

The private sector's climate change risk and adaptation blind spots

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The private sector is already experiencing the impacts of climate change, from increased operational costs to disrupted production. Investors are increasingly asking companies to disclose these risks as the physical consequences of climate change become financially material. In reviewing more than 1,600 corporate adaptation strategies, we find significant blind spots in companies' assessments of climate change impacts and in their development of strategies for managing them. Adaptation approaches that consider broader climate change risks to supply chains, customers and employees, and that integrate ecosystem-based strategies, could limit the 'tragedy of the horizon' characterized by inadequate and too-late action.

Climate change poses considerable risk to the private sector globally. Companies are already experiencing the effects of a changing climate^{1–5}, with the World Economic Forum's annual survey of business and government leaders naming “the failure of climate change mitigation and adaptation” among the most likely and impactful risks to business in 2018⁶. These physical risks manifest in both acute hazards (such as tropical storms experienced over one or several days) and chronic impacts (an increase in the number of extreme heat days experienced as a changing average over decades, for example). Harm to a business may arise through interruptions associated with plant shutdowns or logistics issues, increased operational costs due to rising heating/cooling or water treatment costs, reduced stock prices associated with compromised assets and many other impacts¹.

There is a growing concern among the investment community — the managers of US\$143 trillion⁷ held outside banks worldwide — that companies are not accurately characterizing climate change risk in their reporting nor adequately preparing for its physical impacts. Estimates of the impact of climate change on the financial sector range from US\$2.5–24.2 trillion⁸, whereas valuations of risk to manageable assets range from US\$4.2–43.0 trillion in net present value terms, depending on discount rates used⁷. Yet the financial disclosures of major companies give little inkling that up to 30% of manageable assets globally may be at risk. Although most of the world's largest economies require companies to report on GHG emissions, reporting on risks is typically ‘encouraged’ rather than required⁹. In practice, few companies report on climate change risks and risk-management strategies through mainstream financial filings^{10,11}, despite the physical consequences of climate change being of interest to any ‘reasonable’ investor¹². While marginal investors are sophisticated in pricing risk and financial markets do reflect environmental risk in the cost of capital¹³ and corporate bond ratings¹⁴, institutional investors are increasingly seeing climate change risk as a blind spot.

Recognizing that companies may be underestimating climate change risk and underreporting it to the investors underwriting their assets and activities, in September 2015, Mark Carney (the Chairman of the Financial Stability Board; FSB), gave a keynote address to Lloyd's of London citing climate change as the “tragedy of the horizon”¹⁵. As the head of the international body established

to make recommendations about the global financial system, he highlighted the mismatch between the short-term nature of financial decision-making and the long-term impacts of climate change. The ‘tragedy’ is that by the time climate change “becomes a defining issue for financial stability, it may already be too late”¹⁵. This speech precipitated the creation, in December 2015, of the FSB's Task Force on Climate-related Financial Disclosures (TCFD), which aimed to develop guidelines for companies to report the financial implications of climate risks. In June 2017, the TCFD recommended that companies disclose actual and potential impacts of climate change on their business, as well as risk management processes, metrics and targets. Although these recommendations draw on existing disclosure frameworks, they are important primarily because of their high-profile messenger (the FSB) and their intent to supersede existing frameworks. The TCFD delineates climate change risk into two major categories: the transition risks of shifting to a lower-carbon economy and the physical risks of climate change itself¹⁶.

Here, we survey the current state of corporate disclosures, focusing on physical climate change risks as they have generally received less scrutiny than transition risks, which are more likely to fall within a corporation's traditional strategies of preparing for shifts in markets or regulations. We use responses to CDP's climate change questionnaire, the only global disclosure framework that specifically asks companies to report on climate risk management strategies^{16,17}. So far, analyses of the business costs of climate change have quantified the value of financial assets at risk due to physical impacts^{7,8}, evaluated the impact of carbon pricing on specific industries^{18–20} and identified stranded assets^{21,22}. Several previous studies have drawn on subsets of CDP adaptation data, for example to explore responses from companies comprising the S&P Global 100 Index²³ or oil and gas companies²⁴. Our empirical analysis includes all voluntary disclosures to investors on climate risk management in a given reporting year, 2016 (the most recent year available at the time of writing). These data focus on the subset of the private sector composed of large companies with public debt or equity, a total of 1,630 companies, many of them multinational corporations with global operations.

