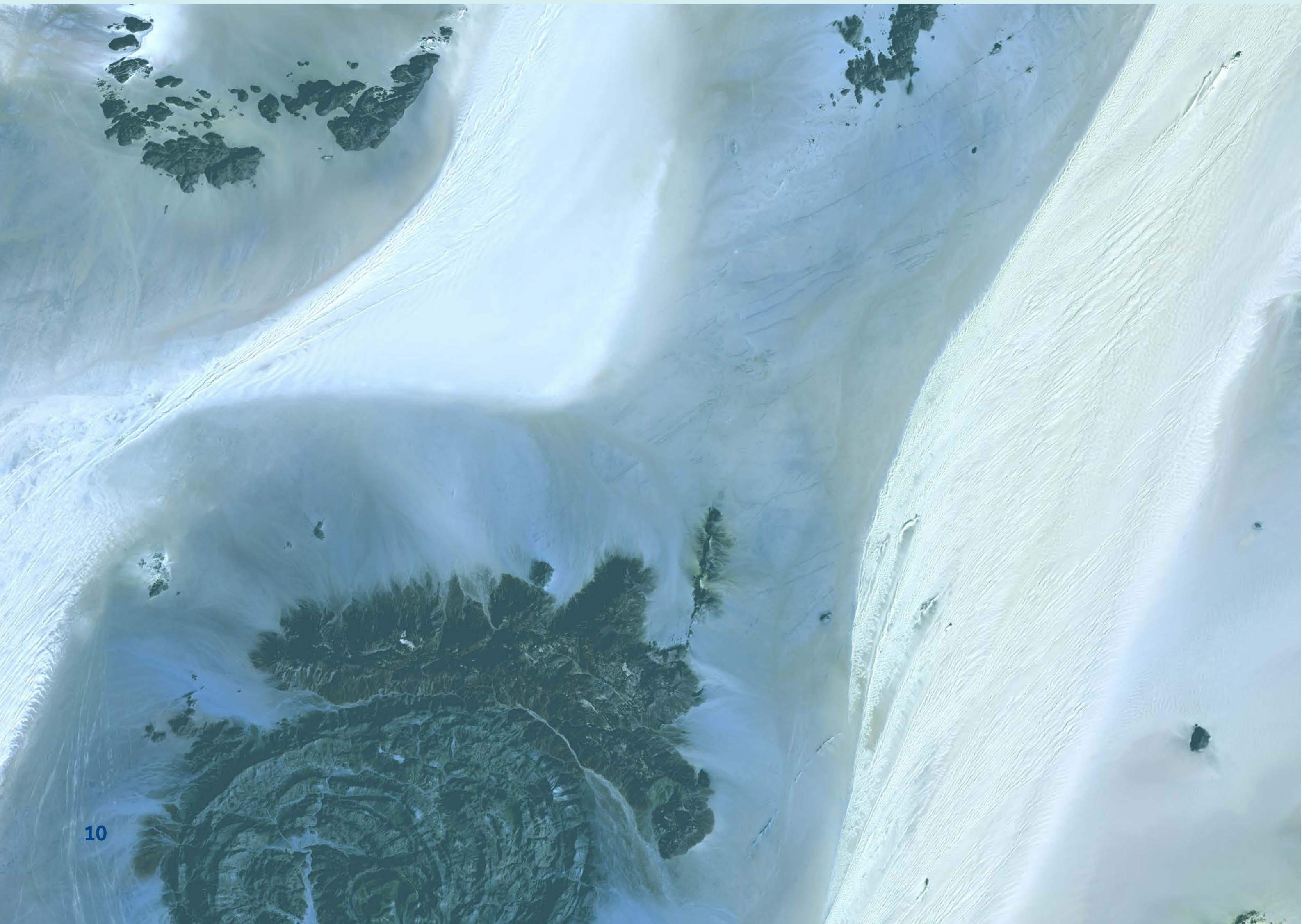
Sources: University of Oxford, IMF PortWatch, Allianz Research. Notes: Latest data September 2024. Bubble size are exports at risk in USDbn.

The share of trade at risk could increase by as much as +38% globally. As climate change intensifies the frequency of weather-related disasters, ports will face heightened vulnerabilities. To illustrate the systemic climate risks at the country trade level, we compare current trade risks at ports with projected risks for 2050 under various climate scenarios. We find that global export losses due to climate-related risks amount to USD226bn under scenarios aiming for net-zero emissions by 2050 and a temperature rise of 1.5°C, reflecting a +40% increase from present losses. As climate change progresses, ports are expected to experience even greater downtimes due to an increase in extreme weather events. This could lead to an additional +22% rise in exports at risk, bringing the total to USD275bn if warming is restricted to 1.8°C (RCP 2.6). In a more severe scenario where CO2 emissions double and warming reaches 4.4°C (RCP 8.5), export losses could escalate by as much as +38% compared to a +1.5°C world, totaling USD312bn. For major trading blocs, these projections indicate significant increases in trade losses and associated supply-chain spillover risks. In a 1.8°C world, China could face an additional loss of 16% compared to an increase to 1.5°C in 2050, bringing the export value at risk to USD54bn, while the US would see an additional loss of 13% to USD25bn and the EU27 of 39% to USD24bn (Figure 6). In the most extreme climate scenario, export at risk could reach USD59bn (+28%) for China and USD7bn (+23%) for the US. The EU would suffer the largest percentage impact, with potential trade losses rising by +62% to USD27bn.

