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Dirk Broeders, Francesco Paolo Mongelli

The Paris Agreement ten years later: Navigating climate uncertainty and tipping points

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Abstract

The climate crisis is an urgent, human-driven systemic challenge whose impacts are unfolding through increasingly frequent and severe extreme events. Although the 2015 Paris Agreement advanced global climate governance, implementation remains insufficient to limit warming to well below 2 °C and pursue 1.5 °C. Accelerating risks, interacting crises and potential tipping points suggest that climate change could become unmanageable if current GHGs emissions trajectories persist. This paper makes three contributions. First, it examines why we are failing to act decisively, highlighting a persistent awareness gap, competing priorities and weak political incentives for ambitious climate action. Second, it draws on NGFS climate-policy scenarios, the climate policy trilemma and a precautionary approach to clarify policymaking trade-offs under uncertainty. Third, it reviews policy, financial and technological levers to accelerate a just green transition. A new climate policy paradigm is needed: a systemic, precautionary, adaptive and incentive-compatible framework that can “tilt the odds” away from irreversible climate damage, even when probabilities are poorly known.

Keywords: Adaptive climate policies, ambition gap, climate crisis, deep uncertainty, Paris Agreement, tipping points

JEL: D81, E61, D62, Q54

Non-technical summary

Where does the world stand ten years after the Paris Agreement, and what actions can still be taken to avoid the worst climate outcomes? Despite historic international policy achievements and rapid progress in clean technologies, global greenhouse gas emissions are still rising, albeit at a slower pace, and climate risks are intensifying faster than expected. Extreme weather events, slow-onset changes such as sea-level rise, and growing evidence of potential tipping points suggest that the climate crisis is becoming harder—and eventually may become impossible—to manage if current trends persist.

The paper advances three main arguments. First, it shows that the climate crisis has evolved into a “triple-track” problem. Physical risks are escalating and becoming increasingly nonlinear, with growing uncertainty about how close we are to irreversible changes in major geophysical systems of the Earth. At the same time, there is a persistent awareness and cognitive gap: climate risks compete with other urgent issues—geopolitical tensions, inflation, pandemics—and often fall down the political agenda. This is compounded by weak and unstable political incentives: the benefits of ambitious climate policies are diffuse and long-term, while costs are often concentrated and immediate, which discourages decisive action.

Second, the paper uses three complementary frameworks to clarify the choices facing policymakers. The NGFS (Network for Greening the Financial System) climate scenarios are used to show how early, orderly action acts as a form of insurance, while delayed or fragmented action leads to more severe physical, transition and fiscal risks. The “climate policy trilemma” highlights the need to balance mitigation (reducing emissions), adaptation (coping with impacts) and restoration (removing carbon and repairing ecosystems). These are not substitutes but complements: delaying mitigation raises future adaptation and restoration costs and heightens the risk of crossing tipping points. A tipping-point and precautionary perspective underscores that waiting for full certainty before acting is both dangerous and costly: once critical thresholds are crossed, options rapidly narrow and climate change becomes irreversible.

Third, the paper reviews practical levers that could still bend the curve towards safer futures, provided they are deployed quickly and fairly. These include credible and predictable carbon pricing; accelerated deployment of renewables and related infrastructure (such as smart grids and storage); innovative climate finance to crowd in private capital and support vulnerable countries; and scalable carbon management (both

nature-based and technological). Advances in technology, finance, data and modeling since 2015 mean that many of the key tools are already available; what is missing is sufficient speed, coordination and commitment.

The paper also emphasizes the importance of governance design. An effective climate policy regime must identify and remove structural bottlenecks to scaling low-carbon solutions; send clear, long-term signals to investors and households; and remain adaptive, with regular reviews and course corrections as new information emerges. Aligning “reaction time” (how quickly societies respond to scientific warnings) with “intervention time” (the shrinking window in which action can still prevent catastrophic outcomes) is central to success.

The paper draws lessons from past collective responses to systemic risks—such as the Montreal Protocol on ozone-depleting substances, action against acid rain, preparations for the Year 2000 software risk, and the response to Covid-19. These episodes show that rapid, coordinated action is possible when risks are clearly communicated, responsibilities are fairly shared, and policy frameworks are credible. The paper concludes that, while the Paris goals are under severe pressure, the Agreement remains a crucial anchor for global climate governance. With decisive use of today’s policy, financial and technological levers, it is still possible to steer away from the most dangerous climate futures and move towards a just, feasible and durable low-carbon transition.

A climate policy paradigm shift is needed—and many of its building blocks already exist. This does not mean abandoning familiar instruments such as carbon pricing, regulation, public investment, innovation policy, disclosure requirements, adaptation finance or international cooperation. Rather, it means changing how these instruments are combined, sequenced and governed. The prevailing approach has often treated climate policy as incremental emissions reduction under well-defined risks, addressed through separate tools and gradual adjustment. The emerging paradigm starts from a different premise: climate change involves deep uncertainty, tail risks, tipping points, long lags, and possibly irreversible or catastrophic outcomes. Policy therefore needs to be systemic, precautionary, adaptive and incentive-compatible—designed not only to reduce emissions, but to keep safe options open, accelerate action, and “tilt the odds” away from the most dangerous futures even when probabilities cannot be precisely known. In this paradigm, climate policy is no longer an add-on to economic policy. It becomes a core organizing principle for macroeconomic, financial, industrial, energy, trade and security policy.

"Son, when you grow up would you be the savior of the broken the beaten and the damned?" "Will you defeat them? Your demons, and all the non-believers the plans that they have made?" "Because one day, I'll leave you a phantom to lead you in the summer to join the black parade."

Welcome to the Black Parade by My Chemical Romance

1. Introduction

The climate crisis is one of the most urgent challenges of the 21st century, and it is largely anthropogenic. Global observational data indicate that mean surface temperatures have been rising for decades, driven by the accumulation of net greenhouse gas (GHG) emissions in the Earth's atmosphere. The Global Carbon Budget 2025 reports that, while global fossil CO_2 emissions are projected to reach a record high of 38.1 billion tonnes, the growth rate of total human-caused emissions has slowed to an average of 0.3% per year over the last decade, compared to 1.9% per year over 2005-2014 (Friedlingstein et al., 2026). See also **Figure 1** for the GHG emissions by gas since 1850. Crucially, this upward trajectory in emissions coincided in 2023 with a near-complete collapse in land carbon uptake.[1] Without a substantial acceleration of climate policies, global temperatures could surpass the 1.5°C threshold as soon as the early 2030s.[2]

Habitability on Earth requires atmospheric CO_2 to remain within a relatively narrow range, functioning as a geological thermostat that prevents the climate from tipping into either a global Snowball Earth state or a runaway hothouse. Over geological

[1] In 2023, forests, vegetation, and soils collectively removed almost no CO_2 from the atmosphere. Because terrestrial ecosystems currently absorb roughly a quarter of our annual emissions, their sudden loss of sink capacity not only accelerates the accumulation of CO_2 in the atmosphere but also severely undermines our primary natural mitigation pathway. Terrestrial ecosystems are thus losing both their carbon storage and uptake capacity, and the oceans are also showing signs of instability. Ke et al. (2024) attribute the 2023 land carbon sink collapse to three main factors: extreme heat and drought, intensified by a strong El Niño, which caused plants to shut down photosynthesis; record-breaking wildfires, especially in Canada, that released vast amounts of stored carbon; and severe drought stress in major tropical forests such as the Amazon, temporarily turning them from CO_2 sinks into net carbon sources.

[2] A 1 °C increase in surface temperature since the pre-industrial era might seem small but represents a large additional heat load in the oceans, ice, and atmosphere. Global average surface temperature reflects Earth's energy balance: the difference between incoming sunlight and heat radiated back to space. Human-produced GHGs have created an imbalance, causing Earth to absorb more energy and warm. Because oceans are vast and store enormous heat, even a small rise in average temperature requires a huge amount of extra energy. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature.

timescales, the silicate weathering–greenhouse feedback regulates CO_2 and stabilizes global temperatures. When atmospheric concentrations fall below roughly 200 ppm (parts per million or about 0.02% of the air), the resulting decline in greenhouse forcing can trigger extensive glaciation and potential snowball conditions. Conversely, when CO_2 rises too quickly or exceeds roughly 1,000 ppm (0.1%), extreme greenhouse warming and associated feedbacks have been linked to past mass extinction events.[3] While life is broadly adaptable, the present biosphere—and human societies embedded within it—has evolved under a relatively low-CO_2 regime. Rapid, anthropogenic increases in atmospheric CO_2 push the climate system beyond the historical “speed limit” for biological and ecosystem adaptation, thereby endangering the climatic conditions that have supported complex life and modern economic activity over thousands of years (Brannen, 2025).

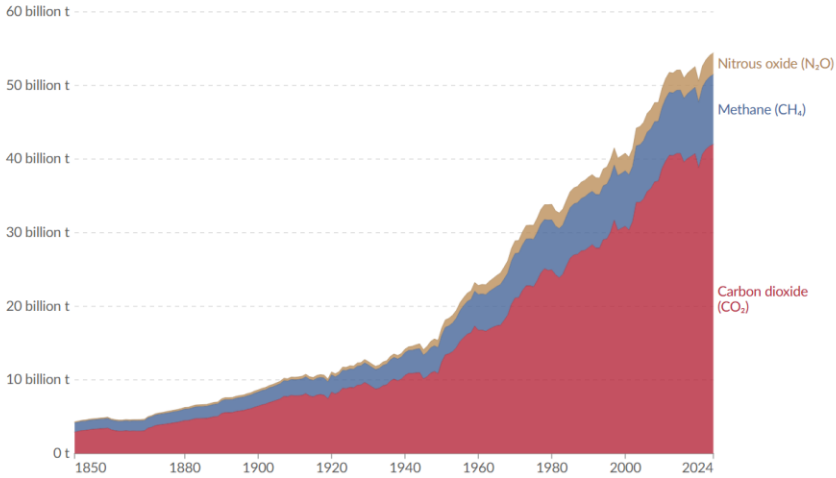

Figure 1. Greenhouse gas emissions by gas, World, 1850 to 2024. *Source: Jones et al. (2025), OurWorldinData.org/co2-and-greenhouse-gas-emissions.*

The climate crisis is accelerating. Assuming no further strengthening of climate mitigation measures in the next few years, a global warming trajectory of about 3.2 °C by the end of the century is projected, with an uncertainty range of roughly 2.2 °C to 3.5 °C (IPCC, 2023; UNEP, 2024). See **Figure 2** for the increase in global land surface temperature since 1850. According to the latest World Economic Forum Global Risks Report, extreme weather events, biodiversity loss, and ecosystem collapse are projected to intensify, ranking as the top three global risks over the next decade (WEF, 2026).

[3] As a reference: before the Industrial Revolution, Earth’s atmosphere contained roughly 280 ppm of CO_2, but human activity has since driven that concentration up to approximately 425 ppm today.

At the same time the worst plausible case scenario now seems less likely. The IPCC is retiring the RCP 8.5 emissions scenario after 15 years—a worst-case pathway based on what was known about the net emissions trajectory at the time of its publication.[4] It projected global warming above 4-5°C by 2100, while current energy and emissions trends make this outcome increasingly unlikely due to falling coal demand, rapid renewable deployment, and stronger climate policies. Even without RCP 8.5, intermediate warming scenarios still increase the frequency and severity of extreme climate events, including droughts, floods, and biodiversity loss. The IPCC will now prioritize a range of new emissions trajectories, reflecting updated evidence and assumptions.

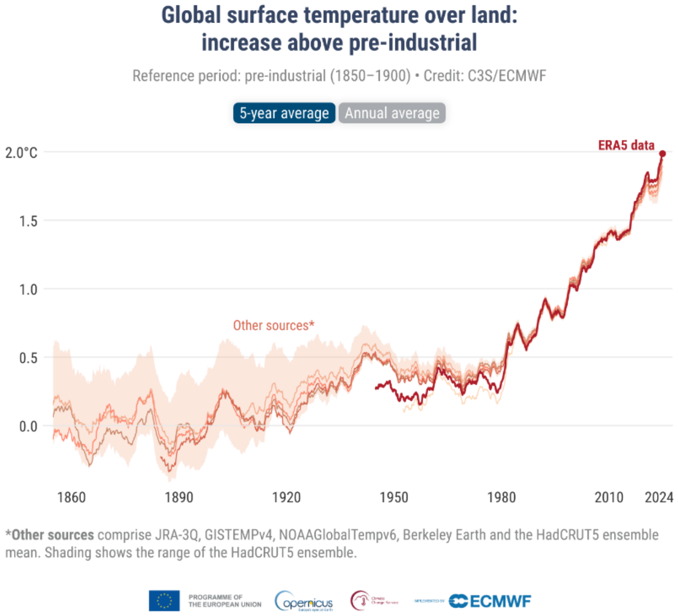

Figure 2. Anomalies in average temperature over all land (°C) shown as five-year averages *(centred running 60-month periods) since 1850, relative to the average for the 1850–1900 designated pre-industrial reference period and shown as annual averages since 1967, relative to the average for the 1991–2020 reference period. Data source: Based on six global temperature datasets. Credit: C3S/ECMWF. Taken from: https://climate.copernicus.eu/climate-indicators/temperature.*

Faced with these alarming trends, the 2015 Paris Agreement stands as a historic milestone in global climate governance. It provides a framework for addressing unmitigated climate change through collective action, despite scientific uncertainty about the full impacts of climate change. The agreement enshrines the commitment of nearly 200

[4] Technically, the scenario was updated by the scientific community (ScenarioMIP) rather than the IPCC. The IPCC is an independent UN panel that assesses existing scientific literature but does not govern or design the underlying climate models.

nations to limit global warming to well below 2 °C—preferably to 1.5 °C—above pre-industrial levels by the end of the 21st century. In the last decade, there have been bright spots and achievements across institutions, technology, finance, and climate modeling. Despite broad-based support, progress in implementing the Paris Agreement has been slower than required to achieve these temperature goals.