Through content analysis of these disclosures, we develop a novel typology of corporate adaptation strategies, assess the frequency with which private-sector actors are implementing different

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strategies and assess the extent to which companies are disclosing costs of climate risks and adaptation. By comparing the needs for private-sector adaptation identified in the literature with the current reporting of a significant portion of the world's largest companies, we identify key private-sector blind spots — the gaps between needs and current actions.

Current company disclosures on climate risk and adaptation

In 2016, CDP collected voluntary public disclosures on physical climate change risks from 1,959 companies representing 69% of global market capitalization²⁵. Among the respondents (see the Supplementary Information for a breakdown by sector and geography), 1,630 companies (83% of total respondents) disclosed the physical climate change risks they faced in the reporting year, as well as the potential business impacts of those risks, the estimated financial implications, the 'management method' implemented to deal with risks and the cost of that adaptation. The most common physical climate risks reported were changes in precipitation extremes and droughts (46% of companies), tropical cyclones (26%), changes in temperature extremes (25%), changes in average temperatures (25%) and changes in precipitation patterns (19%). Companies described 67% of these risks as 'more likely than not' to 'virtually certain' to occur, up from 50% in 2013 and 34% in 2011¹, reflecting increasing acknowledgement of climate change impacts. More than half of reporting companies expect that climate change will increase their operational costs (56%) and/or reduce or disrupt production capacity (52%); 17% report that at least one identified climate risk could result in an 'inability to do business' for a particular geography or time period.

Managing the impacts of increased climate risk, hereafter simply 'adaptation', is critical for businesses themselves but also crucial for the producers that depend on private-sector markets, the consumers that depend on privately produced goods and services, and the employees that depend on companies for their livelihoods. So what does climate change adaptation in the private sector look like?

A universally accepted typology of adaptation actions does not exist, and few efforts to categorize adaptation actions by intervention type²⁶, investment type²⁷, or descriptors such as intent and spatial scope²⁸ have focused on private-sector actions. The few studies that do have only collected case studies and best practices^{29,30} or assessed adaptation strategies for select sectors, including energy and utilities^{3,31}, oil and gas^{5,24}, mining⁴, insurance³² and transportation³³. There has been no comprehensive analysis of companies' climate adaptation strategies across a broad range of sectors and geographies.

To address that gap, we used content analysis to explore and synthesize 1,630 companies' adaptation strategies, reported as textual responses to CDP. First, we assessed whether company-reported adaptation actions fitted under the overarching categories of 'soft', 'hard' and 'ecosystem-based' approaches as identified by Jones et al.³⁴ (level 1 categorization). In the context of private-sector adaptation, we consider that:

- Soft adaptation approaches include planning and de-risking processes, finance, knowledge generation and information flows, human resources development, and/or supply chain measures, as substantive yet physically intangible responses to climate impacts.
- Hard adaptation approaches encompass capital investments in technology or engineered infrastructure, including built structures.
- Ecosystem-based adaptation (EbA) approaches include the sustainable management, conservation and restoration of ecosystems as part of an overall adaptation strategy³⁵.

We found that these three broad categories capture most private-sector adaptation actions and align well with approaches identified

by the companies themselves. Soft approaches were by far the most common, used by 76% of the 1,630 companies that reported one or more climate risks, while nearly half (47%) of companies used hard approaches and only a small percentage (3.3%) implemented EbA (Fig. 1). These categories are not mutually exclusive and the most common configuration was companies implementing one or more soft and hard approaches together. Notably, 299 companies, or 18% of respondents that reported facing a physical climate risk, did not disclose any adaptation strategy.

We then added two layers of categorization to reveal the breakdown of private-sector-specific strategies within those three broad categories. These additional layers were derived from an inductive coding process that involved analysing the more than 3,000 textual disclosures from companies, summarizing each in a few words and iterating until we arrived at short descriptions that captured the range of reported adaptation strategies (see the Supplementary Information). In total, we delineated 39 distinct soft strategies (such as reinsurance/risk transfer, early warning systems, improved logistics), 45 hard strategies (air conditioning installation, building retrofits, back-up power installation) and 18 EbA strategies (grasslands restoration, coastal ecosystem management). These 102 strategies represent a comprehensive categorization of private-sector adaptation actions (that is, level 3), which (for ease of summary and presentation) we then consolidated into six soft, six hard and four EbA 'themes' (level 2), as illustrated in Fig. 2.