Figure 6: Export value at risk from port downtime various climate scenarios, in USD bn



Sources: University of Oxford, IMF PortWatch, Allianz Research. Notes: Trade risk combines the country import and export flows at the port level with the annual expected downtime at ports due to climate risks. Climate scenarios are the IPCC RCP future scenarios for 2050.



Case study: Taiwan

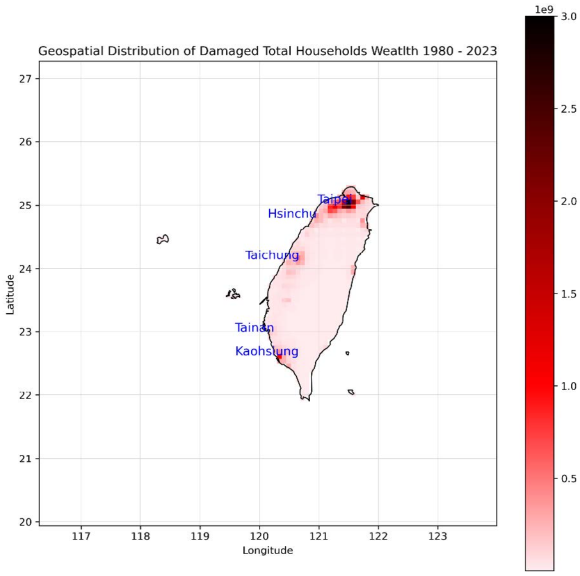
Taiwan stands as a significant focal point for the study of tropical cyclones due to its unique geopolitical, economic and environmental significance. This island nation, strategically located in the Western Pacific, usually experiences around three to four tropical cyclones (typhoons) on average annually, with some years marked by even higher frequencies. The topography of Taiwan, characterized by its mountainous terrain, exacerbates the impact of these cyclones, leading to significant rainfall, flooding and landslides. As a result, the Taiwanese economy is disproportionately affected by TCs compared to other high-income nations exposed to similar extreme weather events. Research indicates that for each additional 1°C increase in global temperatures, Taiwan's per capita economic growth suffers an average decline of -0.6%. This translates to significant financial losses, estimated at an average per capita of USD2,046 annually by the year 2100 under a business-as-usual scenario. These losses are substantial, representing the equivalent of 12 days' worth of household income based on 2019 data[9].

Moreover, Taiwan is a global leader in the semiconductor industry, producing over 60% of the world's microchips. This dominance in microchip production makes Taiwan an indispensable player in the global economy. In this context, disruptions caused by extreme weather events such as tropical cyclones can have far-reaching implications, affecting not only local industries but also global supply chains (Boxes 1 and 2). In addition, Taiwan's strategic location in East Asia, coupled with its economic prowess, positions it as a key geopolitical player. The island's stability and security are of paramount importance to major global economies, including the US and China. Understanding and mitigating the impact of tropical cyclones in Taiwan is therefore critical for maintaining regional stability and ensuring the continuity of global economic activities.

[9] https://www.nature.com/articles/s41467-023-43114-4

Figure 7 shows the distribution of damaged assets by TCs in Taiwan. The distribution indicates a concentration of damages around big cities, especially Taipei and Kaohsiung, which has significant implications for both the broader manufacturing sector and the microchip industry in particular. Taipei and its surrounding areas are home to a substantial portion of Taiwan's high-tech manufacturing facilities, including those of Taiwan Semiconductor Manufacturing Company (TSMC), the world's largest contract chipmaker. When typhoons strike this region, the resulting damage can disrupt production lines, delay shipments and cause financial losses in the microchip industry. These have already been observed in the aftermath of major earthquakes and drought events.

Figure 7 Geographical distribution of damaged total assets in Taiwan (1980 – 2023)



Source: CLIMADA, Allianz Research

At a larger scale, TCs have had a significant impact on Taiwan's population and economy. Between 1980 and 2023, 0.62% of Taiwan's population on average was directly affected by these severe weather events every year, resulting in an estimated USD26.2bn in annual damages to infrastructure, property and other assets. These figures underscore the substantial economic and human toll that TCs have historically imposed on the region. To better understand the potential future impacts of TC under varying climate change scenarios, we conducted a series of simulations using the CLIMADA framework[10]. These simulations were based on the historical tracks and intensities of past tropical cyclones and examined how these storms might behave under different RCPs. Specifically, we explored three RCP scenarios: RCP2.6, which assumes ambitious efforts to mitigate climate change; RCP4.5, a moderate scenario with some mitigation and RCP8.5, representing a „business-as-usual" pathway with minimal mitigation efforts. The simulations revealed that under constant socioeconomic conditions, the proportion of Taiwan's population exposed to tropical cyclones is expected to increase as we move from lower to higher emission scenarios. Under the RCP2.6 scenario, the percentage of the population affected by tropical cyclones remains relatively stable (0.69% yearly for the period 2024-2050). However, as we transition to the RCP4.5 and RCP8.5 scenarios, which assume progressively less ambitious mitigation efforts, the percentage of the population exposed to these extreme weather events rises notably. In the most extreme scenario, RCP8.5, the share of the population impacted by TCs is projected to reach 0.78% yearly for the period 2024-2050, reflecting the heightened vulnerability of Taiwan in a world with more intense and frequent cyclonic activity.