Ten years after Paris, global climate governance has altered the baseline trajectory of GHG emissions. Even without factoring in extreme pathways like the now-retired RCP 8.5 emissions scenario, GHG emissions are still rising, albeit at a slower pace than in previous decades. Mitigation efforts fall short of what is required to keep 1.5°C within reach. Land-carbon uptake is weakening, and the remaining carbon budget for 1.5°C is almost exhausted, implying a growing probability of crossing geophysical tipping points. As tipping points loom and urgency increases, the question is no longer whether to act, but how to act decisively, adaptively and collectively to tilt the odds in favor of a sustainable future. It is a race against time. While climate mitigation receives considerable attention, climate adaptation is also a rising policy priority.

This paper has three objectives. We first take stock of where the world stands a decade after the Paris Agreement and explain why humanity has so far failed to act decisively despite mounting evidence of escalating climate risks. We show that the climate crisis is evolving into a systemic "triple-track" problem. Our second objective is to draw on three complementary frameworks—the climate policy trilemma, NGFS climate-policy scenarios, and a precautionary approach—to clarify the trade-offs, risks and temporal dynamics that shape feasible decarbonization pathways. Our third objective is to provide an integrated review of policy, financial and technological levers that can still tilt the odds away from disorderly, high-damage futures if deployed at scale and with attention to fairness. Credible carbon pricing, accelerated renewable deployment, innovative climate finance and scalable carbon management emerge as mutually reinforcing instruments to accelerate a just green transition and, over time, reduce and potentially reverse climate risks in light of advances in technology, finance, data and modeling.

The paper is structured into three parts. In the *first*, we take stock of where we stand, drawing on available data and analyses. **Section 2** reviews the main features of global climate governance and how progress in implementing the 2015 Paris Agreement has unfolded. As net GHG emissions continue to rise and climate risks surge, **Section 3** examines increasing climate uncertainties and non-linearities. **Section 4** discusses tipping points and "potential surprises." **Section 5** reviews a large literature on why signatory countries are collectively failing to act more decisively, pointing to a confluence of factors. **Section 6** argues that the climate crisis is evolving into a systemic "triple-track" problem: (i) escalating and increasingly nonlinear physical risks; (ii) a persistent cognitive and awareness gap; and (iii) weak and unstable political incentives for more ambitious climate action. The *second part* presents three policy frameworks for examining key aspects and implications of the climate crisis. Using NGFS scenarios, in **Section 7**, and the climate policy trilemma, in **Section 8**, we show that mitigation, adaptation, and restoration are complements rather than substitutes, and that postponing mitigation simultaneously amplifies physical, transition and fiscal risks. In **Section 9**, a tipping-point framework clarifies how deep uncertainty and irreversibility create a finite—and rapidly narrowing—window for effective intervention, strengthening the case for precautionary, adaptive policies. The *third part* of the paper reviews potential responses to the climate crisis. In **Section 10**, we identify a set of policy, financial and technological levers—including credible carbon pricing, accelerated renewable deployment, innovative climate finance and scalable carbon management—that, if deployed at speed and with attention to fairness, can still tilt the odds away from disorderly, high-damage climate futures. In **Section 11** we review how collective actions have successfully addressed environmental and health threats in the past. In **Section 12,** we provide some final remarks.

PART I: Taking stock of climate facts, governance and policies

In this part, we review the evolution of climate governance since the early 1990s, the escalation of acute and chronic physical climate risks, the prospect of tipping points and polycrises, and the implications under deep uncertainty. We then turn to the "elephant in the room": what might explain the persistent failure to act commensurately with climate facts and scientific warnings? We highlight cognitive, political, and institutional barriers. We then synthesize these insights in a new "triple-track" framing of the climate crisis.

2. The evolution of global climate governance since the early 1990s

Climate change has long been recognized as a global challenge. Scientific studies show that global temperatures have increased over the past two centuries, primarily due to human-caused greenhouse gas emissions (IPCC, 2014). The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). Since then, it has released six major assessment report cycles. Global climate governance began in earnest in 1992 at the Earth Summit in Rio de Janeiro, which established the United Nations Framework Convention on Climate Change (UNFCCC). The aim of the UNFCCC is to encourage climate policies to stabilize GHG concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. The principle of climate equity is also embedded in the UNFCCC through the notion of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), which acknowledges that countries share a duty to address global environmental issues, but that their responsibilities vary based on their stage of economic development and historical contributions to GHG accumulation and environmental degradation (e.g. through earlier industrialization).[5]

Faced with increasingly alarming climate trends, the 2015 Paris Agreement stands as a historic and ambitious milestone in global climate governance. It provides a framework for addressing unmitigated climate change through collective action. The agreement enshrines the commitment of 193 countries to limit global warming to well below 2 °C—preferably to 1.5 °C—above pre-industrial levels by the end of the 21st century.[6] A key objective is to reduce global GHG emissions as quickly as possible in order to achieve net-zero emissions by the mid-21st century, balancing remaining human-caused emissions with natural absorption. Additionally, the agreement seeks to enhance climate adaptation and resilience, align global finance with low-emission development, and strengthen Nationally Determined Contributions (NDCs). Overall progress is assessed through five-year review cycles (the Global Stocktake), and the Conference of the Parties (COP) meets annually to drive implementation.[7]

Despite broad-based support, progress in implementing the goals of the Paris Agreement has been slower than required to limit global warming. The Global Stocktake

[5] Signatories to the UNFCCC then met in Berlin at the first Conference of the Parties (COP1) to outline specific emissions targets, which were subsequently formalized in the 1997 Kyoto Protocol, establishing differentiated obligations for developed countries (Wang and Gao, 2018). The CBDR-RC principle thus remains relevant as it promotes equity in climate action, although its operationalisation is still uneven and widely debated.
[6] The COP21 in Paris was concluded with an agreement on 12th December 2015, while the actual signing of the Paris Agreement was on 22 April 2016. Today over 140 countries still have net-zero targets.
[7] The Wuppertal Institute has been summarizing the United Nations climate negotiations since 1995, see: https://wupperinst.org/en/topics/climate/global-climate-governance/

concluded at COP28 in Dubai in 2023 found that the world is off track to limit warming to 1.5 °C and that current national pledges are inadequate, as shown in the previous figures.[8] The carbon budget originally calculated in 2015 for a 50% chance of limiting warming to 1.5 °C above pre-industrial levels is almost exhausted, and the room for maneuver to limit warming to 2 °C is closing.[9] For the first time in a UN climate agreement, countries were called upon to "transition away from fossil fuels" in energy systems. Parties also agreed to triple global renewable energy capacity and double the rate of energy-efficiency improvements by 2030. This stocktake reinforces concerns about both an "ambition gap" and an "implementation gap" (UNEP, 2021; IPCC, 2022).[10] The ambition gap reflects the fact that climate targets are collectively insufficient to meet the Paris objectives, while the implementation gap refers to the shortfall between stated commitments and the policies, actions, and investments undertaken to deliver those goals.

A decade after the Paris Agreement, we are witnessing a faster deterioration of key climate indicators (Table 1). The observed warming cannot be explained by natural variability alone. While there is an ongoing discussion about the contribution of natural variations—which might be reversible—to short-term climate fluctuations, recent work by Rahmstorf and Foster (2025) isolates the influence of three main natural variability factors: El Niño, volcanism (e.g., the eruption in Tonga in 2022), and the 11-year solar cycle. Their adjusted data, net of these natural variations, show that after 2015 global temperature rose significantly faster, by 0.36 °C per decade, than in any previous 10-year period since 1945. Similar conclusions can be found in Hansen et al. (2025).

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[8] See https://www.umweltbundesamt.de/en/topics/climate-energy/the-global-stocktake-under-the-paris-agreement#modalities-of-the-global-stocktake.

[9] Parry et al. (2022) and Black et al. (2022) argue that "measures equivalent to a global carbon price exceeding $ 75 per tonne by 2030 are needed to stay below 2 °C, whereas the current global average carbon price is only $ 5 per tonne". Significantly higher carbon prices are estimated in other studies.

[10] See https://climateactiontracker.org/, www.climatewatchdata.org/net-zero-tracker, and https://globalenergymonitor.org/.

Indicator	Status / Record Value	Trend & Observation	Source
Global Temperature	+1.55°C (above 1850-1900)	2024 was the warmest year on record. It was the first calendar year to exceed the 1.5°C threshold.	WMO State of the Global Climate 2024, Copernicus Global Climate Highlights 2024
CO_2, CH_4 and N_2O Concentrations	422.8 ppm (2024 average)	Highest in at least 2 million years. The 2024 increase was the largest single-year rise ever recorded.	NOAA Global Monitoring Laboratory, Copernicus Indicators of Global Climate Change 2024
Ocean Heat Content	+23 Zettajoules (2025 gain)	2025 set a new record for the 9th consecutive year. About 90% of excess Earth heat is stored in the oceans.	Pan, Y., Cheng, L., Abraham, J. et al. Ocean Heat Content Sets Another Record in 2025. Adv. Atmos. Sci. (2026)
Sea Level Rise	~4.7 mm per year (current rate)	The rate of rise has more than doubled since the 1990s (from 2.1 mm/yr to 4.7 mm/yr).	WMO State of the Global Climate 2024
Antarctic Sea Ice	< 2.0 mln km^2 (minimum)	For three consecutive years (2022-2024), the summer minimum has stayed below the 2 million km^2 mark.	National Snow and Ice Data Center, Copernicus Global Climate Highlights 2024

Table 1. The data clearly illustrates an alarming acceleration in climate change. *Most of the key indicators are not only increasing but doing so at a growing pace. For example, both the rate of sea-level rise and the amount of heat absorbed by the oceans have risen significantly over the past two decades. The temporary crossing of 1.5°C of warming in a single year—projected at around 1.55°C for 2024—does not itself violate the Paris Agreement, which is based on multi-decade averages. However, it is a stark warning that the remaining global "carbon budget" is close to being exhausted. Equally concerning is the record-breaking ocean heat content. Because the oceans store the vast majority of the excess heat in the climate system, this unprecedented warming effectively commits the planet to continued climate impacts for centuries, even if greenhouse gas emissions were to cease immediately.*

Climate change adaptation is also framed as a legal obligation. The Paris Agreement introduced a "global adaptation goal" in Article 7, aiming to enhance adaptive capacity, strengthen resilience and reduce vulnerability (Mongelli et al., 2024). Yet adaptation remains largely a process-based obligation: Parties must plan and report on adaptation "as appropriate," without a uniform definition, specific targets or robust enforcement mechanisms. The EU, however, has begun to translate this soft international goal into binding regional law. The 2021 European Climate Law requires Union institutions and Member States to ensure “continuous progress” towards climate resilience by 2050, to mainstream adaptation across all relevant policies, and to adopt and implement national adaptation strategies and plans. The Commission’s 2021 EU Adaptation Strategy operationalizes these duties by promoting smarter, more systemic and faster adaptation across key sectors. There is evidence that climate adaptation is currently underfunded and inadequate (Mongelli et al., 2024).

A recent phenomenon is that climate litigation is emerging as an important driver of adaptation. Claimants increasingly invoke human rights, international and national obligations, and tort principles to argue that failures to plan and implement adaptation measures violate duties of care and undermine rights such as life, health, housing and a healthy environment. Strategic “failure to adapt” cases seek orders compelling governments or companies to take additional measures, while “polluter pays” cases aim to recover adaptation costs or damages linked to foreseeable risks. Additional support comes from the 2022 UN General Assembly resolution recognizing a clean, healthy and sustainable environment as a universal human right (UN, 2022). This strengthens the legal basis for individuals and communities to challenge ecological degradation and climate inaction, reinforcing biodiversity conservation and climate stability as matters of human dignity and intergenerational justice.

Summing up, it is increasingly apparent that global GHG emissions continue to rise, albeit at a slower pace. This is attributable to both an ambition gap and an implementation gap in pursuing the goals of the Paris Agreement. Climate change may in fact be accelerating, and if this trend continues, the world faces an era of increasingly severe extreme climate events, with risks escalating with every additional increment of global warming (IPCC, 2022; UNFCCC, 2022; EEA, 2024). As we discuss later, this is narrowing the window for implementing timely and effective mitigation and adaptation measures. In recent years, climate litigation has emerged as an important driver of climate action.