Among soft strategies, planning and knowledge generation and information flows were the most common themes (containing 25% and 19% of strategies, respectively), reflecting in part a focus on maintaining business continuity through disruptive climatic events. For example, Kuehne + Nagel, a Swiss transportation company, revised its Emergency Response and Preparedness Plan and created a new annual budget allocation for facilities to anticipate operations disruption due to hurricanes. In many cases, knowledge generation activities such as risk assessment, research and development, and ongoing monitoring served as a precursor for investment in hard infrastructure. Citing climate model projections of significant changes in precipitation patterns in sub-Saharan Africa, South African mining company Anglo American Platinum started modelling changes in its water supply over the next 20 years and made capital investments in water infrastructure to adapt to these changes. In this way, companies may move along a continuum towards more proactive adaptation.

Among hard strategies, water infrastructure and energy infrastructure strategies were the most common themes (containing 30% and 25% of strategies, respectively) as they included investments that often make business sense for multiple reasons, such as energy efficiency installations, flood infrastructure and improved drainage systems. For example, Alphabet Inc. (Google's parent company) reported to investors that efficiency upgrades would help them respond to increased cooling needs in data centres. Companies also often used soft and hard strategies together as complementary approaches that address different aspects of climate impacts. For example, the Japanese technology company Hitachi factors flood risk into its facility siting, a soft strategy, but also implements hard preventative measures such as installing bulkheads to mitigate flooding.

Although EbA strategies were only rarely used overall (just over 3% of all strategies), the most prominent themes within this approach were sustainable agriculture, watershed protection and restoration, and sustainable forest management. For example, in response to a national climate study that projected declining precipitation in its watershed, Colombian utility Celsia SA supported hundreds of hectares of forest restoration upstream of its hydroelectric plants in hopes of regulating runoff and reducing siltation to their dams. EbA was almost always used in concert with soft and/or hard adaptation approaches (Fig. 1). Facing potential climate change impacts on raw materials supply, Swiss flavours and