Furthermore, the economic impacts in terms of damaged assets increase significantly under more severe climate scenarios. Under the RCP2.6 scenario, the estimated damages amount to approximately USD1.1trn, representing a +12% increase compared to the historical period. However, under the RCP8.5 scenario, the damages could rise to around USD1.4trn, reflecting a substantial +40% increase compared to the historical baseline. These projections emphasize the escalating economic risks associated with climate inaction, and the urgent need for robust adaptation strategies to protect vulnerable regions like Taiwan from the growing threat of tropical cyclones.

[10] https://climada-python.readthedocs.io/en/stable/

Sectoral shockwaves: How Taiwan's economic sectors respond to tropical cyclones

Tropical cyclones have a profound impact on Taiwan's economy, affecting multiple sectors with varying degrees of severity. However, quantifying damages in certain sectors, particularly in terms of production losses, can be challenging due to the complexity and timing of the impacts. Some effects may not be immediately apparent but emerge over time, driven by disruptions in supply chains or shifts in demand. For instance, a tropical cyclone that damages key infrastructure or facilities in one sector could trigger widespread ripple effects, leading to significant production losses in other interconnected sectors. These cascading impacts can amplify the overall economic damage as industries reliant on affected suppliers face delays, increased costs or shortages. Additionally, changes in consumer behavior or reduced demand following a disaster can further exacerbate these indirect losses, making it even more difficult to fully assess the long-term economic toll on the affected sectors.

In the subsequent analysis, we employ a panel regression framework based on the methodology developed by Kunze et al. (2021) to evaluate the impact of tropical cyclones on the growth of various economic sectors in Taiwan. This model is designed to capture both the medium- and long-term effects of tropical cyclones on sector-specific per capita GDP (up to five years). By incorporating the share of people affected by tropical cyclones as an exogenous variable, the model allows us to quantify how these extreme weather events influence economic performance across different sectors over time.

Our analysis reveals that, with the exception of the construction sector, all economic sectors in Taiwan are projected to experience negative growth impacts due to TCs, particularly as the intensity of future events increases (see Figure 8a). For instance, under the RCP8.5 scenario, the mining and utilities sector emerges as the most vulnerable. By 2050, the sector's per capita GDP growth is expected to be 2.1pps lower compared to a scenario without climate change. Interestingly, the construction sector presents an anomaly, showing a positive growth effect initially, followed by a mild negative impact from 2030 onward. This positive effect can be attributed to the increased demand for rebuilding and reconstruction efforts following widespread property damage caused by TCs. As large-scale destruction necessitates significant construction activity, the sector temporarily benefits from the surge in demand, which offsets some of the broader economic downturns experienced by other sectors. However, as the frequency and severity of TCs increase, even the construction sector begins to feel the strain, leading to a more subdued growth outlook in the later years starting from 2027. By converting the per capita growth loss across all sectors into monetary terms (Figure 8b), the indirect economic costs attributed to tropical cyclones (TCs) are expected to accumulate to USD343bn under the RCP8.5 scenario (2024 – 2050), which is USD40bn more than the projected costs under the RCP2.6 scenario (USD304bn).

Figure 8a: Indirect economic loss driven by tropical cyclones in Taiwan: a) sector-specific per capita GDP growth decline under the RCP8.5 scenario, b) total monetized sector-specific indirect loss under three RCP scenarios

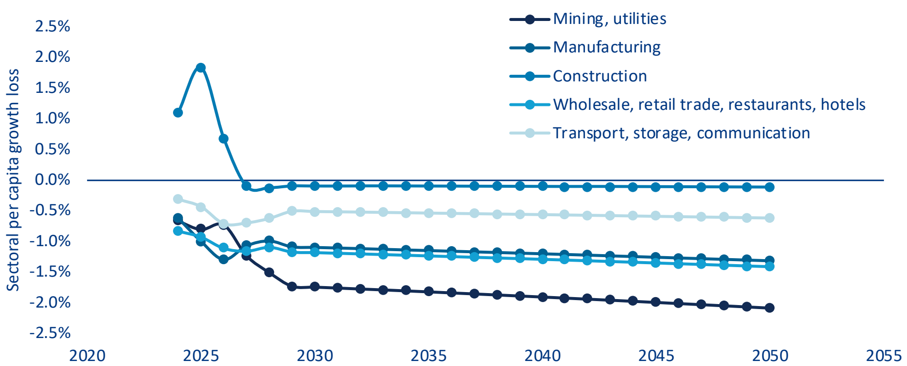
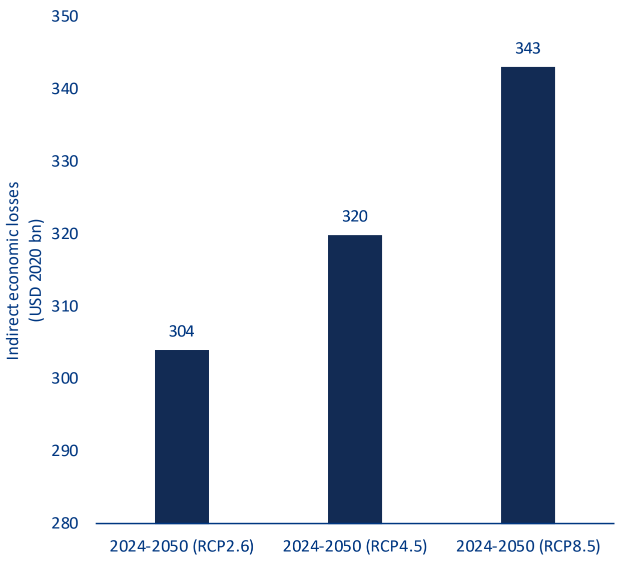


Figure 8b: .