3. An emerging climate era (I): escalating extreme climate events and damage

Recent years have been marked by an escalation in severe extreme climate events causing widespread damage. Both acute and chronic physical risks are increasingly materializing across regions and economic sectors. Most notably, deadly, record-breaking heatwaves across Europe and South Asia have caused tens of thousands of excess deaths and shattered long-standing temperature records. Attribution studies have determined that these events were made substantially more probable by anthropogenic climate change (see, e.g., Gallo et al., 2024). This trend of intensifying extremes is equally evident in catastrophic flooding events, such as those in Pakistan in 2022, Brazil in 2024, and Valencia in 2024, where warmer air capable of holding more moisture content contributed to extreme precipitation, massive displacement, loss of life and extensive destruction of infrastructure and livelihoods. Compounding these crises are unprecedented wildfire seasons, including the “Black Summer” fires in Australia (2019–2020) and the record-setting blazes in Canada (2023), where prolonged droughts and elevated temperatures created highly conducive conditions for fast-spreading and destructive wildfires. In January 2025, a series of catastrophic wildfires in Southern California (including the Eaton, Palisades and Altadena fires) resulted in significant loss of life, property, and wildlife.[11] The 2024 Typhoon Yagi was the strongest typhoon to make landfall in Vietnam in 70 years, underscoring the growing intensity of tropical cyclones. In recent years, climate change-induced extreme heat and prolonged dry conditions have also fueled extensive wildfires in Spain, Portugal, Greece, Turkey, Russia, Australia, Indonesia, Algeria, Chile and across the Balkans, among other regions.

Alongside these acute extreme events, steady and chronic climate stresses are also becoming increasingly apparent. Advancing desertification and soil degradation, water scarcity and contamination, worsening air pollution, the decline of nature-based services (such as pollination and flood regulation), and accelerating biodiversity loss in several regions are all on the rise. These processes erode agricultural productivity, reduce labor productivity (particularly in heat-exposed sectors), strain public health systems, and undermine the natural capital on which economies depend. Collectively, these phenomena

[11] See https://www.epa.gov/california-wildfires.

illustrate the manifestation of physical climate risks that may be acute, chronic, or a combination of both, and their growing imprint is increasingly visible in economic loss data.

The European Environment Agency (EEA) tracks the increasing economic losses caused by climate change in Europe. Its CLIM039 indicator explicitly measures financial damages from weather- and climate-related extremes across the EU and EEA member countries.[12] Between 1980 and 2024, total losses reached approximately EUR 822 billion. Notably, 25% of these losses (over EUR 208 billion) occurred in just the last four years (2021–2024). So far, 2021 was the worst year in Europe, with a total loss of EUR 65 billion, which may come across as low compared to European GDP. The economic losses reported by the EEA are, however, widely seen as conservative and likely underestimate the true costs of climate change. The main reason is that they focus on direct, monetizable damage to assets—such as destroyed buildings, infrastructure, and crops—while largely omitting indirect losses. These indirect impacts include disrupted supply chains, lost productivity during heatwaves, business interruptions, and temporary unemployment, all of which are harder to measure and rarely captured fully. The figures also undercount certain hazards. Sudden disasters like storms and floods are relatively well documented, but heatwaves and droughts—despite causing the most climate-related fatalities in Europe—are poorly reflected in monetary terms. Slow-onset processes such as sea-level rise or biodiversity loss typically do not appear in annual disaster loss statistics at all. Data gaps further depress reported losses.

The PESETA project provides such a broader assessment of climate change costs.[13] PESETA top-down simulations, carried out by the European Commission's Joint Research Centre (EU, 2024), focus on long-term "welfare losses" and systemic risks rather than only on immediate physical damage (bottom-up). These simulations show that costs could dramatically increase once wider economic impacts are included. In PESETA IV and V (TRACE), a mid-century warming scenario points to an average EU GDP loss of about 0.7%

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[12] See https://www.eea.europa.eu/en/analysis/indicators/economic-losses-from-climate-related/annual-economic-losses-caused-by. The EEA's CLIM039 indicator covers meteorological (storms, hail, wind), hydrological (floods) and climatological shocks (heatwaves, wildfires, droughts, cold spells, frost) and is based on several specialized sources. The core dataset on recorded economic losses comes from RiskLayer (CATDAT), a private German company. Working with Eurostat, the EEA then formats these data within the framework of the EU Sustainable Development Goal indicators, particularly SDG 13 on climate action. In addition, Munich Re's NatCatSERVICE database provides key global and regional information on natural catastrophes, which the EEA uses to cross-validate its estimates.
[13] See https://joint-research-centre.ec.europa.eu/projects-and-activities/peseta-climate-change-projects_en.

by 2050—roughly EUR 2.5 trillion in accumulated losses—while, by 2100, a high-warming pathway could produce annual welfare losses of about 1.9% of EU GDP (around EUR 240 billion per year).[14] Sector-specific projections are even more striking: coastal flood damages could rise from about EUR 1.4 billion today to EUR 240 billion per year by 2100 without adaptation; river flood losses could increase six-fold to EUR 48 billion annually; and drought-related losses could grow five-fold to EUR 45 billion per year. These higher figures stem from PESETA's inclusion of "hidden" costs typically absent from disaster databases, such as labor productivity losses from heat stress, supply chain shocks that can reduce sectoral exports, and the monetized value of heat-related mortality, which in some scenarios dominates total economic impacts.[15]

Long-run data indicate that aggregate past climate damages may be far larger than previously assumed. Using long-run data and a time-series approach, Bilal and Kaenzig (2024) find that macroeconomic damage from climate change are an order of magnitude larger than standard empirical estimates. In their baseline results, a permanent 1 °C increase in global temperature reduces world GDP by more than 20%, and a business-as-usual warming path implies a present welfare loss of over 30%. Methodologically, they show that identifying global temperature shocks—rather than relying on country-level temperature as in most panel studies—better captures the macroeconomic impact of extreme climatic events and explains why their damage estimates are substantially larger.

An insurance gap is widening and deepening. Only about a quarter of climate-related catastrophe damages and losses in the EU are insured. Information on uninsured damages is often incomplete, especially in lower-income regions (ECB and

[14] A seemingly modest 2% loss of output is macroeconomically large once framed relative to trend growth, dynamics, and composition. For many advanced European economies, long-run real growth is only 1.5–2% per year, so a persistent 2% climate-induced shortfall effectively eliminates an entire year of net progress and shifts the level path of GDP downward. Unlike a transitory shock, this loss compounds through foregone investment and infrastructure, akin to a permanent tax on aggregate production. Moreover, the aggregate figure masks concentrated damage in foundational sectors—agriculture, water, energy—where much larger local contractions undermine non-substitutable inputs, force defensive rather than productive expenditure, and erode fiscal buffers, increasing systemic fragility.

[15] PESETA also highlight strong geographic heterogeneity: Southern and Eastern European countries like Greece, Italy, Spain, and Romania bear disproportionate burdens from productivity losses, droughts, and wildfires, while Northern Europe may register some limited agricultural benefits but faces rising flood risks. A conclusion that is reinforced by emerging global evidence on rising long-run damages and losses. We return to these considerations in Section 6.

EIOPA, 2023). Public spending on emergency response and long-term recovery is hard to track and not fully integrated. In addition, many databases only record events that pass certain "disaster" thresholds, so numerous smaller but frequent events go uncounted. On top of that, some of the most important climate impacts are not easy to price: such as loss of life, long-term health effects, ecosystem degradation, and damage to cultural and natural heritage. Since the EEA's indicators are built around what can be clearly observed, reported, and priced, they inevitably capture only part of the real losses caused by climate change, making it essential to complement them with broader assessments.

Summing up, an increasing share of the global population and economy is directly and indirectly exposed to extreme climate events. Worst-case climate scenarios are materializing at rates that would have been considered implausible only a few years ago. Evidence suggests that the costs of extreme climate events are severely underestimated. Taken together, these developments mark not only a phase of rapidly escalating climate damages, but also a transition into an era in which growing physical risks are intertwined with deep uncertainty about future climate dynamics, tipping points and "potential surprises." By potential adverse surprises, we mean unexpected but plausible unfavorable climate outcomes.

4. An emerging climate era (II): rising uncertainty, tipping points, and "potential surprises"

Over the past decade, it has become clear that climate change involves deep uncertainty, especially about when and how severely high-impact events and long-term trends could disrupt natural systems and societies. If insufficiently mitigated, global warming risks pushing the Earth system across critical "tipping points" that could lock in catastrophic, long-lasting, or effectively irreversible changes. These tipping points encompass planetary boundaries, geophysical thresholds and other forms of climate- and nature-related nonlinear change. Emerging evidence suggests that several of these thresholds may be approached or crossed earlier than previously anticipated. Current research suggests that, at 1.2 °C of warming, we have already entered a "danger zone" (Lenton, et al., 2019; Armstrong McKay et al., 2022). The thresholds include, inter alia, the potential collapse of the Greenland and West Antarctic ice sheets; a disruption or collapse of the Atlantic Meridional Overturning Circulation (AMOC); widespread die-off of coral reefs in the Southern Hemisphere; large-scale thawing of permafrost in the Northern Hemisphere with associated greenhouse-gas releases; and the loss of sea ice in the Barents Sea (Stern, 2022). The disappearance of land and sea ice reduces surface albedo, amplifying warming through feedback loops.[16] Converging scientific assessments further indicate accelerating sea-level rise and coastal flooding; increasing frequency and intensity of tropical cyclones, droughts and wildfires; growing risks of food and water insecurity in vulnerable regions; rapid biodiversity loss; and heightened human health burdens from heat stress, air pollution and vector-borne disease transmission (IPCC, 2022, Chapter 3).

The impacts of these changes extend far beyond emblematic cases such as declining polar bear populations and displaced Inuit communities. One indication of the scale and urgency of the problem is provided by recent observations of the Greenland Ice Sheet: satellite records show that it is now losing mass at rates that closely track the most extreme sea-level rise projections made in the 1990s and 2000s. A scenario once regarded as a worst case has effectively become present reality, materializing decades earlier than anticipated by earlier climate and ice-sheet models (Otosaka et al., 2023). These developments highlight not only the accelerating pace of physical change, but also the profound uncertainty surrounding future trajectories, underscoring the need for climate policies that are flexible and adaptive rather than static and purely predictive.

In addition to tipping points, climate change is also associated with "potential surprises."[17] These are developments that fall outside the range of outcomes envisioned in standard scenarios yet remain plausibly within the envelope of what the Earth system can deliver. These surprises may arise from poorly understood feedback loops, from interactions between climate processes and socio-economic systems, or from structural breaks in trends that had previously appeared stable. Examples include the abrupt emergence of compound extremes, faster-than-expected shifts in ocean or atmospheric circulation, or unforeseen cascade effects triggered by critical infrastructure failures. Because such outcomes cannot

[16] Albedo is the share of incoming sunlight that a surface reflects back into space rather than absorbing. Bright surfaces like ice, snow, and some clouds have a high albedo and reflect much of the sunlight; dark surfaces like ocean water or forests have a low albedo and absorb more energy.

[17] The notion of "potential surprise" is central to George L. S. Shackle's theory of decision-making under uncertainty, in which outcomes are evaluated by their perceived possibility rather than by mathematically defined probabilities. Shackle emphasized the extent to which outcomes may depart from prior expectations—i.e. their potential to surprise—as a key determinant of choice in situations of fundamental uncertainty (Shackle, 1961). This perspective is particularly pertinent to climate policy, where low-probability but high-impact events and structural breaks in the climate system challenge conventional probabilistic approaches to risk assessment.

be meaningfully assigned precise probabilities or even imagined ex ante, they challenge conventional risk-management tools that rely on historical data and probabilistic forecasts and underscore the need for decision frameworks that explicitly accommodate the possibility of radical departures from expected trajectories.

Deeply uncertain climate trajectories and potential surprises require adaptive and responsive climate policies. The evolution of geophysical processes, and thus of the climate system, is deeply uncertain. It may involve unknown nonlinear shifts, feedback loops and tipping points. In this context, governments, policymakers, firms, investors, and consumers must remain prepared to revise courses of action as new information about climate dynamics and emerging technologies becomes available. This necessitates flexible, adaptive climate policies and decision-making frameworks that explicitly accommodate potential surprises, while remaining anchored in the overarching objective of phasing out net greenhouse-gas emissions and limiting the most severe climate impacts (discussed further in Section 6 with respect to the climate policy trilemma).

Summing up, pervasive deep uncertainty and potential surprises in the climate system imply the need for a fundamental paradigm shift in climate policy. In such an environment, policy cannot rely on point forecasts or expected outcomes alone; it must be precautionary, adaptive, and robust to radical deviations from current trajectories, while staying firmly oriented toward rapid reductions in net greenhouse-gas emissions. Against this backdrop, a central puzzle emerges: why, despite mounting evidence of potential catastrophe, is collective climate action still so hesitant and inadequate?

5. An enigma: why is humanity failing to act decisively in the face of a massive threat?

An enigma lies at the center of climate policy: why has humanity failed to act decisively and collectively in the face of a threat of such magnitude? Carbon emissions, and the climate change they induce, constitute a near-perfect global externality. The consequences of an individual agent's actions—whether emitting greenhouse gases, reducing emissions, financing low-carbon technologies, or sequestering carbon—are dispersed across billions of people, future generations, and the broader biosphere. As a result, each agent captures only a minute fraction of the social benefit from mitigation, while the costs remain private and immediate. This free-rider problem is compounded by the long atmospheric lifetime of GHG concentrations, which means that today's emissions affect not only current populations but also generations yet to be born. Societies have developed institutions to manage many localized externalities, such as regional pollution, congestion, and noise. Governments can prohibit harmful activities, impose taxes, regulate behavior, assign property rights, and subsidize alternatives. But effective governance typically requires an authority whose jurisdiction broadly matches the scale of the externality. In the case of greenhouse gases, the externality is global, while political authority remains overwhelmingly national. No government has jurisdiction commensurate with the scope of the climate problem.