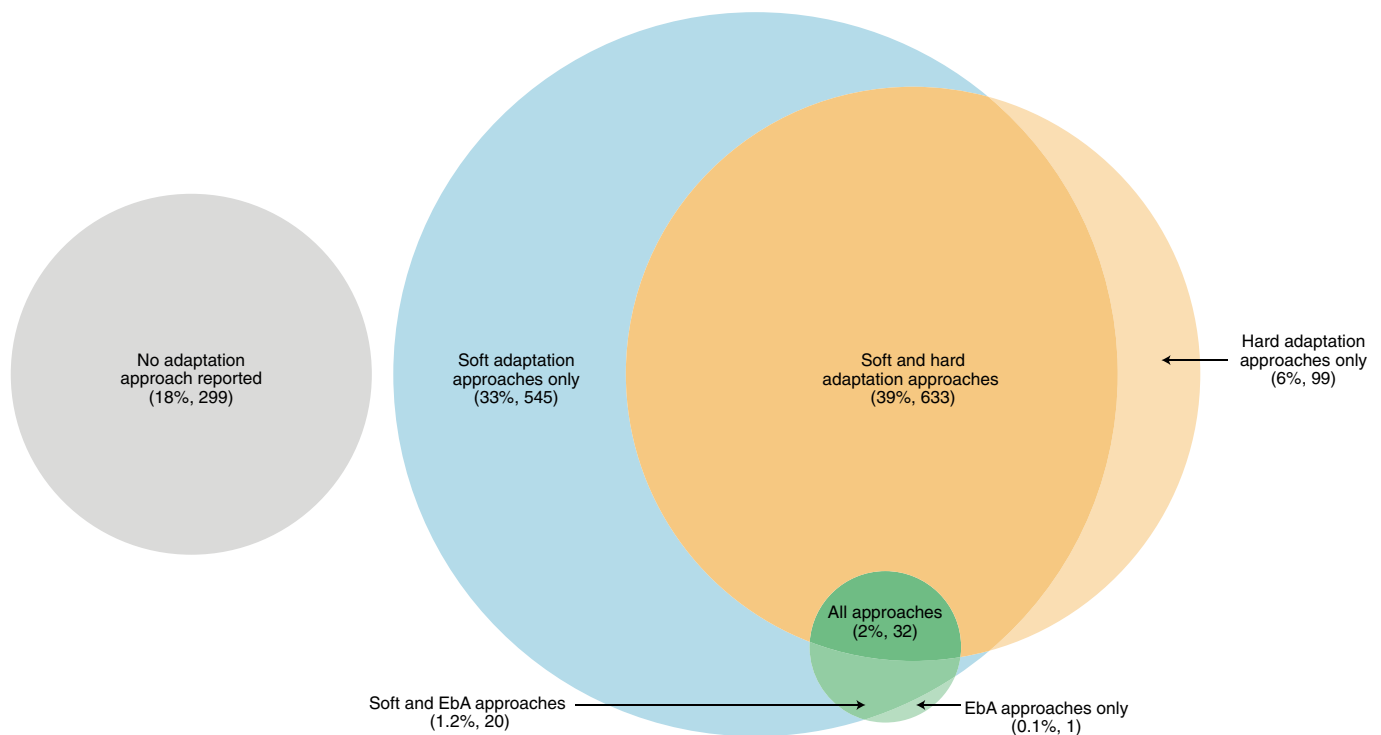


Fig. 1 | Relative use of soft, hard and EbA approaches among companies. Total of 1,630 companies reporting (percentages and counts of companies are given in parentheses). Data relate to adaptation actions undertaken before the reporting period in 2016.

fragrances company Givaudan implemented an EbA approach by creating conservation agreements with Venezuelan farmers, paying communities to preserve the local environment while also securing the company's tonka bean supply from these producers, to be used in luxury fragrances. In conjunction with this approach, Givaudan created alternative ingredient production plans (a soft strategy) and began increasing production of synthetic materials (a hard strategy).

These results find a strong echo in existing sector-specific reviews from industry groups^{2,4}, as well as earlier studies of subsets of CDP disclosures²³. However, because our typology is extracted from more than 1,600 company narratives, it represents a more comprehensive snapshot of corporate adaptation strategies.

Key blind spots

The premise of the TCFD recommendations is that companies may not be accurately capturing the magnitude and implications of climate change risk in disclosures to investors and, further, that they may be doing too little too late to prepare for these risks. Although our analysis finds that many companies are in fact trying to incorporate climate change into core risk management practices, with some reporting both risks and risk management strategies in detail, it also reveals that the TCFD's supposition is largely accurate. Comparing companies' disclosures with the climate risks and adaptation needs documented in the literature reveals five key blind spots.

The magnitude and costs of physical climate change risks. Most global estimates predict that the price tag of climate change will run into the trillions of dollars in terms of its negative impact on manageable assets^{8,36,37}. In contrast, our analysis finds that the aggregate financial risk reported through corporate disclosures runs only in the tens of billions, a discrepancy of at least two orders of magnitude. This reflects both that a large number of companies do not report financial impacts and that many that do are probably underestimating them. Content analysis of the CDP cost disclosures highlights how assessing even the passive costs (costs incurred absent

of any management action) is challenging. We find that companies reported quantitatively to investors only 21% of the time, and that responses varied widely in terms of reporting units (from increased insurance premiums to raw material pricing) and timeframes (from hourly facility shutdown costs to decades-long impacts). Examples of the financial implications reported by companies illustrate the varied types of costs reported, and demonstrate why aggregating these values is difficult (Table 1). Companies clearly need further guidance on estimating the costs of physical climate change impacts, particularly in using scenario analysis to derive cost ranges for risks that, if not addressed, could require longer-term shifts in everything from product design and customer acquisition to the location of built assets and the configuration of global supply chains.

Climate change risks and adaptation strategies 'beyond the fence-line'. Climate change risks to business extend far beyond direct operations, affecting corporate supply chains, employees and customers. For example, one global study found that climate change could reduce average incomes by 23% by 2100³⁸, while another estimated that, without welfare, climate change impacts would reduce the consumption of goods and services by 5–20% per person³⁶. Although this would substantially dampen demand for goods and services globally, fewer than 3% of companies indicated that climate change would impact their business through 'wider social disadvantages'. Of the physical climate risks companies disclosed to investors in the CDP data, 76% were considered direct, 15% were incurred in the company's supply chains and only 8% affected their clients. This narrow view of risk often led to narrowly focused adaptation strategies. For instance, 58 companies chose to shift production location due to climate change. While this may be an effective short-term risk management strategy, it abandons producers in the affected location, and it works for the company only as long as there is a new location to move to. Many companies' myopic perspectives make it difficult for investors to assess when companies may be undermining wider societal adaptation³⁹.