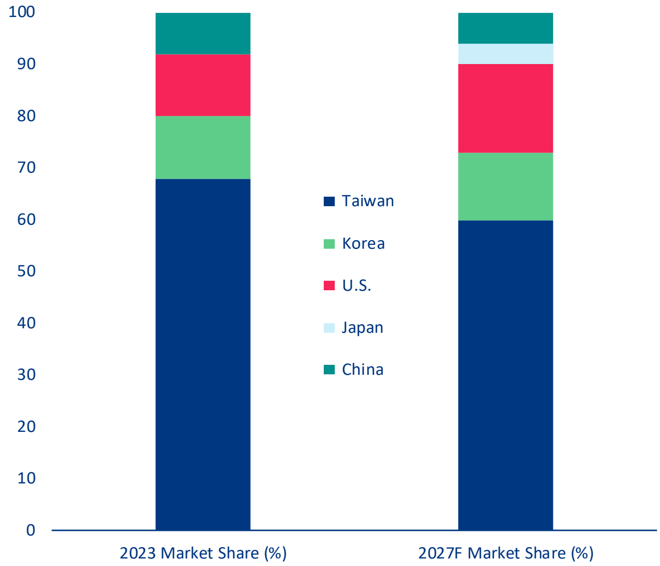
Sources: UNSD/NGFS/CLIMADA/Kunze et al. (2021), Allianz Research

The ripple effects of Taiwanese cyclones

TC-related disruptions in various sectors not only impact Taiwan's domestic production but also have far-reaching effects on global trade and supply chains (Boxes 1 and 2). With one of the highest trade-to-GDP ratios in the world, projected at 118% in 2024, Taiwan plays a vital role as a key supplier in the semiconductor industry with a current market share of 68% (Figure 9), as well as in other electronics, machinery and metals. In 2022 the economy exported about USD320bn in those sectors, accounting for roughly 72% of its total exports, which made it the 16th largest merchandise exporter in the world[11]. As a result, TC-related physical damages can adverse economic effects on industries and countries dependent on Taiwanese exports. For instance, even a brief shutdown of semiconductor plants due to infrastructure damage, power outages or supply chain interruptions could lead to substantial delays in chip production. This, in turn, would affect major technology companies which depend on timely deliveries of advanced semiconductors to power their devices. A supply disruption could result in production slowdowns, increased costs and delays in product launches, impacting global markets and industries that are deeply integrated into technology, from consumer electronics to automotive manufacturing.

[11] Taiwan's Trade: An Overview of Taiwan's Major Exporting Sectors (USITC)

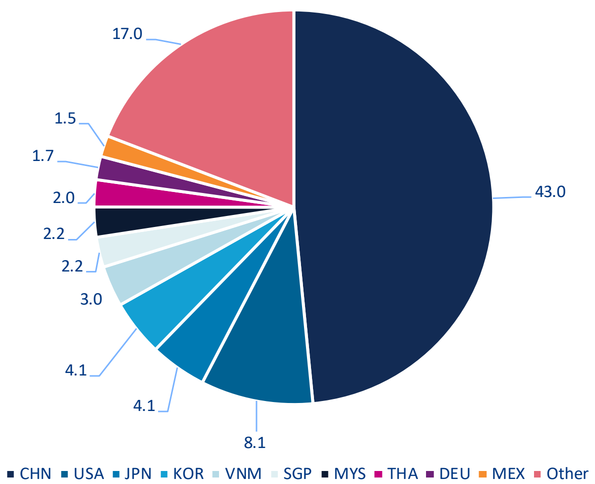
Figure 9: Advanced semiconductor market share (foundry capacity) by country (2023-2027f)



Sources: TrendForce (Dec 2023), Allianz Research

To analyze these effects, we employ a supply-driven input-output model (Ghosh 1958), which is used to evaluate the cascading impact of an initial disruption to the value added of Taiwanese sectors on the global economy via a multi-region input-output table. Our estimates suggest that cumulative external economic damages from TC-induced shocks could range from USD84.7bn (RCP2.6) to USD94.6bn (RCP8.5) by 2050[12]. Among Taiwan's largest trading partners, China faces the highest losses, accounting for almost 50% of the overall external losses. In a warming scenario of 1.1-2.6°C (RCP 4.5), China's potential cumulative losses could reach USD43bn, followed by the US at USD8.1bn and Japan and South Korea both at USD4.1bn (see Figure 10). In Europe, Germany is the most exposed to the consequences of Taiwanese tropical cyclones, potentially incurring over USD1.7bn in cumulative damages by 2050.