The closest approximations to global climate governance are the United Nations and its climate- and nature-related agencies and scientific bodies, including the UNFCCC and the IPCC. Thus far, a series of COPs and international agreements have attempted to coordinate and mobilize national actions to slow down and eventually reverse carbon emissions (with some limited effects). Coordination is complex, enforcement is weak, and questions of climate equity remain unresolved. Climate equity refers to the unresolved disagreement over how to fairly share the costs, responsibilities, and burdens of fighting climate change between rich and poor nations. Meanwhile, modern civilization remains dependent on rising energy consumption, still supplied in large part by fossil fuels. Despite technological progress, the global economy continues to generate positive net GHG emissions, as discussed in Sections 2 and 3. The resulting dilemma is stark: can societies rapidly transform energy systems, infrastructure, and patterns of production and consumption—incurring large, immediate, and often privately borne costs—to generate benefits that are global, diffuse, and long term, in the absence of either a fully effective market mechanism or a central global authority to coordinate action?

From another perspective, an explanation for slow and insufficient collective climate action reflects the fact that carbon reduction is a global public good. Its benefits are widely shared, while the costs often fall on local communities immediately. This creates room for free riding among individuals, firms, and governments, making public awareness alone insufficient to generate the scale of collective action required. Recognizing climate change mitigation as a public-good problem is therefore essential for diagnosing the policy challenge accurately and designing effective responses, including coordination mechanisms, credible commitments, carbon pricing, and institutions that align private incentives with collective benefits. One possible institutional form is the creation of climate clubs, as suggested by Nordhaus (2015).

The public-good framing also helps clarify why two well-known "tragedies" are often invoked to explain inadequate responses to the climate crisis. The "tragedy of the commons" describes how self-interested firms and individuals overuse and degrade shared and finite resources (**Box 1**). The "tragedy of the horizon" highlights instead the systematic failure to address long-term, potentially catastrophic risks. While both metaphors provide powerful diagnostic lenses, they are insufficient on their own. Humanity's collective failure to act decisively on climate risks reflects instead the interaction of multiple, mutually reinforcing factors spanning cognition, politics, economics, and geopolitics. At a deeper level, these factors may also reflect a form of limited collective consciousness: a detachment from the natural systems on which human societies depend and from the long-run consequences of present choices. This detachment affects not only citizens and consumers, but also firms and policymakers, whose decisions are often shaped by short horizons, institutional routines, and mental models that separate economic activity from its ecological foundations. We briefly examine several of these factors. In addition, a rapidly growing and increasingly relevant force is artificial intelligence (AI), whose potential implications for climate mitigation and adaptation are summarized in **Box 2**.

First, a cognitive deficit in how societies perceive climate risks appears to play an important role in the awareness gap. Samama (2025) argues that inadequate climate action does not primarily reflect failures of science, technology, or even formal politics, but rather a "*failure of our mental model of the world and how societies understand progress, threats, and responsibilities*". Insights from cognitive science indicate that individuals and societies construct internal models from experience and that these models often cease to be updated in line with new evidence, leaving collective perceptions trapped within *"societal bubbles".* This cognitive deficit contributes to the persistent awareness gap and to the limited recognition, by the public at large, of the magnitude, speed and systemic nature of the climate dynamics currently unfolding and the risks they entail (Broeders et al., 2019; Hondroyiannis et al., 2022; Mongelli, 2023). Samama therefore calls for a "cognitive reframing" and a shift in perspective that would foster a more holistic understanding of planetary systems and human dependence on them.[18]

Second, a succession of health, financial and geopolitical shocks, as well as armed conflicts, has distressed the global economy and the international order. The

[18] When Apollo 17 photographed Earth from space, it revealed our planet as a distinctive blue sphere in darkness, a "Blue Marble". Astronauts described the resulting "overview effect," a shift in perspective that we should strive to regain.

COVID-19 pandemic beginning in early 2020 and the associated lockdowns generated bottlenecks, widespread shortages and severe strains on global value chains (Draghi, 2026). Subsequent geopolitical shocks have disrupted global energy and commodity markets, affecting both fossil fuels and critical minerals for low-carbon technologies, and have contributed to heightened macroeconomic uncertainty.[19] Diverging national interests, ongoing conflicts and regional tensions have further increased geopolitical risk, eroded trust and complicated international cooperation, including efforts to coordinate long-term climate and energy policies.

Third, since the signing of the 2015 Paris Agreement, the ranking of public-sector policy priorities has shifted. Concerns about energy security, autonomy and affordability, health and inequality have increasingly taken precedence over global warming and broader environmental risks. Geopolitical and military conflicts, together with the perceived need to raise defense expenditure, are putting additional pressure on public budgets. Wars not only divert financial and political resources away from climate action; they also destroy ecosystems and trigger humanitarian and economic crises. Intensifying trade tensions and the weaponization of supply chains further complicate efforts to advance coordinated, multilateral progress on climate policy. In this context, climate policy has slipped down the political agenda and is frequently crowded out by more immediate security, economic and geopolitical concerns—a development that is particularly problematic given that governments have already fallen short of what were, in many cases, modest climate commitments. At the same time, there is growing "climate regulation fatigue," accompanied by resistance to additional regulatory measures intended to compensate for persistently low and uneven carbon prices.

Fourth, public attitudes toward climate change might have shifted in recent years, particularly in high-income countries. Survey evidence indicates that the share of respondents who regard climate change as a major threat has declined in many advanced economies, including the United States, Canada and several European countries, while concern has increased or remained high in countries such as Brazil and India.[20] Public opinion now spans a wide spectrum—from outright denial of anthropogenic climate change, to the belief that societies can adapt to projected levels of warming and that

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[19] The IEA argues that restrictions on critical raw materials such as lithium, nickel and rare earths, increase input costs and delay renewable projects (IEA, 2025b).
[20] See https://www.pewresearch.org/2025/08/19/global-climate-change-as-a-threat/.

improvements in health, technology, and prosperity will provide sufficient protection (Gates, 2025), to catastrophism. These attitudinal developments are occurring against a backdrop of growing political polarization, especially in the United States and parts of Europe. Far-right parties and movements are, on average, more likely to deny the scientific consensus on climate change and to oppose the implementation of the Paris Agreement and related decarbonization policies (Jylhä et al., 2020). This polarization not only shapes public discourse but also constrains the political feasibility and durability of ambitious climate measures.

Fifth, widespread disillusionment about the prospects for effective collective action may further dampen support for ambitious climate policies. Even if the awareness gap and underlying cognitive deficits were reduced, a significant share of the population may still doubt that societies and institutions are capable of responding in a timely and effective manner to the scale of the challenge (Eichhorn and Grabbe, 2025). Such perceptions of collective impotence or "climate fatalism" can generate disengagement, resignation and a reluctance to incur short-term costs for measures that are perceived as unlikely to succeed. These dynamics risk becoming self-fulfilling: expectations of political inaction lower public pressure on decision-makers, which in turn reinforces skepticism about the feasibility of transformative climate action.

Sixth, some companies and their lobbyists chase short-term profits, even when this undermines climate action. Lobbyists act as intermediaries between powerful economic actors and policymakers, translating corporate priorities into legislative language and political strategy. As illustrated by the Competitiveness Roundtable's campaign against the EU's Corporate Sustainability Due Diligence Directive, lobbying extends far beyond formal consultations (De Leth, 2026). It encompasses orchestrated pressure on key legislators, the strategic use of think tanks, and the mobilization of foreign governments to reframe domestic rules as trade barriers. Such activity can reshape climate and human-rights law while largely evading public scrutiny, exposing how vulnerable ostensibly technocratic regulatory processes remain too concentrated on private influence. Climate change is not only an environmental crisis but a profound human rights crisis that is already eroding basic rights—especially for the most vulnerable—and current political and legal systems are failing to protect people adequately. Yadav (2025) argues that climate harms should be understood and treated as human rights violations, that wealthy countries bear responsibility to cut emissions faster to create "carbon space" for others, and that a just transition and recognition of a collective right to a stable climate are essential to prevent deepening global injustice and irreversible damage.

Investors are unlikely to commit long-term capital when the green transition is clouded by policy uncertainty. Especially if they also perceive growing political or social pushback against green initiatives. Creating the right environment begins with credibility: honoring existing climate commitments, implementing announced green targets, and steadily increasing carbon prices so they better reflect the true social costs of emissions.[21] A lack of harmonized approval and permitting procedures is equally important. In the European Union, for example, the permitting process can take up to five years for utility-scale solar photovoltaic projects and up to nine years for onshore wind projects (IEA, 2025c). Reducing such delays would materially improve investment incentives and accelerate the transition. Balancing energy security, affordability, and sustainability requires a predictable environment for sustained investment in renewable energy (Lagarde, 2025).

Summing up, these barriers underscore the need to confront the urgency of effective climate policies head-on and at multiple levels. While the combined obstacles are formidable, opportunities exist for innovation and progress that demonstrate the potential for impactful change—provided that climate ambition, commitment and implementation are scaled up with urgency. To close this first part, we next explore the nature of the climate crisis in more depth.

Box 1. Political Economy (1): two metaphors that illuminate the paradox of inaction in the face of escalating climate risk

Two well-known statements capture core features of the political economy of climate change. Nordhaus (2013) observes that "*the problem is that those who produce the emissions do not pay for that privilege, and those who are harmed are not compensated.*" Carney (2015) warns that "*[O]nce climate change becomes a defining issue for financial stability, it may already be too late.*" These quotations point, respectively, to the "tragedy of the commons" and the "tragedy of the horizon" as metaphors for the persistent misalignment between private incentives and socially optimal climate action.

[21] The Social Cost of Carbon (SCC) estimates the long-term economic damages caused by emitting one additional ton of carbon dioxide today. SCC is used to evaluate climate policies by comparing the costs of emission reductions with the monetary value of avoided climate impacts, such as health problems, property damage, and agricultural losses (Nordhaus, 2017).

The first metaphor is the "tragedy of the commons." A root cause of anthropogenic climate change can be characterized as a tragedy of the commons: firms and individuals, acting in their own self-interest, overuse and degrade a shared, finite resource, even when such behavior is collectively irrational and undermines the long-term interests of all (Hardin, 1968). When common-pool resources—such as clean air, a stable climate, or freshwater—are weakly governed or lack clearly defined and enforceable property rights, overexploitation is likely to occur. The global climate system exhibits precisely these characteristics.

Solutions to the tragedy of the commons include assigning property or usage rights to resources such as water or clean air. In this way, negative externalities such as pollution can be internalized by owners, giving them an incentive to address those externalities. This, however, is not straightforward. Critics argue that full privatization of essential resources can endanger access for vulnerable groups, especially as water is widely recognized as a basic human right. Other approaches therefore include government regulation—for example, quotas or taxes that limit use. In addition, community management offers another path, whereby local groups develop their own rules and institutions for sustainable resource use and nature preservation (Ostrom, 1990).

The second, related metaphor is the "tragedy of the horizon." This captures the systematic failure to address long-term, potentially catastrophic risks—such as climate change, ecosystem degradation, and biodiversity loss—because their most severe impacts lie beyond the conventional decision horizons of households, firms, policymakers and financial markets. In such a setting, the immediate and visible costs of ambitious climate policies are systematically overweighted relative to the diffuse, delayed, and uncertain benefits of avoided damage, which will largely accrue to future generations. This intertemporal asymmetry helps explain persistent underinvestment in mitigation and adaptation, despite a strong scientific consensus on the magnitude of the risks.

Box 2. The rapid ascent of artificial intelligence over the past decade

A decade ago, when the Paris Agreement was ratified, few foresaw the rapid ascent of digitalization or the growing capability and versatility of AI in processing vast datasets, recognizing complex patterns, generating content, building predictive models, and automating routine tasks. AI has now entered nearly every sector of the economy. At the same time, we have witnessed soaring investment in power-hungry data centers and in the hardware and software needed to develop and operate AI models and AI-based workflows.

AI touches upon several topics discussed in this paper. Here, we list a few open questions.

How might AI change the way people think and learn?

AI offers transformative benefits across many industries, acting as a powerful tool to amplify human potential, streamline operations, and drive innovation. It can take over routine tasks, enabling individuals and firms to save resources, reduce errors, and focus on high-level strategic work.

Yet, there are legitimate concerns about *"AI deception"* (Novy-Marx and Veliko, 2026). There is a risk of *"cognitive offloading"* and the "Google effect" when delegating specific tasks to technology (Chirayath et al., 2025). There is also a risk of "*cognitive surrender*" when people stop thinking critically for themselves. This exposes individuals and organizations to risks of "groupthink" and uniformity of views. Creativity and originality might suffer. Firms will increasingly search for employees with a high need for cognition and critical-thinking skills (The Economist, May 2026).

AI requires substantial resources and energy

From an energy perspective AI presents a large new source of electricity demand, although it may also generate offsetting benefits, such as, such as booking trips online, safety features in cars, applications in healthcare, and other uses. AI capabilities and data centers require substantial financial and material resources and are highly energy-intensive. The International Energy Agency's 2025 analysis estimated that data centers, including those supporting AI, used about 415 terawatt-hours (TWh) of electricity in 2024, around 1.5% of global electricity consumption. The IEA projects that data-center demand could rise to about 945 TWh by 2030. By comparison, the Bitcoin network is estimated to consume between 150 and 178 TWh of electricity per year, although its social value remains highly contested.