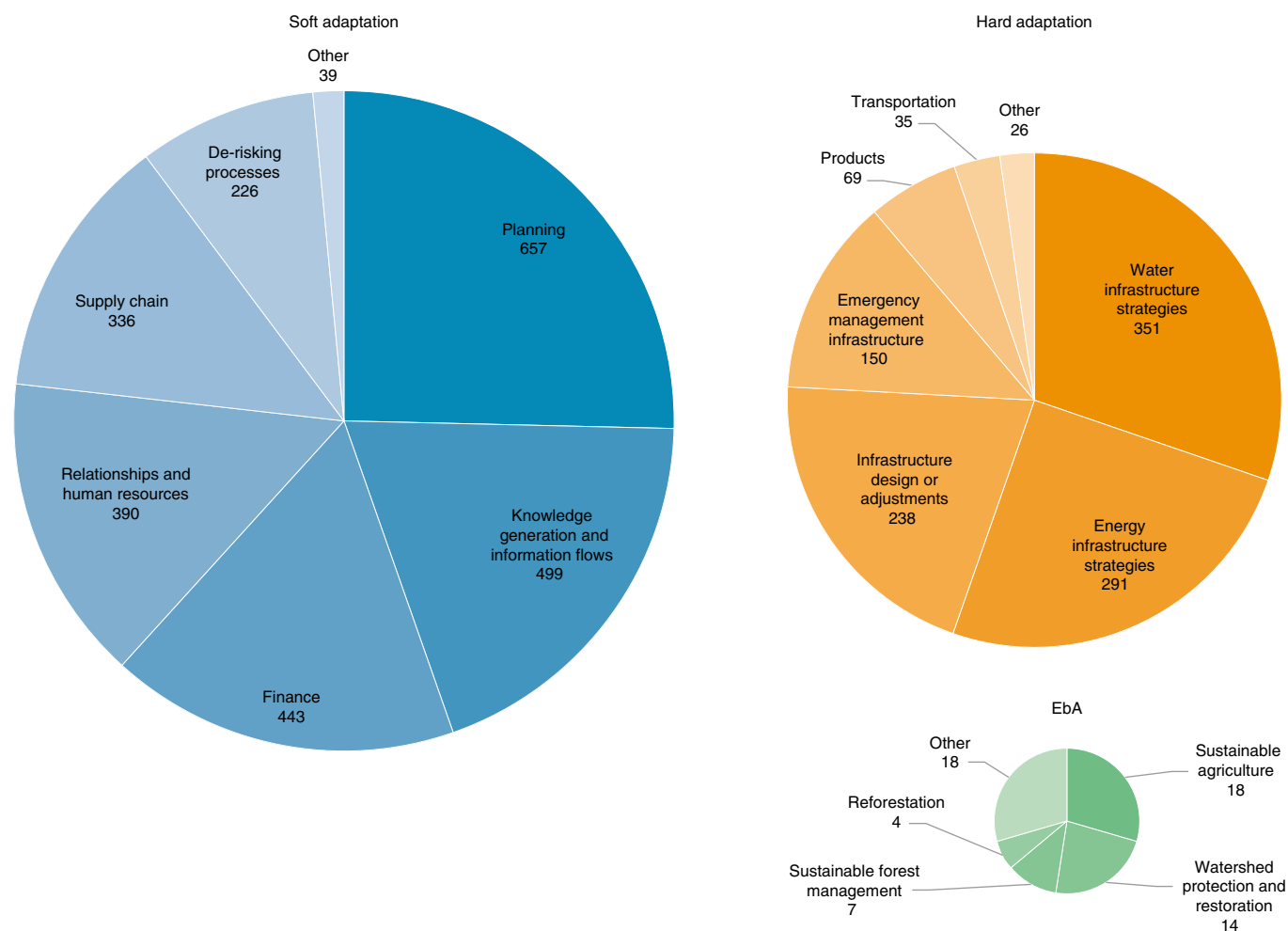


Fig. 2 | Typology of soft, hard and EbA private-sector themes. A total of 1,230 companies reported 2,590 instances of soft adaptation across six main themes, 765 companies reported 1,160 instances of hard adaptation across six themes and 54 companies reported 61 instances of EbA across four themes. The size of the circles represents the relative use of soft, hard and EbA approaches overall, as reflected in Fig. 1. The full typology of strategies is available in Supplementary Table 1.