Figure 10: Cumulative external damages by country (2024-2050) (in USD bn)

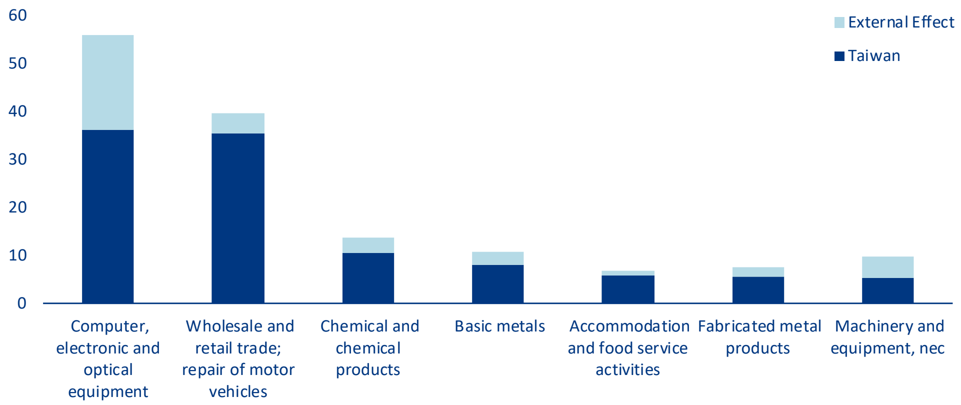


Sources: Allianz Research, OECD, Note: Impact analysis based on RCP4.5

[12] Note that in this analysis we abstract from sectoral growth effects and changes in international supply chains. While there are positive adaption effects that could lower overall losses, the growth potential of the international tech sector (specifically AI) suggests that the estimates constitute a lower bound to the potential losses.

At the sector level, the damages are primarily driven by losses in two key sectors: computer, electronic and optical equipment, as well as wholesale and retail trade, with combined external losses amounting to USD24bn (Figure 11). Notably, while Taiwanese companies bear the largest share of the overall economic burden, incurring almost 65% of the total TC-related damages, there is substantial external exposure. Sectors such as electrical equipment and motor vehicles, trailers and semitrailers all have an external damage share of more than 50%. This highlights a significant global exposure due to Taiwan's critical role, particularly in the technology supply chain (see Figure 12).

Figure 11: Cumulative external sector damage for downstream sectors between 2024-2050 (in USD bn)



Sources: Allianz Research, OECD, Note: Impact analysis based on RCP4.5

Figure 12: Cumulative external sector damage for most affected countries until 2050 (in USD mn)

	CHN	DEU	JPN	KOR	USA
Chemical and chemical products	-1666.0	-50.0	-188.0	-157.3	-228.9
Computer, electronic and optical equipment	-13702.7	-155.1	-199.0	-1255.0	-239.8
Construction	-2964.0	-93.1	-326.0	-204.3	-675.6
Electrical equipment	-2158.7	-91.6	-149.4	-170.0	-106.9
Machinery and equipment, nec	-2666.6	-167.4	-300.5	-225.0	-334.7
Motor vehicles, trailers and semi-trailers	-1619.5	-206.0	-456.2	-291.3	-842.2
Wholesale and retail trade; repair of motor vehicles	-1057.3	-79.0	-375.0	-110.1	-578.3

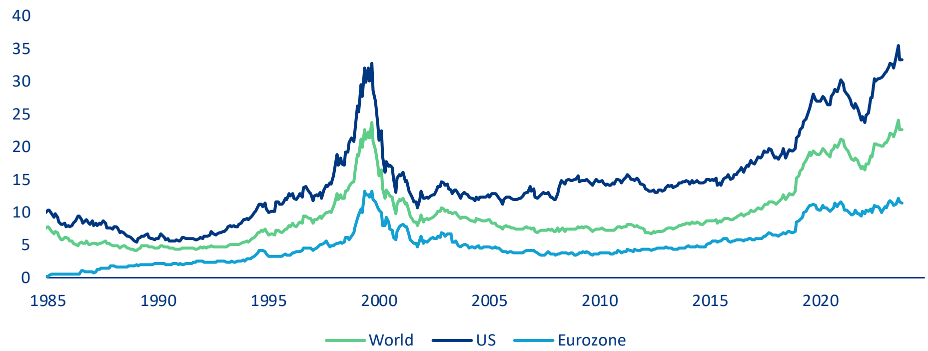
Sources: Allianz Research, OECD, Note: Impact analysis based on RCP4.5

Markets are highly sensitive to potential supply-chain disruptions

Market participants, especially on the equity side, tend to be extremely sensitive to events than can temporarily and structurally disrupt the functioning of a company's operations, whether they are caused by extreme weather events, geopolitical tensions, accidents or other factors. Investors and market participants closely monitor these risks as they can significantly impact a company's current and future financial performance. Any disruption can lead to sharp adjustments in pricing and valuation, reflecting the anticipated effects on sales, earnings, balance sheets and cash flows.

Coastal regions in East and Southeast Asia are highly vulnerable to cyclones, which can severely impact industrial sites located there. This is particularly concerning because about 80% of the world's semiconductor production is concentrated in this area. The heavy reliance on this cyclone-prone region for semiconductors is troubling for international investors. Since technology companies constitute a significant portion of global stock market indices, around 30% in the case of US equity indices, any supply-chain disruptions in the semiconductor sector due to cyclones could have a substantial immediate negative effect on global stock market performance (Figure 13). Of course, as a second-round effect, industries such as automotive, telecommunications and industrial sectors, which also depend on semiconductors, could experience knock-on effects, which would contribute to a more widespread market correction.