There is also increasing documentation of the environmental impacts from data centers and AI applications (IEA, 2025a). As such tools expand and data analysis of various types consumes ever more resources and energy, what scenarios might unfold? In the long term, AI's potential to further automate and optimize processes across industries, from energy production to logistics, could significantly decrease the global carbon footprint (Davarakota et al., 2025). This positive impact is anticipated to outweigh the initial emissions bump, creating value for businesses and society in areas where traditional solutions have fallen short. In essence, AI might cause some initial growing pains for the environment, but it has the potential to support climate mitigation efforts.

Is AI stimulating higher productivity and growth? Micro versus macro evidence

There is micro-level evidence that AI can raise productivity, but not yet strong macro evidence that it is raising economy-wide productivity and growth—that is enough to reduce energy dependence.

The strongest evidence is at the task, worker, or firm level. A well-known field study of 5,172 customer-support agents found that access to a generative-AI assistant raised productivity by 15% on average, measured as issues resolved per hour, with the largest gains for less experienced workers (Brynjolfsson et al., 2024). The study also found improvements in learning and language fluency. There are also field-experiment results in online retail showing that generative-AI tools can increase sales in some workflows, with treatment effects ranging up to 16.3%, especially where AI materially improves consumer experience or reduces friction (Fang et al., 2026).

Does AI increase aggregate economic output, resilience, and decarbonization by more than it increases total energy demand and fossil-fuel dependence? Contucci et al. (2025) calculate the Economic Productivity of Energy (EPE)—GDP generated per unit of energy consumed— and find that, as with other technological innovations in recent decades, EPE fell following AI deployment. The authors argue that AI should be assessed by whether it improves or worsens this ratio, and they call for transparent reporting of AI-related energy use and productivity-linked incentives.

Summing up, the verdict on AI's long-term impacts remains open, including its effects on the awareness of the risks of unmitigated climate change and whether it will be neutral toward, or supportive of, the goals of the Paris Agreement. Indicators such as Economic Productivity of Energy should be monitored. If AI raises GDP but requires large new gas exploitation, grid reinforcement, water use, and imported chips, the energy-security case is weak. If, on the other hand, AI enables faster electrification, better grid use, lower industrial energy intensity, and higher-value domestic production, the case becomes much stronger.

6. The triple-track nature of the climate crisis

Understanding the climate crisis today requires more than tracking GHG emissions and concentrations or tracing global temperature trends. It requires recognizing that climate risk is advancing simultaneously along three distinct but tightly coupled tracks: the geophysical lag of the Earth system, the cognitive gap in societal risk perception, and the policy lag in collective responses. Each of these tracks has its own sources of inertia, feedback loops, and tipping dynamics; together, they shape not only how fast climate risks materialize, but also how quickly—and how effectively—societies can respond. What follows is an examination of these three tracks and their interaction, which will underpin the analysis in the remainder of this paper.

The contemporary climate crisis is unfolding along three interconnected tracks, each with its own dynamics. Recognizing their interaction is perhaps one of the most neglected challenges of climate policy. Above all, we must adapt to the "day after tomorrow" weather.

First, there is a deepening geophysical crisis, in which human activity is destabilizing the fundamental conditions of the Earth system. At the geophysical level, anthropogenic greenhouse gas emissions are driving profound perturbations to the Earth system. These changes represent the unrelenting progression of global warming, accompanied by an increase in extreme climate events and the resulting damage, as previously discussed. These dynamics are characterized by pronounced inertia and nonlinear risks, which manifest as shifting extremes, altered variability, and persistent trends in temperature, precipitation and related hazards. Crucially, both the climate system and the energy system exhibit inertia: even ambitious mitigation undertaken today will only gradually translate into reduced physical risks, while the low-carbon transition itself requires time-consuming reconfiguration of infrastructure, technologies, and institutions. Fundamentally, this underscores the importance of understanding and anticipating the climate scenarios projected for the next 10 to 20 years. It highlights the urgent need to adapt to the climate of the coming decades. We must think in terms of the day after tomorrow's climate conditions. We refer to this aspect of the climate crisis as *"geophysical inertia."*

Geophysical inertia means that even strong mitigation efforts today may only yield benefits after substantial delays. In the meantime, the climate continues to warm, exposing the world to more extreme events and heightened risks from nonlinear processes such as planetary boundaries, tipping points, and compound hazards.[22] Together, these forms of inertia create deep uncertainty and increase the likelihood of crossing critical climate tipping points. Climate policies must therefore be anchored in long-term commitments if sustained results are to be achieved.

Second, there is a deficit in societal awareness and understanding of the scale, speed and systemic nature of climate scenarios, as discussed in Section 4. This *"cognitive gap"* reflects not only information gaps but also entrenched mental models that underestimate compounding and tail risks. Closing this gap requires more than additional data; it calls for cognitive reframing and communicative strategies that help individuals,

[22] The initial warming response to a greenhouse gas pulse occurs within roughly a decade, the full impact on global temperatures is delayed by 20 to 40 years due to the massive heat-absorption capacity of the Earth's oceans. The temperature may remain elevated for centuries or even millennia because GHG persists in the atmosphere for lengthy periods, depending on the type of gas. Addressing this long impulse–response time of the climate system—where the full effects of today's emissions and policies take 20–40 years to materialize—requires strategies that balance immediate action with sustained commitment over decades.

institutions, and publics internalize the urgency and irreversibility of crossing critical thresholds.

Third, there is "*climate policy lag*" as responses to climate change are constrained by weak collective incentives and political will. In many jurisdictions, the absence of a sufficiently broad and durable climate constituency translates into limited public support for stringent climate policies, fragmented coalitions for action, and the vulnerability of climate measures to electoral cycles and polarization. This political and institutional inertia interacts with geophysical and cognitive lags, reinforcing a trajectory in which action systematically falls short of what is required to stabilize the climate system.

The triple-track nature of the climate crisis gives rise to a critical relationship between reaction time and intervention time. On one side is the reaction time to scientific warnings—about unabated GHG accumulation, accelerating warming, more frequent and extreme climate events, growing uncertainties, and emerging tipping points—that is, how long it takes most countries to grasp the urgency of the problem and agree on and implement a meaningful response, for example, at annual COP negotiations. On the other side is the rapidly shrinking intervention window—the time remaining to prevent climate tipping points from being crossed irreversibly (Lenton et al., 2019). This mismatch combines two forms of inertia: one in climate policy responses and another in the geophysical system itself. Policy inertia stems from slow processes, including international negotiation, domestic legislation, implementation, and periodic adjustments based on new data and technologies.

Summing up, as the climate crisis unfolds, substantial progress has been made in understanding both the current and projected effects of climate change. Climate data and models have become more sophisticated, our grasp of interactions between ecosystems, societies, and the economy has deepened, and the contours of effective climate policy are clearer. We also increasingly appreciate our vulnerability to ecosystem degradation and our dependence on nature's services (Ceglar et al., 2025). Yet major limitations and caveats remain: it is still impossible to precisely forecast the future climate trajectory and its impacts. Against this backdrop, a central question for Parts II and III is which combinations of public policy, private-sector engagement and technological and social innovation can still meaningfully "tilt the odds" away from catastrophic outcomes. As discussed in **Box 3**, this will require overcoming substantial political resistance, coordination failures, misinformation, and free-riding pressures at both the domestic and international levels. The next sections explore why decisive climate action is essential and how it can be achieved if ambition and implementation are intensified.

Box 3. Political economy (2): domestic and international obstacles to effective climate policy

At the domestic level, efforts to implement consistent climate policies face several obstacles, including political resistance, coordination failures, and misaligned incentives. Short electoral cycles and intense distributional conflicts—centered on who pays, who benefits, and over what horizon—frequently result in delays, partial measures, and policy reversals, undermining the sustained ambition needed for deep mitigation and effective adaptation. Vested interests in carbon-intensive sectors, coupled with regulatory capture and lobbying, can further slow, weaken, or selectively shape climate legislation and regulation. Limited public understanding of climate risks, widespread exposure to misinformation and disinformation, and the perception that individual or even national efforts are negligible in addressing a global problem erode societal support for transformative policy interventions.

Misinformation may be shared without intent to deceive, whereas disinformation is deliberately created or disseminated to mislead, manipulate or protect specific interests. For example, misinformation might include claims that the power grid will “go dark” without fossil fuels because “the sun doesn’t always shine.” While renewable energy is indeed variable, modern grids are capable of integrating high shares of renewables with high reliability. Major geopolitical disruptions to fossil-fuel supply further illustrate the risks associated with continued reliance on fossil fuels.

Institutional fragmentation poses another national challenge. Climate policy responsibilities are often dispersed across multiple ministries, agencies, and levels of government. This dispersion complicates the design of coherent strategies, blurs accountability, and undermines long-term policy consistency.

At the international level, climate change remains a paradigmatic collective-action problem. Strong incentives exist for countries to free ride on others’ mitigation efforts, and asymmetries in historical responsibility and adaptive capacity hinder the adoption of more stringent and enforceable commitments. While the principle of climate equity—enshrined in agreements at successive COPs and reiterated in the 2015 Paris Agreement—serves as a guiding framework, its practical implementation remains weak and inconsistent.

Part II: Mapping climate futures through three analytical frameworks

This part uses three complementary modeling frameworks to interrogate the macro-financial consequences of climate change and climate policy. First, the Network for Greening the Financial System (NGFS) climate–macro scenarios translate alternative transition pathways into distributions of physical and transition risks, temperature outcomes, and GDP losses over the long run. Second, the climate policy trilemma, cast from a public-finance perspective, highlights the evolving trade-offs between mitigation, adaptation and restoration, and their implications for fiscal space and risk-sharing. Third, a precautionary framework sketches how deep uncertainty and irreversible damages create a finite window for effective intervention, strengthening the case for early, coordinated, and robust climate action.

7. NGFS scenarios: The erosion of an orderly transition

The NGFS framework integrates several strands of climate research into a unified analytical structure.[23] This synthesis suggests a path-dependent escalation of both transition and physical risks, characterized by heightened severity and increased stochasticity. Consequently, decarbonization imperatives—the mitigation of emissions and subsequent sequestration—face mounting structural headwinds. The NGFS macro-financial scenarios formalize this impasse, parameterizing the trade-offs between the intertemporal timing and the magnitude of adaptation and mitigation interventions. While these scenarios necessarily abstract from granular complexities to mitigate cognitive friction and bridge the information gap, they provide a robust heuristic for evaluating four divergent yet plausible states of the world (**Figure 3**).

[23] The Network for Greening the Financial System (NGFS) is a voluntary coalition of central banks and supervisors dedicated to sharing tools and best approaches to managing climate and environmental risks in the financial sector and accelerating the transition to a sustainable economy. The NGFS was launched by 8 National central Banks in Paris in December 2017 (see https://www.ngfs.net/en). It currently has 152 members across over 95 countries, alongside 24 observers.

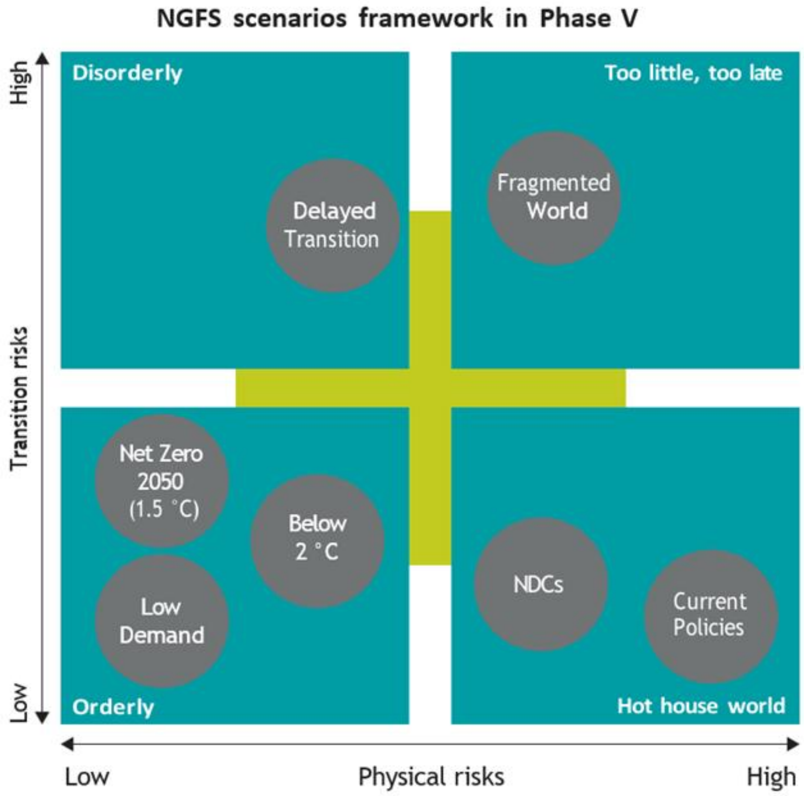

Figure 3. Key NGFS scenarios along the physical risks and transition risks dimensions. Source: https://www.ngfs.net/ngfs-scenarios-portal/explore/. Note: Positioning of scenarios is approximate, based on an assessment of physical and transition risks out to 2100.