The potential for EbA. Recent evidence identifies substantial potential for ecosystem conservation, restoration and sustainable management to reduce various physical impacts of climate change to business^{40–42}, alone or in combination with hard and soft adaptation measures. EbA approaches are potentially even more germane as companies increasingly understand their dependence on nature, from the hydropower company that relies on upstream cloud forests for water generation, to the pharmaceuticals company that relies on biodiversity for new drug discovery. Appropriate protection and management of ecosystems could serve as a form of insurance against future climate change risks. EbA may be especially prudent given that the refinement of future climate projections⁴³ has not necessarily led to reduced uncertainty, so ‘low regrets’ adaptation strategies that are effective under a range of future climate scenarios are needed⁴⁴. For example, as a strategy to protect coastal assets, restored dune or mangrove ecosystems can autonomously migrate inland over time (assuming they are not physically blocked by development) as sea levels rise, offering flexibility in contrast to immovable structures such as seawalls⁴⁵. Furthermore, whereas hard infrastructure seldom provides benefits beyond its specific purpose, EbA interventions often provide co-benefits, including carbon sequestration, biodiversity conservation, enhanced community livelihoods, improved water quality and recreational benefits^{46–48}. Yet our analysis shows that companies rarely used EbA to

manage climate risk, with just 54 (3.3%) including EbA within their mix of strategies.

The costs of adaptation. Global estimates of the current scale of private-sector adaptation finance and needs remain elusive^{49,50}, and current company disclosures to investors do not provide much illumination. CDP respondents reported the ‘management costs’ of their climate risk management strategies only 27% of the time. However, because most reported investments make business sense even in the absence of climate risk, these disclosures of climate risk management costs do not necessarily represent additional expenditures on adaptation, which is the metric of interest to investors asking for this disclosure. Management costs also ranged so widely in scope, from the incremental costs of building retrofits to setting up community disaster relief funds, and timeframe, from one-time investments to annual ones, that (as in blind spot 1) a summed figure is meaningless (Table 2). Reported adaptation costs overwhelmingly represented upfront investment figures with little indication of how those compare to the counterfactual — the estimated costs of inaction. Only six of the 833 cost values reported mentioned a timeframe for return on investment and only four companies reported negative values to reflect avoidance of future costs or cost savings over time. The near-absence of these cost comparisons limits investors’ ability to understand or assess the

Table 1 | Representative examples of the financial implications of climate change risks as reported by companies to investors

Company	Sector and headquarters	Climate risk	Business impact	Financial implication (US\$ millions)	Description	Actual or anticipated/potential financial impact
Hewlett-Packard	Technology, United States	Monsoon floods	Increased capital cost	4,000	Decline in revenue due to hard drive disk production stoppages in Thailand in 2011	Actual
Chevron	Oil and gas, United States	Hurricanes	Reduction/disruption in production capacity	1,400	Damages from Hurricane Katrina in the United States in 2005	Actual
Kinross Gold Corporation	Mining, Canada	Thawing permafrost	Increased operational cost	800	Value of asset at risk (Kupol mine in Russia)	Anticipated/potential
Samsung	Technology, South Korea	Tropical cyclones	Reduction/disruption in production capacity	110	Cost of shutting down a semiconductor manufacturing facility for a single day	Anticipated/potential
Caixa Geral de Depósitos	Bank, Portugal	Increased average temperature	Increased operational cost	1.8	Cost associated with a projected 11% increase in electricity prices through 2020	Anticipated/potential
Larsen & Toubro	Construction and buildings, India	Extreme heat	Increased operational cost	1.5	Cost of worker absenteeism associated with a hypothetical 10% increase in the incidence of heat stroke	Anticipated/potential

These examples were selected to cover a range of sectors and geographies as well as a range of the types of financial implications companies reported, from actual assessed damages from an extreme event to estimated potential losses from business disruption. Financial implications should be considered passive, reflecting the company's assessment of actual or anticipated cost in the absence of proactive adaptation. All values were converted to US\$ based on 2015 conversion rates, if originally reported in different currencies.