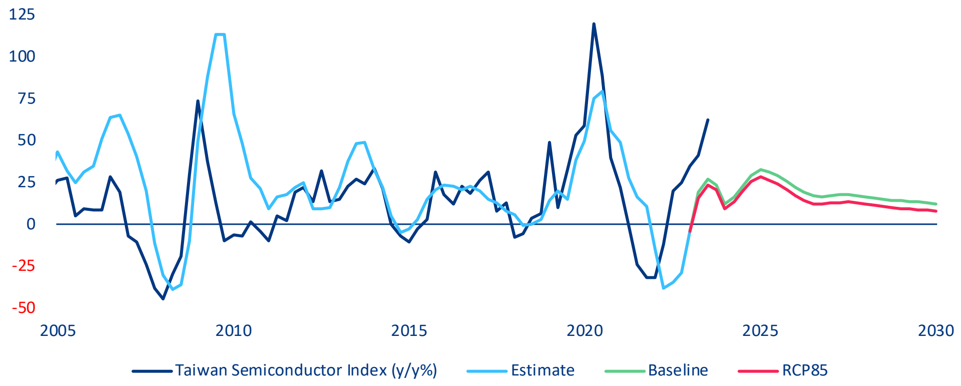
Figure 13: Technology sector weight within global equity indices (in %)



Sources: LSEG Datastream, Allianz Research

To understand how cyclones might impact future stock returns, we explored the relationship between the manufacturing GDP (under three different climate scenarios) and the Taiwanese semiconductor stock index. Our findings hint that over the forecast period of 2024 to 2050, the difference in expected annual equity returns between the baseline scenario (market consensus) and the most severe scenario (RCP85) is about 4%. This means that considering the expected decline in Taiwanese manufacturing growth as the sole predictor of stock performance, Taiwanese semiconductor companies' stocks could grow at approximately 8% per year in the long term under the baseline scenario while, under the most disruptive RCP85 scenario, the annual growth rate could decrease to around 4%, effectively halving future return expectations (Figure 14).

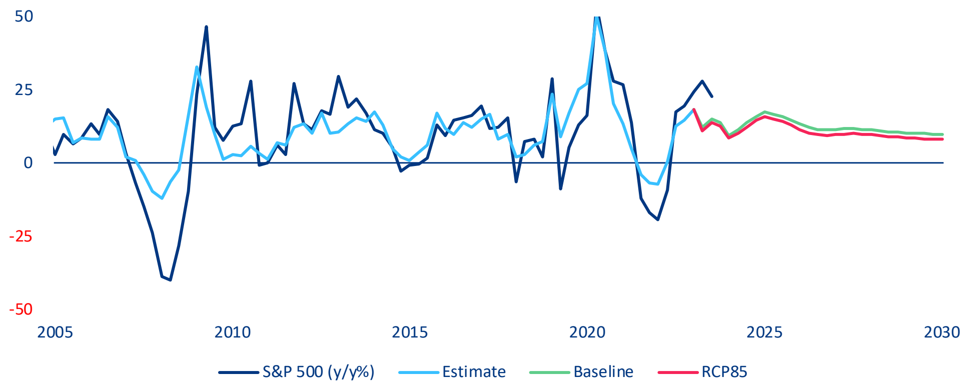
Figure 14: Taiwan semiconductor equity index under different climate scenarios (in y/y%)



Sources: LSEG Datastream, Allianz Research

Given Taiwan's small economy, it is surprising to see how its stock market could significantly impact global equity markets. However, as previously discussed, the quasi-dominance of Taiwan's semiconductor sector, combined with global equity indices' bias toward technology, suggests that Taiwan could have a substantial ripple effect on global equity return expectations. To assess the extent of this pass-through effect, we examine the relationship between Taiwan's semiconductor equity index and the S&P 500. Interestingly, this modeling approach confirms that the S&P 500's price returns can be predicted with relative accuracy using the Taiwanese semiconductor index as an input. With this in mind, and assuming the sectoral composition (e.g., bias toward technology) will persist, our estimation suggests that the impact of cyclones could reduce returns by 2pps in the RCP8.5 scenario, lowering long-term return expectations to approximately ~6% per year, compared to an implicit baseline of ~8% (Figure 15). As in the previous case, and despite our focus on the technology sector, it is important to bear in mind that if a typhoon causes prolonged production delays, chip shortages could likely lead to a broader global slowdown in manufacturing consumer electronics, vehicles, and even industrial equipment, adding additional downward pressure beyond just the technology sector.

Figure 15: S&P 500 under different cyclone scenarios (in y/y%)



Sources: LSEG Datastream, Allianz Research

Therefore, cyclones can significantly affect global equity markets, and their impact extends beyond immediate price corrections in technology companies and others that heavily rely on Taiwanese semiconductors. According to our analysis, the expected impact on equity returns could be more structural, potentially reducing future global equity market returns by about 2% without climate-mitigation efforts. Furthermore, this dependence underscores Taiwan's importance in international tech trade but also exposes the vulnerability of global value chains to physical climate risks. It also highlights the fragility of the global tech industry's reliance on a few key players for critical components, such as TSMC. Consequently, as observed in recent times, efforts are being made to mitigate these geographical concentration risks in the technology sector to reduce the inherent dependency on a geopolitically and climatically vulnerable location.