Growing and interacting transition and physical risks are fundamentally contingent on the timing and strength of mitigation and adaptation, rendering an orderly transition far from guaranteed. Mitigation addresses the causes of climate change by reducing greenhouse gas emissions and enhancing natural sinks, thereby limiting the extent of future warming. Adaptation addresses the consequences by adjusting infrastructure, economic systems, and behaviors to cope with realized and anticipated climate impacts, thereby enhancing resilience to unavoidable changes. Both dimensions are necessary and mutually reinforcing. Insufficient mitigation locks in higher long-run physical risks that may overwhelm adaptive capacity, while weak adaptation amplifies the near- and medium-term economic costs of a given mitigation path and can erode political support for sustained emissions reductions.

Within the NGFS framework, this interdependence is captured by scenarios that differ not only in the ultimate stringency of climate policy but also in the temporal

profile and coordination of mitigation and adaptation efforts. Early, credible, and well-sequenced interventions can dampen both transition and physical risks, approximating an orderly transition. By contrast, delayed, fragmented, or weak interventions increase the likelihood of abrupt policy adjustments, stranded assets, and elevated macro-financial volatility alongside more severe physical damage—outcomes that are increasingly characteristic of a disorderly or "too little, too late" transition.

The NGFS taxonomy distinguishes three "orderly" scenarios. In these scenarios, rapid adaptation and a swift transition to a low-carbon economy reduce future climate risks: the ***Low Demand*** scenario, where behavioral change, carbon pricing, and technology lower energy use and help reach global net zero CO_2 around 2050; the ***Below 2°C*** scenario, where gradually tightening climate policies give a two-thirds chance of limiting warming below 2°C; and the ***Net Zero 2050*** scenario, where very stringent policies and innovation limit warming to 1.5°C with net zero around mid-century. Conversely, the taxonomy also contemplates more deleterious outcomes. A ***"too little, too late"*** scenario, ***Fragmented World***, features delayed and uneven action, high physical and transition risks, and only partial delivery on net zero pledges. Two "Hot House World" scenarios—the Nationally Determined Contributions and Current Policies scenarios—involve limited further mitigation—either only pledged targets or just today's policies—resulting in high physical but low transition risks. Finally, in the "disorderly" ***Delayed Transition*** scenario, emissions do not fall before 2030, forcing much stronger policies to keep warming below 2 °C.

The NGFS disseminates the projected paths of key macroeconomic and climate variables through an online portal.[24] Among its many outputs are trajectories for temperature anomalies and real GDP relative to a reference (no-additional-policy) scenario. **Figure 4** presents the distribution of global temperature increases in 2100 for selected scenarios, focusing on the best- and worst-case percentiles. In the most adverse case, end-of-century warming reaches approximately 4.5 °C, whereas the most optimistic scenario constrains warming to around 1.5 °C. Notably, the distributions overlap: for example, the 95th percentile outcome under the Net Zero 2050 scenario is comparable, in terms of warming, to the 5th percentile under Current Policies. **Figure 5** reports the worst-case declines in GDP relative to the baseline in 2050, 2075, and 2100 across models and scenarios. The distributions become progressively more left-skewed over time,

[24] See https://data.ene.iiasa.ac.at/ngfs/#/workspaces.

indicating an increasing prevalence of large negative macroeconomic outcomes and thus escalating downside risk in the long run.

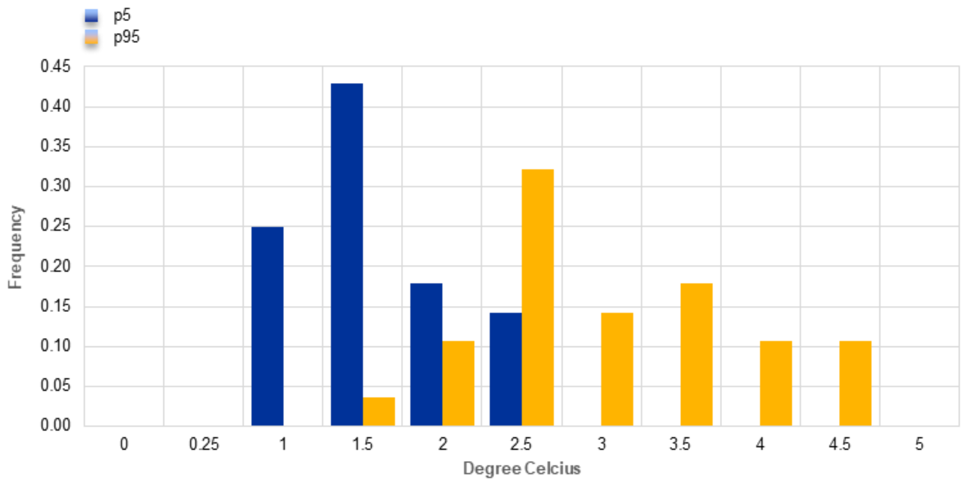

Figure 4. Note: Histogram of global temperature increase (°C) by 2100 across NGFS models and scenarios, under Kotz-Wenz 95th percentile." Models: GCAM 6.0 NGFS, MESSAGEix-GLOBIOM 2.0-M-R12-NGFS, REMIND-MAgPIE 3.3-4.8, REMIND-MAgPIE 3.3-4.8 IntegratedPhysicalDamages. Scenarios: Below 2°C, Current Policies, Delayed transition, Fragmented World, Low demand, Nationally Determined Contributions (NDCs), Net Zero 2050. Source: NGFS Phase 5 Scenario Explorer https://data.ene.iiasa.ac.at/ngfs.

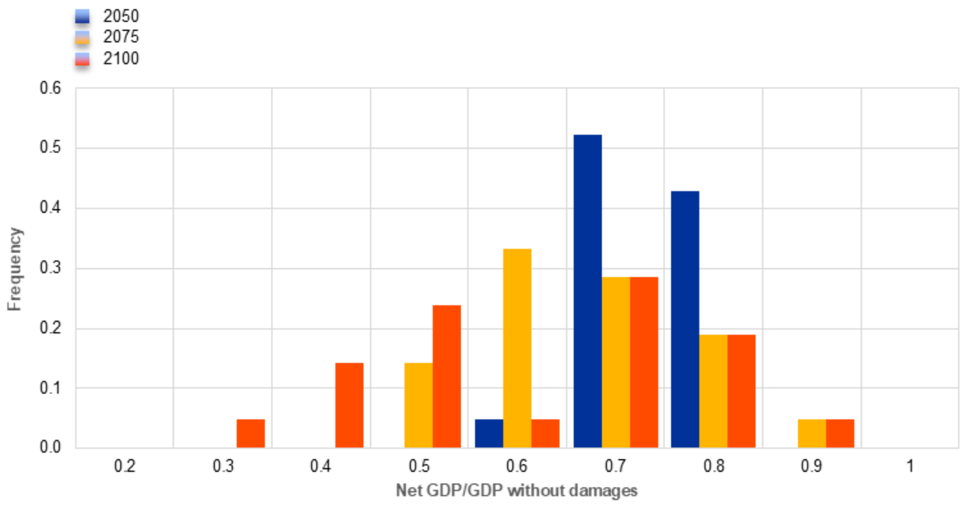

Figure 5. Histogram of net GDP/GDP without damages by 2050, 2075 and 2100 across NGFS models and scenarios, *in the 5th and 95th percentiles". Models: GCAM 6.0 NGFS (counterfactual without damage), MESSAGEix-GLOBIOM 2.0-M-R12-NGFS, REMIND-MAgPIE 3.3-4.8. Scenarios: Below 2°C, Current Policies, Delayed transition, Fragmented World, Low demand, Nationally Determined Contributions (NDCs), Net Zero 2050. Source: NGFS Phase 5 Scenario Explorer https://data.ene.iiasa.ac.at/ngfs.*

Summing up, the NGFS scenarios highlight that delaying or weakening climate mitigation and adaptation policies not only erodes the prospect of an orderly transition but also amplifies long-term macro-financial downside risks. This tightening nexus between transition and physical risks directly shapes the scale, timing and composition of public and private climate expenditures. Against this backdrop, the next section examines the climate policy trilemma from a public finance perspective, focusing on how to balance mitigation, adaptation, and restoration under growing fiscal and financial constraints.

8. The climate policy trilemma from a public finance perspective

Within a dynamically changing and deteriorating geophysical system, and weaker public finances, the world faces a climate policy trilemma. In Europe, for example, this trilemma comprises three interrelated challenges: (i) inadequate climate change mitigation, including an incomplete green energy transition; (ii) insufficient and underfunded adaptation to growing acute and chronic climate risks; and (iii) rapidly rising damage and restoration costs as those risks materialize (**Figure 6**). Financing needs and gaps remain large for mitigation, but are even greater for adaptation (Mongelli et al., 2024). All the while, public finance indicators have severely worsened globally, and concerns about sustainability of public finances have risen in several countries. Public climate funds are under stress and have to compete with shifting priorities, such as public health during the COVID-19 pandemic and, more recently, defense and rearmament.

The climate policy trilemma underscores the need to accelerate mitigation to slow and eventually reverse the accumulation of greenhouse gases, while simultaneously scaling up adaptation to contain mounting losses and restoration needs from extreme climate events (Bilal et al., 2024). Effective adaptation can buy time for mitigation policies to take effect, whereas delay makes both strategies progressively riskier, costlier and potentially less effective.

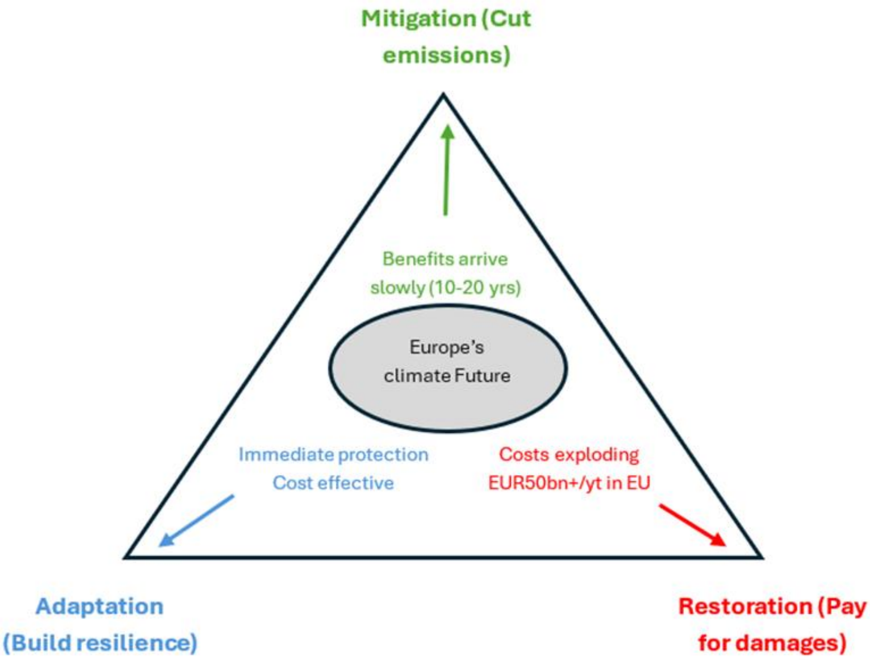

Figure 6. The Climate Trilemma: mitigation is essential but slow to take effect, restoration alone is unsustainable, and adaptation remains the neglected middle ground. Source: authors.

A central feature of the trilemma is that transition risks and physical risks are not substitutes that offset one another if action is postponed; they are mutually reinforcing. If mitigation, including the green energy transition, is delayed, atmospheric greenhouse gas concentrations will continue to rise, geophysical inertia will lock in additional warming, and physical risks (extreme events, tipping points and associated restoration costs) will intensify.[25] At the same time, the later a significant transition begins, the steeper and more disruptive it must be, raising transition risks for firms, communities, regions, financial systems and public finances.[26] Deferred action on either front therefore amplifies overall climate, economic and financial risks, and increases the costs of managing them.

The climate policy trilemma—balancing mitigation, adaptation and restoration—has three important implications for macro-financial stability.

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[25] Rising physical risks and increasing global temperatures could lead to reduced carbon uptake (e.g., warmer oceans, fewer trees, methane release from thawing permafrost), making it harder to meaningfully mitigate emissions.
[26] See progress in climate mitigation across Europe being tracked by Eurostat Environmental accounts: https://ec.europa.eu/eurostat/statistics-explained.

- First, climate hazards and extreme events reduce output, weaken fiscal positions and debt sustainability, and can adversely affect sovereign and corporate credit ratings and borrowing costs. This, in turn, constrains the fiscal space available to finance mitigation, including the green energy transition. Using a sovereign default model, Mallucci (2022) finds that natural disasters undermine governments' ability to borrow externally, lower welfare, and that ongoing climate change will further tighten governments' access to international capital markets.
- Second, increasing climate-related losses must be absorbed by insurance and other risk-sharing mechanisms to buffer their economic and financial impacts. Where coverage is limited or absent, losses are either met through ad hoc ex post government support or are borne directly by households, firms and financial institutions, further crowding out resources for mitigation and adaptation.
- Third, beyond the immediate repair and relief costs, public budgets are indirectly hit through a shrinking tax base: climate shocks can induce long-lasting output losses and sectoral spillovers, which reduce tax revenues via hysteresis effects (Bachner et al., 2019). These dynamics underpin the macro-financial climate scenarios developed by the Network for Greening the Financial System (NGFS), a global coalition of central banks and financial supervisors that seeks to integrate climate-related risks into financial supervision, mobilize green finance and support the transition to a sustainable economy consistent with the goals of the Paris Agreement.[27]

To sum up, the climate policy trilemma shows that, in a rapidly deteriorating geophysical environment, governments should simultaneously accelerate mitigation, scale up adaptation, and finance growing restoration needs, all under tightening fiscal and financial constraints. Because transition and physical risks are mutually reinforcing rather than offsetting, delayed action on either front amplifies overall climate and macro-financial vulnerabilities and raises the long-run costs of adjustment. These dynamics underscore that climate policy is not only about choosing the "right" instruments, but also about acting within a shrinking window in which those instruments remain effective and affordable—an issue that becomes even more pressing once deep uncertainty and tipping points are taken into account.