Table 2 | Representative examples of the costs of climate change management strategies as reported by companies to investors

Company	Company sector and headquarters	Climate risk	Management cost (US\$ millions)	Description of management strategy
Antofagasta	Mining, United Kingdom	Drought	300	Investment in seawater pumping system
Kurita Water Industries	Electrical equipment, Japan	Tropical cyclones	22.2	Relocating select offices to less vulnerable locations
SK Holdings	Technology, South Korea	Change in average temperature	2.5	Investment in solar power and more efficient cooling over four years
Unilever	Household products, United Kingdom	Change in precipitation patterns	1.6	Annual cost of tea farmer training through the Rainforest Alliance
GlaxoSmithKline	Pharmaceuticals and health care, United Kingdom	Biodiversity loss	<1.0	Annual cost of participating in partnerships that protect biodiversity needed to develop new products
Praxair	Chemicals, United States	Change in precipitation extremes	0.02	Annual cost of assessing natural catastrophe risk
Investa Property Group	Real estate, Australia	Extreme weather	0.012	Incremental cost of climate scenario modelling per new building

Examples were selected to cover a range of climate change risks reported, as well as a range of sectors and geographies. All values were converted to US\$ based on 2015 conversion rates, if originally reported in different currencies.

strategy against available alternatives, including 'no adaptation'. Similarly, for widely applicable EbA such as mangrove and wetlands conservation⁵¹ or watershed management, there is a need to translate the risk reduction value into terms relevant to private-sector decision-makers. Although some have argued that translating ecological values into economic ones distracts from the deeper

systemic change needed⁵², such translation has nevertheless been the driver of several recent innovations in private-sector adaptation, including Swiss Re's issuance of the first insurance policy for natural infrastructure (a coral reef)⁵³ and the utility Entergy's investment in wetlands restoration as cost-effective coastal infrastructure protection⁵⁴. EbA and other more transformational

adaptation approaches are likely to remain largely untapped until the costs of all strategies are better articulated.

Nonlinear climate risks and the need for radical change. Although most climate science presumes a quasilinear relationship between the accumulation of GHG in the atmosphere and global temperature rise, there is growing concern that nonlinearities in the climate system and biophysical feedback processes, including permafrost thawing, loss of polar ice sheets, and Amazon forest dieback, could lead to more abrupt changes and severe risks to society⁵⁵. The IPCC cites evidence of ‘emergent’ climate risks, some of which could lead to unexpected tipping points. For instance, the melting of the Greenland ice sheet, which is likely to occur at a threshold somewhere between 1 and 4 °C of warming, could cause 7 m of sea-level rise; extensive biodiversity loss with associated loss of ecosystem services⁵⁶ is likely to occur by 3 °C. The financial implications of these emergent climate risks are difficult to quantify, but coupled socioeconomic and biophysical modelling and ecosystem services valuations can provide proximate minimum values. For example, sea-level rise of under 1 m could place between US\$21–210 trillion in global assets in the 100-year flood zone by 2100⁵⁷. Ecosystem services contribute an estimated US\$125–145 trillion to the global economy annually⁵⁸ — who will pay for their substitution? While some policymakers and businesses are reluctant to plan for tipping points they deem to be far-fetched, past predictions of climate impacts have actually been found to be conservative⁵⁹, and some argue that the dismissal of extreme risks is simply a “failure of imagination”⁶⁰. Nonlinear climate risks will require radical change and truly transformative adaptation⁶¹.

Yet companies’ disclosures on climate risk reveal a preference for incremental or reactive adaptation strategies such as business continuity planning and energy efficiency installations. Strategies such as retreating from certain areas, desalination infrastructure, disaster relief programs and coastal ecosystem restoration that begin to consider nonlinear change were notable for their near absence from reporting. Our findings therefore provide global, cross-sectoral evidence supporting previous research that many companies’ climate change reporting is dominated by risk management language that mainly avoids ‘ethical discourse’⁶² and that companies too often translate the complex challenge of climate change into solutions that align with business-as-usual⁶³ practices. Winn et al.⁶⁴ find that organizations’ enduring assumption that “current economic and social conditions will continue to flourish regardless of unfavorable biophysical conditions in Earth’s natural and climate systems” predispose them to a risk management approach that is inadequate in the face of the scope, scale and systemic uncertainty associated with climate change impacts. Radical adaptation for radical change, it seems, is not yet part of the business agenda.