Building resilience

Climate adaptation

Without improved adaptation measures and enhanced resilience, the economic consequences of tropical cyclones are likely to escalate as these events become more frequent and intense. Research indicates the existence of a "resilience threshold toward extreme events" a critical point below which a country can absorb the impacts of such events with relatively minimal disruption to its economy and society. However, once this threshold is exceeded, the human and economic toll rises sharply[13].

As climate change intensifies the frequency and severity of extreme events, such as tropical cyclones, more countries will see their resilience thresholds being surpassed, leading to increasingly severe economic damage. The strain of these repeated events can weaken a nation's ability to cope with future hazards, reducing its fiscal resources and stretching the capacity of the insurance sector (Box 3). Over time, this could cause the resilience threshold to decline, making even less severe events more economically damaging. Investing in adaptation measures – such as improved infrastructure, early warning systems financial safety nets, and nature-based solutions (Box 4) – can help mitigate the economic costs associated with tropical cyclones and potentially raise a country's resilience threshold. By doing so, cyclone-prone nations can better manage the growing risks posed by climate-related TCs and avoid the compounding economic and social costs of being repeatedly overwhelmed by such events.

National Adaptation Plans (NAPs) under the UNFCCC are critical tools for adapting to the growing impacts of climate change, particularly for vulnerable countries. As of 2023, 140 countries have either started or submitted their NAPs, highlighting the increasing importance of adaptation in the global climate agenda. During COP negotiations, these plans are at the forefront of discussions, particularly in relation to financing, as developing countries seek the estimated USD140bn to

[13] https://www.ngfs.net/sites/default/files/medias/documents/ngfs_acute_physical_impacts_from_climate_change_and_monetary_policy.pdf

USD300bn needed annually by 2030 for adaptation efforts (USD280bn to USD500bn by 2050). One key success of NAPs in COP discussions are initiatives such as the Adaptation Fund reaching USD356mn in pledges at COP26. In addition to advocating for increased adaptation finance during COP discussions, NAPs provide developing countries with a platform to present their strategies for reducing climate vulnerability and avoiding maladaptation. They help ensure the seamless integration of climate-change adaptation into both new and existing policies, programs and activities, particularly within development-planning processes. By aligning adaptation efforts across all relevant sectors and levels of governance, NAPs enable countries to build resilience in a more coordinated and effective manner, addressing climate risks while supporting sustainable development goals.

Box 3: The role of insurance in mitigating economic damages from tropical cyclones

Disruptions to value chains can create huge risks – also for the insurance sector. The interdependencies can lead to an accumulation of losses that trigger claims in many lines of business, from business interruption to property damage and liability. Therefore, the insurance sector has an inherent interest in making value chains more resilient. Operational resilience is the key. It is not just about business continuity, i.e. restoring the status quo after an interruption, but also about continuous improvement and adaptation.

Insurance is a natural partner as a product provider that offers financial compensation after an interruption, but above all as a risk advisor that is already active beforehand. This implies a change of the insurance industry's business model: away from a simple product logic focused on financial compensation towards comprehensive solutions for risk mitigation and prevention, for managing adaptation, mitigation and resilience measures. The result is long-term partnerships for shared expertise and better understanding of risk. In many cases, however, the best risk protection is reducing exposure by avoiding building in high-risk areas (or relocating existing facilities). The past increase in losses from natural catastrophes is only to a smaller extent due to their increasing number and severity; the main driver is the strong growth in assets in the affected areas. This trend has to be reversed. In that, risk-adequate premiums have an important role to play as risk-signals. The non-disclosure of risks through artificially low premiums would only create false incentives, leading to inadequate adaptation measures.

The risk-management instruments remain the same, but their application is becoming more challenging in view of the strong interconnectedness. Better risk modeling is key although it could remain inadequate in view of the cumulative effects; further steps include better data collection and a more intensive exchange of information. Pooling risks and transferring risks to the capital markets are also ways of increasing the insurability of risks. Nevertheless, massive disasters could lead to losses that exceed the limits of insurability. Therefore, besides innovative insurance solutions like parametric insurance, public-private partnerships are also needed, with the state assuming the role of „reinsurer of last resort", acting as a backstop in the event of a loss that exceeds the capacity of the insurance sector. This ensures that risks can continue to be insured and insurance cover remains accessible and affordable.

Box 4: Nature-based solutions for adapting to tropical cyclones: rebuilding resilience and restoring biodiversity

Nature-based adaptations to tropical cyclones offer a sustainable and effective way to protect communities and ecosystems from the increasing intensity of storms. By harnessing the power of natural systems, these approaches not only mitigate damage from tropical cyclones but also provide a range of long-term benefits to both the environment and society.

Mangroves, for instance, play a crucial role in shielding coastlines from the destructive forces of cyclones. Acting as natural buffers, they absorb storm surges and reduce the intensity of waves and wind. The dense root networks of mangroves help stabilize shorelines and prevent erosion. With the restoration of mangroves for coastal protection, the share of people protected in TC-prone countries can increase by up to 39%.

Similarly, coral reefs provide a natural barrier against storm surges. By dissipating up to 97% of wave energy, these ecosystems help to reduce the impact of tropical cyclones on coastal areas. Restoration efforts have demonstrated that healthy coral reefs can dramatically lower the risks of flooding and erosion, helping communities withstand the effects of more frequent and severe storms.