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[27] See https://www.ngfs.net/en.

9. Deep uncertainty, tipping points and the case for precautionary climate actions

Future climate scenarios are not merely abstract constructs; they reveal profound uncertainty about future climate dynamics and the tipping points that may lie ahead. Therefore, they reinforce the case for robust precautionary actions (Broeders and Schlooz, 2021).[28] The human drive toward precautionary action is rooted in our evolutionary operating system designed to prioritize survival in the face of ambiguity. Just as a driver instinctively decelerates when approaching an unlit tunnel, the human nervous system responds to sensory gaps by increasing caution to avoid irreversible harm. This biological risk management—where the potential for a catastrophic loss outweighs the marginal benefit of speed or inaction—mirrors the logic of climate precaution: when facing a threat of global proportions and uncertain timing, the most adaptive response is to reduce velocity and proceed with extreme care, acknowledging that the cost of irreversible climate change is far greater than the cost of early intervention. Especially if not all information is available.[29]

Many future climate impacts — and the timing and magnitude of possible disasters — are not just unknown. They are fundamentally unknowable with current scientific tools, beyond the scope of standard statistical risk assessment (Bolton et al., 2020). Existing climate–economic models do not capture tail climate-related risks well and therefore may fail to anticipate how they could unfold. Because scientists cannot reliably quantify worst-case possibilities, conventional cost–benefit analysis is an inadequate guide to climate policy. This limitation is closely related to Weitzman's seminal critique of standard climate–economic damage functions. Weitzman (2009, 2011) argued that climate

[28] Deep or radical uncertainty refers to situations where neither the probabilities nor the impacts of future events can be known or quantified, unlike risk, where possible outcomes are identifiable and measurable. It encompasses unforeseeable events, such as natural disasters or technological disruptions, that may require re-evaluating current actions. Despite radical uncertainty and to manage such potential surprises, precautionary and adaptive strategies are necessary.

[29] The Threat Imminence Continuum model provides a key framework for understanding how humans shift both behavior and brain activity as danger becomes more immediate. Mobbs et al. (2007) used a virtual predator maze to show that the brain processes distal and proximal threats in fundamentally different ways. When a threat is remote or uncertain, activity is concentrated in the ventromedial prefrontal cortex, supporting slower, strategic evaluation and complex decision-making. As the threat moves closer and becomes clearer, neural activity shifts toward the periaqueductal gray in the midbrain, which orchestrates rapid, reflexive responses such as flight or panic.

policy cannot be evaluated adequately by focusing only on expected or average warming outcomes, as in conventional integrated assessment models such as DICE. The central problem is that climate change involves fat-tailed risks: low-probability but extremely high-damage outcomes whose probabilities and magnitudes are themselves deeply uncertain. Under such conditions, the expected welfare losses from catastrophic climate outcomes may dominate the policy calculus, even when the probability of those outcomes appears small or cannot be estimated with confidence. This "dismal theorem" logic implies that conventional cost–benefit analysis, when based on smooth damage functions and best-estimate scenarios, may understate the value of early and stringent mitigation. It therefore strengthens the case for precautionary, robust, and adaptive climate policy aimed at limiting exposure to catastrophic tail risks rather than merely optimizing around central projections. A precautionary approach holds that society should act strongly and early to avoid potentially irreversible, catastrophic harm at tipping points, even without complete certainty. This is indeed warranted precisely because the world may be drifting from an orderly transition toward a "too little, too late" scenario (Chenet et al., 2021; Gollier and Treich, 2023).

The last moment at which a precautionary approach remains both effective and affordable is not the tipping point itself: it occurs well before. Crossing a geophysical tipping point may mean triggering irreversible changes with significant latency. Therefore, if humanity's reaction time exceeds the intervention time remaining, risks are more likely to materialize, forcing humanity into crisis management and recovery rather than prevention. Effective ex-ante prevention is only possible when reaction time is shorter than intervention time, making early, proactive action essential long before the climate system reaches the physical brink. A window of effective climate intervention is the critical period during which specific mitigation and adaptation actions can produce the most positive outcomes.[30]

Building on this logic, deep uncertainty does not simply argue for "more" or vaguely defined "earlier" climate action: it calls for acting before the window of effective intervention closes. Rather than focusing solely on the scale of action, it also emphasizes timing – the narrowing period in which mitigation can still prevent dangerous, potentially irreversible shifts in the Earth's geophysical system. Suppose a climate tipping point could occur around an uncertain date $t = T$. Well before this date, the risk is still

[30] The concept of a window of effective intervention is applied in many fields. It is, for instance, crucial in medicine and is based on the merits of stopping the disease process at an early stage.

actionable: societies can adopt measures to avoid crossing the tipping point, and mitigation efforts can still have a large effect. We assess this by comparing the present discounted cost of adaptation (PDA) with the present discounted severity of a tipping point (PDS). The PDA measures present discounted value of the expense of planning and implementing actions such as building dikes or transitioning energy systems, which moderate harm and that reduces the need for crisis measures and large-scale restoration later on. The PDS presents the present discounted value of the expected damages and disruptions resulting from crossing the tipping point, including physical impacts (e.g. sea-level rise, extreme events), economic losses (e.g. productivity declines, asset destruction), and wider social consequences (e.g. displacement, instability).

Crucially, the height and shape of the PDS curve are not fixed: they depend on the level and timing of mitigation. Stronger and earlier efforts to decarbonize and undertake the green energy transition can lower the expected severity of a tipping point and reduce its probability, thereby flattening the PDS curve and effectively "opening up" or extending the window in which intervention remains effective. Early in time, the PDA may exceed the PDS – the present value of extensive damages, economic losses, and potential societal disruption from inaction – but as the window narrows and the tipping point approaches, the PDS rises steeply. **Figure 7** shows this effect and is provided for illustrative purposes and to build intuition. Analogously, the present discounted cost of adaptation (PDA) is also endogenous. Its height and shape depend on when and how adaptation and mitigation are undertaken. Early, coordinated mitigation and adaptation investments can reduce PDA over time by exploiting learning effects, technological progress, and better planning, and by avoiding costly lock-in, to vulnerable infrastructures and behaviors.

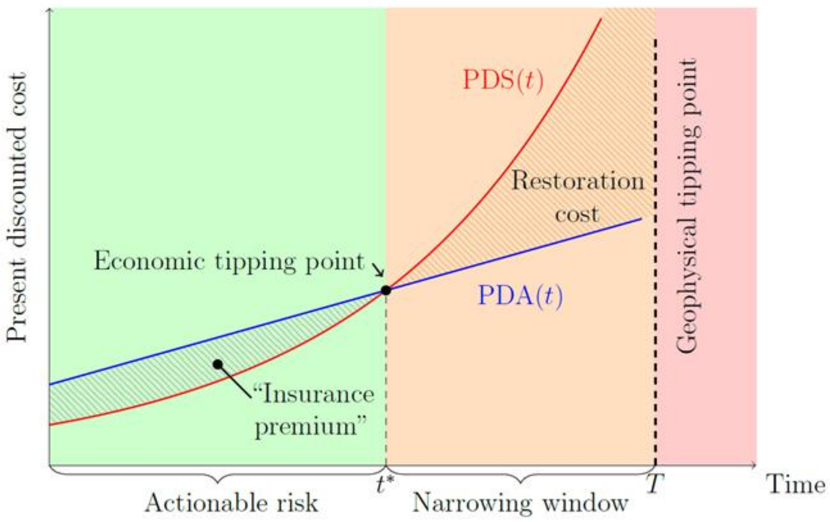

Figure 7. Economic tipping point. Source: authors.

By contrast, delayed or fragmented action tends to increase PDA: adaptation must then be implemented under higher physical stress, with less room for optimization, often in crisis conditions, making it more expensive and less efficient. Thus, both the PDS and PDA curves are shaped by today's mitigation and adaptation choices, and, together, they determine how quickly the effective window for intervention narrows or can be kept open. The insurance premium in Figure 7 can be understood as the difference between the PDA and the PDS before the economic tipping point is reached. This reflects the cost of hedging against catastrophic risks before they materialize. From an economic perspective, this premium is justified because early action reduces the probability of severe long-term damages, which are exponentially more expensive and disruptive to manage. By investing in adaptation and mitigation now, societies can avoid disproportionately higher costs of crisis management and restoration later, preserving economic stability and reducing the likelihood of draconian interventions that could undermine growth and social welfare. Restoration costs are defined as the difference between the PDS and the PDA after the economic tipping point has passed. These costs represent the financial, social, and environmental burden of attempting to recover from irreversible damage caused by delayed action. Restoration costs highlight the inefficiencies and financial burdens of delayed climate action.

Proactive climate action is crucial to prevent reaching an economic tipping point where mitigation becomes unfeasible. As we move closer to T, however, the risk becomes progressively less actionable. Simultaneously, the less action taken to avoid the tipping point, the more severe and potentially catastrophic the eventual impact becomes, causing the PDS to rise exponentially. At some point, well before T, these two trajectories cross in an economic "tipping point". Beyond this point, avoiding the tipping point would start requiring extreme, draconian measures, and it may in practice become unavoidable as the PDS has ballooned and the window for affordable, efficient prevention has closed. Early, precautionary climate action therefore acts as a hedge against the cost of catastrophic impacts and extreme, draconian interventions later. At the same time, the cost of this hedging should not be allowed to undermine the current economy. There are examples of actionable risks from recent history.

Deep uncertainty around climate tipping points demands immediate, precautionary actions. Waiting until risks become imminent makes effective intervention both prohibitively expensive and technically unfeasible, leaving only crisis management as an option. This dynamic is reflected in the NGFS scenarios: early, "Orderly" action operates as proactive hedging against catastrophic outcomes, while delayed or insufficient action in the "Disorderly" and "Hot House World" scenarios lead to escalating damages and a heightened likelihood of crossing irreversible tipping points. Overall, the analysis suggests that timely, decisive climate policy is essential to prevent the global economy from reaching its own tipping point, beyond which large-scale mitigation becomes economically and politically unfeasible, as illustrated in the NGFS pathways.

Two important caveats qualify this stylized representation. First, the diagram implicitly assumes that the relevant geophysical tipping point still lies ahead, whereas in reality some climatic thresholds may already have been crossed or irreversibly approached; in such cases, the window of actionable risk is already narrower than the figure suggests, and the scope for effective prevention is correspondingly constrained. Second, the figure abstracts from the post-tipping regime: beyond a geophysical tipping point, societies will still incur substantial adaptation, mitigation, and restoration costs, but the scale, composition, and dynamics of these expenditures are fundamentally uncertain and not amenable to meaningful quantitative characterization. We therefore deliberately omit this "unknown unknown" region from the schematic, using Figure 7 primarily as an intuition-building device for the pre-tipping trade-offs rather than as a complete depiction of the climate–economy system.

To sum up, deep uncertainty around climate tipping points shifts the policy question from whether to act to how early and how decisively to intervene before the window of effective action closes. Because worst-case damages are only imperfectly knowable yet rise steeply near tipping points, a precautionary strategy—treating mitigation and adaptation as insurance—dominates a wait-and-see approach that risks locking economies into crisis management and costly restoration. Building on this logic, Part III turns to the governance principles and policy levers needed to implement a just, feasible low-carbon transition.

PART III. Accelerating a just and feasible climate transition

This part explores practical strategies to accelerate a fair and feasible low-carbon transition, highlighting design principles and governance attributes, key levers that can accelerate mitigation and adaptation in practice, the importance of collective action, and lessons from the Paris Agreement to strengthen climate governance.

10. Levers to speed up the transition

Numerous countries have introduced green industrial and financial policies to foster decarbonization. Prominent examples are the 2019 European Green Deal, the US Inflation Reduction Act (IRA), and China's successive five-year plans for clean energy. Although the pace of decarbonization implied by the Paris Agreement remains insufficient, and current trajectories are still undershooting climate targets, the Paris Agreement nonetheless marked a turning point in global climate governance and in the deployment of renewables, thanks to clean-energy support packages.

Despite the world remaining off track relative to agreed climate targets, several levers for accelerating mitigation and adaptation have emerged. The following seven levers, discussed below, exemplify how targeted policy, financial and technological interventions can materially reduce both transition and physical risks while preserving macro-financial stability. At scale, the levers might be less costly than bearing the economic and welfare losses associated with escalating extreme climate events, particularly under disorderly NGFS transition pathways.