Averting the tragedy of the horizon

Our review of the disclosures of 1,630 of the world’s largest companies reveals that Mark Carney’s fear of a tragedy of the horizon has a solid empirical basis. Indeed, companies report the costs of both physical climate change impacts and the strategies required to manage them sporadically and inconsistently, while the strategies themselves overall reflect a narrow view of risk that underestimates supply chain and broader societal impacts.

There are several reasons why companies may underplay physical climate risk in disclosures. Companies may genuinely underestimate or misunderstand the various pathways through which climate change can manifest in business impacts, from lost consumer purchasing power to employee absenteeism to raw material shortages. They may not have frameworks in place for explaining how climate change risk management differs from business-as-usual risk management, or know how to parse the marginal cost of climate risk from investments implemented for multiple reasons⁶⁵. They may be predisposed

to short-term thinking and heavily discount impacts expected to occur in the future or with unknown probability⁶⁶, especially when current accounting frameworks do not provide clear guidance on reporting long-term, uncertain risks. Physical climate change risks may place some companies at a competitive disadvantage, incentivizing those companies to obscure these risks. Finally, business executives, like all people, face psychological barriers in understanding extreme risks and weighing the need for radical change, especially in the face of inherent uncertainty and sunk costs⁶⁷.

These barriers to improved disclosure and ultimately better climate change adaptation strategies are deeply ingrained in the private sector but not insurmountable. Drawing lessons from the evolution of voluntary corporate GHG reporting may be instructive. For example, companies that employ a Chief Sustainability Officer or ensure institutional overlap between their environmental and audit committees are more likely to disclose emissions information transparently⁶⁸, indicating that corporate governance structures matter for climate change reporting. Hess argues that mandatory reporting requirements and standardized performance indicators are key to combating the perverse incentives for firms to obscure important contextual information, provide positive but meaningless disclosures and/or stay silent rather than report unfavourable data⁶⁹. The high-profile nature of the TCFD recommendations and an increasing number of shareholder resolutions^{70,71} on climate change could drive more companies to view climate risk disclosure as mandatory to investors, even if not always required by regulation. As for standardization, the adaptation strategies laid out here and the analysis of their relative frequency could serve as a baseline for tracking the future evolution of companies’ actions.

Institutional investors have the ability to shift the incentives driving large companies and have begun to do so by promoting the TCFD recommendations. To avoid the tragedy of the horizon, companies would benefit from looking beyond the fenceline to assess climate impacts further upstream and downstream in their supply chains, as well as risks to employees, customers and the communities in which they operate. Aside from reducing global GHG emissions, the best way to reduce the costs of climate change is to proactively manage for its consequences³⁶, implementing adaptation measures earlier rather than later^{7,37}. Given that the impacts of climate change are projected to worsen in the coming decades under almost every emissions scenario⁴⁴ and that impacts could become extremely severe if planetary boundaries are crossed⁵⁵, companies will need to move from incremental adaptation approaches to transformational ones.

Our review indicates that companies should more thoroughly consider EbA to risk management, both in addition to and in some cases in lieu of hard infrastructure. One key barrier to such approaches is expertise mismatch: company decision-makers often have more knowledge of engineering-based risk management techniques than they do of watershed restoration techniques, for instance. This is apparent in the fact that many of the companies that did implement EbA reported working with a non-profit or government partner to do so, reflecting a sharing of expertise. The most effective adaptation strategies for physical climate change impacts may be those that reduce, for example, flood risk across large geographic areas or build resilience across an entire raw material supply chain. Individual companies are sometimes disincentivized from making these investments because some of their benefits become public goods that flow to multiple actors⁷². A wider view of climate risk management in the private sector will therefore require new partnership models that share costs, both with other companies and with governments. Investors that recognize the inherently shared nature of these costs can open the door for disclosures that better capture the risks and opportunities at hand.

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Author contributions

D.G.H. and A.G. conceived the study. A.G. wrote the manuscript. D.G.H., W.R.T. and J.D. contributed to and commented on the manuscript.

Competing interests

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Additional information

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