Wetlands – complex ecosystems comprised of swamp, marsh or coastal woodland – also play a vital role in reducing flood risks. Acting as natural sponges, wetlands absorb excess water from storm surges and heavy rainfall, protecting low-lying areas from flooding. Wetlands in Mississippi and Texas, for example, are among the top five most valuable in the nation, providing storm protection valued at over USD5,000 per acre each year.

In addition to these coastal ecosystems, natural defences such as sand dunes provide essential protection from tropical cyclones. Coastal sand dunes act as a physical barrier, absorbing storm surges and reducing the risk of inland flooding. Other approaches, such as living shorelines and seagrass bed restoration, provide adaptable, long-term solutions. Living shorelines, which use natural materials like plants and shellfish beds, grow and strengthen over time, offering dynamic protection against erosion while preserving habitats. In addition to their adaptation power, living shorelines store carbon dioxide, which contribute in mitigate climate change. Seagrass beds, meanwhile, stabilize the seabed and act as buffers against storm surges, reducing the vulnerability of coastal communities while improving water quality and supporting local fisheries.

These nature-based adaptations offer broader benefits beyond immediate cyclone protection. They are often more cost-effective than traditional engineering solutions and require less maintenance over time. Additionally, they enhance biodiversity, improve water quality, and provide economic opportunities, particularly in coastal and rural communities. As these systems grow and adapt over time, they become more resilient, offering greater protection against extreme hydro-meteorological events and acting as effective climate regulation ecosystem services.

Climate mitigation

While adaptation measures can reduce impacts of extreme events, they are not sufficient on their own. The *'resilience threshold toward extreme events'*, the point at which a country can no longer absorb the economic and social shocks of such disasters, can be surpassed when extreme events occur frequently and in quick succession. A recent example of this is the major flood in Vermont, which followed just weeks after Hurricane Beryl, demonstrating the compounded pressure that back-to-back disasters place on affected areas. Such overlapping events highlight the need for robust mitigation efforts alongside adaptation strategies, through limiting global warming to prevent overwhelming economic and social disruption. By limiting global warming to 1.5°C, the likelihood of mitigating the worst impacts of TCs increases, reducing the associated economic damages and safeguarding the stability of global markets. According to Burke et al. (2018)[14], limiting global warming to 1.5°C, compared to 2°C, would significantly reduce economic damages. Their analysis further indicates a greater than 60% probability that the cumulative global economic benefits of staying within the 1.5°C threshold would exceed USD20trn, based on a 3% discount rate.

An ambitious social cost of carbon (SCC), reflected through carbon pricing, is crucial to achieving effective climate-change mitigation. The SCC represents the estimated economic cost of the damage caused by emitting one additional ton of carbon dioxide into the atmosphere. By setting a high and accurately calculated carbon price, policymakers can internalize the environmental costs of emissions, ensuring that businesses and consumers account for the true impact of their carbon footprint in economic decisions. Current estimates of the SCC have faced significant criticism for being too conservative and not fully capturing the wide-ranging impacts of climate change, particularly with regard to extreme weather events. Traditionally, SCC calculations focus on the long-term economic effects of rising global temperatures. However, this narrow approach fails to adequately account for the role of climate change in exacerbating extreme events like tropical cyclones, floods and wildfires, which cause severe economic and social disruption. As climate-attribution science increasingly links extreme weather events to anthropogenic climate change, it becomes clear that these events are critically underrepresented in carbon-pricing models.

A recent meta-analysis of 207 studies, encompassing more than 5,000 SCC estimates, shows that the median SCC has quadrupled over the past decade. This sharp increase reflects a growing recognition of the escalating costs of climate change. Yet even these updated estimates are criticized for not fully accounting for the economic toll of extreme weather events driven by climate change. Even the most current SCC estimates remain largely temperature-driven, neglecting the substantial, and often far more immediate, damages caused by climate-induced disasters.

In the analysis of *'What's Missed in the Social Cost of Carbon'*, it is evident that carbon pricing must be adjusted to account for damages that are difficult to monetize, such as extreme weather events, biodiversity loss, ocean acidification and catastrophic events like conflicts and migration. Krichene et al. (2023)[15] demonstrate the significant impact of including tropical cyclones in SCC estimates, showing a +22.2% increase in the global social cost of carbon, and an even higher increase of +44.4% in tropical cyclone-affected countries. This adjustment raises the median SCC of TC-prone nations from USD173 to USD212 per ton of CO2, underscoring the need for a more comprehensive approach to carbon pricing that better reflects the full scope of climate-related damages.

Incorporating the attribution of extreme events into SCC calculations is essential for several reasons. First, it ensures a more comprehensive and accurate assessment of the true costs of carbon emissions, covering both gradual warming impacts and the more acute damages from extreme weather events, such as tropical cyclones discussed in the current report. Second, by recognizing the attribution of climate change in the more frequent and intensive extreme events, more ambitious mitigation measures will be implemented as it would drive carbon prices higher, creating stronger financial incentives for reducing emissions and accelerating the transition to renewable energy and climate-resilient infrastructure.

[14] https://www.nature.com/articles/s41586-018-0071-9
[15] https://www.nature.com/articles/s41467-023-43114-4

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