Lever 1. Raise the cost of carbon to align with the social cost of carbon. One crucial lever to accelerate climate action is increasing the cost of carbon emissions to better reflect the true social cost of carbon (SCC). Estimates of the SCC stand between $ 51 and $ 185 per ton of CO_2 (although much higher estimates exist). The average global carbon tax is currently about $ 5 per ton.[31] By gradually aligning carbon pricing with the SCC, policymakers can internalize the externalities of emissions and provide stronger economic incentives for businesses and individuals to shift toward low-carbon alternatives. Higher carbon prices can be implemented through mechanisms such as carbon taxes or cap-and-trade systems, both of which have proven effective in curbing emissions when designed appropriately.

However, rising carbon costs must be accompanied by measures to ensure fairness and equity. Proceeds from carbon pricing can be redistributed to mitigate the financial burden on vulnerable social groups and countries, contributing to an inclusive transition. Options include direct cash transfers, subsidized green investments, or funding for climate adaptation in low-income nations, particularly those most affected by climate change but least responsible for historic emissions. Redistribution mechanisms can also help gain public support for carbon pricing by addressing concerns over affordability and inequality. Additionally, integrating carbon pricing into international agreements could foster global cooperation by incentivizing countries to adopt more ambitious climate policies while discouraging carbon leakage.

Lever 2. Enhance climate disclosures and sustainability reporting. Reliable data enhances risk management, access to capital, compliance, planning, and coverage of value-chain and nature-related risks, among other functions (Salvi et al., 2025). The International Sustainability Standards Board (ISSB) developed the 2024 IFRS Sustainability Disclosure Standards to provide a global baseline for reporting material sustainability- and climate-related risks and opportunities that may affect enterprise value, cash flows, and the cost of capital over the short, medium, and long term. The standards, which were based on the earlier TCFD voluntary principles, are structured around four reporting pillars: governance, strategy, risk management, and metrics and targets. The EU's 2024 Corporate Sustainability Reporting Directive (CSRD) is also an important development using the

[31] The SCC is an estimate of the economic damages caused by emitting one additional metric ton of carbon dioxide into the atmosphere, or conversely the benefit of avoiding it (Hamber et al., 2024 and Asdourian and Wessel, 2023). For reference to OECD and IMF work on the "effective social cost of carbon", see also Mongelli (2023).

European Sustainability Reporting Standards (ESRS). Compared with earlier sustainability reporting frameworks, the CSRD/ESRS regime is mandatory and requires more structured disclosures across climate, workforce, biodiversity, pollution, water, governance, and value-chain topics.[32] More recently, the EU has been simplifying parts of the disclosure regime and materially reduced the scope of the CSRD through its "Omnibus" process.

Lever 3. Tax windfall rents to finance a faster, fairer climate transition. Taxing windfall profits from fossil fuels can help in three main ways (Baunsgaard and Vernon, 2022). *First*, windfall profits largely reflect economic rents generated by unexpected commodity price surges, not productive effort. Well-designed rent-targeting instruments—such as cash-flow taxes that apply only after a normal rate of return is earned—can capture these excess returns without distorting investment or production decisions. This preserves energy supply while raising substantial public revenue. *Second*, channeling this revenue into climate action can speed both mitigation and adaptation. Governments can fund clean energy deployment, energy efficiency, and low-carbon infrastructure, as well as climate-resilient infrastructure and social protection for households hit by higher energy prices. Because rents are concentrated in fossil-fuel-producing countries, using them for diversification supports a smoother transition away from carbon-intensive growth. *Third*, integrating rent taxes with carbon and methane pricing in the fossil fuel fiscal regime strengthens incentives to reduce direct (Scope 1) emissions from extraction and to retire high-emitting assets over time. A progressive, predictable regime also reduces pressure for ad hoc windfall taxes that might otherwise encourage new fossil fuel investment through generous allowances, thereby locking in emissions.

Lever 4. Expand profitable renewable energy deployment. A remarkable development over the past decade has been the rapid expansion of renewable electricity, much of which is now cost-competitive without subsidy support.[33] This shift reflects cumulative advances in science and technology, early-stage policy support, and economies of scale. Renewables supplied about 30% of global electricity in 2025, up from roughly 23% in 2015 (IEA, 2025b). In the EU, 2025 marked a symbolic milestone: wind and

[32] The CSRD's defining feature is double materiality. The European Financial Reporting Advisory Group (EFRAG), established in 2001, provides technical expertise and advice to the European Commission. EFRAG and the Global Reporting Initiative (GRI), an independent international organization, also advocate for the interoperability of disclosure standards.
[33] See: https://www.breakthroughenergy.org/ and the technologies for the decarbonization are mapped in a new Climate Tech Map, see: https://climatetechmap.com/.

solar together generated more electricity than fossil fuels for the first time, with renewables accounting for over 90% of new power capacity added between 2023 and 2025.[34] Solar photovoltaics has become the cheapest source of electricity in many regions after cost declines approaching 90% since 2010, though wind power expansion has been hampered by supply-chain bottlenecks, permitting delays and higher capital costs. Grid-scale battery storage, negligible in 2015, has scaled rapidly, enhancing system flexibility and facilitating the integration of variable renewables, whereas hydropower, geothermal and bioenergy have grown more modestly owing to environmental and geographic constraints.

Addressing remaining supply-chain and regulatory frictions is critical to sustaining this momentum. Scalability faces bottlenecks, including limited access to rare earths and essential minerals like copper and aluminum. Addressing these supply chain issues is vital to accelerating clean energy transitions. Recent estimates suggest that the deployment of renewables over 2015–2025 has avoided on the order of 7–10 Gt CO_2 that would otherwise have been emitted by fossil-fuel power generation, a non-trivial contribution given annual global CO_2 emissions of around 36–37 Gt.[35]

Lever 5. Deploy more innovative finance. Even though Europe has ample private savings, current financing arrangements are not channeling this supply toward demand. Nearly four in ten European firms see the lack of investor willingness to finance green investment as a significant obstacle (Lagarde, 2025). The types of funding encompass bank loans, loans with fiscal support, retained earnings, debt securities and equity (Andersson et al. 2025). A weak link here is capital markets: debt and equity financing currently rank lowest among the funding sources that firms expect to use for green investment. Deepening and integrating EU capital markets is critical to supporting the large-scale investments needed. Closing the climate investment gap requires not just more capital, but smart financial structures that can mobilize private investment at scale. Innovative finance aims to reduce risks, lower the cost of capital, and align financial incentives with long-term climate goals.

One avenue is the growth of blended finance and innovative climate bonds, where public funds are used to "crowd in" private capital. If governments provide first-

[34] See https://ember-energy.org/latest-insights/european-electricity-review-2026/.

[35] So renewable expansion has avoided roughly 20–30% of one year's global emissions, spread over the past decade. This has resulted in about a 0.01°C reduction in warming so far. Yet the pace is accelerating. In 2025 alone, renewables are projected to prevent around 2 Gt CO_2—an amount comparable to the annual emissions of the entire European Union.

loss tranches or credit guarantees, they can make projects that would otherwise be considered too risky more attractive to private financiers (Monasterolo et al., 2025). Another area is the growth of green, sustainability-linked, and transition bonds and loans. Green bonds earmark proceeds for climate-aligned projects, while sustainability-linked instruments tie the pay-off to the achievement of emissions-reduction or other environmental targets. Transition finance is emerging to support high-emitting sectors — such as steel, cement, and shipping —in credibly moving toward lower-carbon technologies rather than being starved of capital altogether. Ensuring robust taxonomies and disclosure standards is essential here to avoid greenwashing and to maintain investor confidence. Climate-linked bonds can accelerate the transition process by directly aligning governments' financial incentives with climate action, encouraging immediate mitigation efforts. The bonds' structure, where payouts are linked to climate variables, means the present discounted cost of servicing the debt decreases with better climate outcomes, providing a long-term fiscal motivation for effective climate policies and continuity across administrations. By distributing long-term climate risks and enhancing market pricing, these bonds signal a credible commitment to a net-zero future, mobilizing private sector investment in sustainable practices (Broeders et al., 2025). Furthermore, innovative instruments should be complemented by mainstreaming climate objectives in traditional finance, with macroprudential policy using targeted buffers and incentives to steer funding toward credible transition activities, away from non-transitioning firms, thereby safeguarding financial stability (Ikeda and Monnin, 2024).

Lever 6. Address the supply side of fossil fuels alongside demand-side measures. The current transition discourse is largely focused on the demand side, emphasizing efficiency improvements, behavioral change and the deployment of low-carbon technologies. Yet an effective and orderly transition also requires sustained attention to the supply side of fossil fuel production and use. Without credible strategies to manage the gradual phase-down of fossil fuel extraction, demand-side efforts risk being undermined by continued investment in carbon-intensive assets and infrastructure. This is particularly salient for countries whose political economies and public finances remain heavily dependent on fossil fuel rents and related export revenues. In these cases, governments face complex trade-offs between short-term fiscal stability, employment and growth, on the one hand, and long-term climate commitments and transition risks, on the other. Integrating supply-side measures—such as caps on new exploration, sunset clauses for production licenses, and frameworks for diversifying resource-dependent economies—

into climate policy debates is therefore essential. Doing so would help align national development strategies with the objectives of the Paris Agreement and reduce the risk that continued wealth generation from fossil fuels locks in high-emission pathways and deepens global climate and distributional tensions.

Lever 7. Increase the role for carbon management. Carbon management includes various techniques such as carbon capture and storage (CCS), carbon dioxide removal (CDR), and carbon capture, utilization and storage (CCUS). The IPCC highlights that, if we are to achieve the ambitions of the 2015 Paris Agreement and limit future temperature increases, we must do more than simply increase efforts to reduce emissions—we also need to deploy technologies to remove CO_2 from the atmosphere. The IPCC defines CCS as a "process in which a relatively pure stream of carbon dioxide (CO_2) from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere" (IPCC, 2022). The Potsdam Institute for Climate Impact Research (PIK) is especially interested in options to remove carbon dioxide from the atmosphere (CDR), and approaches to capture and store CO_2 emissions (carbon capture, storage and usage, CCUS), comprising both biogenic and anthropogenic carbon flows (Strefler et al., 2021).[36] Occupying the upper end of the marginal abatement cost curve, these techniques are often treated as a last resort compared to cheaper primary mitigation like renewables. The current combined contributions of carbon management approaches appear to be in the range of 0.1% of current GHG emissions. At the same time, the technologies are advancing rapidly and hold potential in specific sectors such as cement production and oil refining.[37]

Climate policy effectiveness depends also on perception, salience, trust, fairness, and political acceptance. The emphasis on cognitive and psychological factors discussed in Section 5 does not imply that climate policy can be reduced to psychology, nor that formal economic models should be expected to incorporate the full complexity of human perception, attention and belief formation. Rather, these factors help explain why technically sound policy prescriptions are often delayed, diluted or resisted in practice. The levers mentioned here therefore remain useful for clarifying the economic structure of the climate problem—externalities, public-good provision, intertemporal trade-offs and policy

[36] See https://www.pik-potsdam.de/en/institute/departments/transformation-pathways/wgs/integrated-assessment-modelling/carbon-management-1.
[37] See https://en.wikipedia.org/wiki/Carbon_capture_and_storage.

constraints—but they must be complemented by an explicit recognition that policy effectiveness depends on perception, salience, trust and political acceptability. For this reason, the policy levers should be understood not only as technological, financial or regulatory instruments, but also as instruments that must be designed to overcome cognitive and behavioral barriers: by making climate risks more salient, reducing complexity, building credible long-term commitments, increasing trust in institutions, and aligning short-term private incentives with long-term collective goals. In this sense, psychological factors are not external to the policy framework; they are part of the transmission mechanism through which climate policies become feasible, credible and effective.

To sum up, despite slow global progress, community management and green industrial policy show that well-designed interventions can materially reduce emissions and support a low-carbon transition. A successful climate policy regime must be comprehensive, coherent, and incentive-compatible. It should not consist of fragmented measures that pull in different directions, but of a mutually reinforcing framework that aligns private incentives with the social objective of rapid decarbonization while preserving energy security, affordability, and financial stability. Such a framework should be coordinated at the international (e.g., EU) level and, where possible, beyond, given cross-border energy markets, carbon leakage risks, industrial supply chains, and the global nature of climate externalities. It must also be consistent with a long-term strategy for transforming the energy system, including the expansion of renewable generation, grid infrastructure, storage, electrification, demand-side flexibility, low-carbon industrial processes, and resilient supply chains.

11. Past successes of collective action

The levers discussed in the previous section illustrate that accelerating mitigation and adaptation is technically and financially feasible, and likely far less costly than facing escalating climate damage. At the same time, it is clear that climate perception, salience, trust, fairness, and political acceptance must be strengthened. The remaining question is whether these instruments can be deployed at sufficient scale and speed. Are there relevant historical precedents?

Collective action has successfully addressed environmental and health threats in the past. Examples include the international response to acid rain in the 1980s. In

Europe and North America, coordinated policies—such as sulfur dioxide (SO_2) emission caps, flue-gas desulfurization technologies ("scrubbers"), and switching to lower-sulfur fuels—led to sharp reductions in transboundary air pollution and a gradual recovery of affected ecosystems. Similarly, the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, strengthened by subsequent amendments, mandated a global phase-out of chlorofluorocarbons (CFCs) and related chemicals. As a result, atmospheric concentrations of ozone-depleting substances have declined, and the ozone layer is on track to recover over the course of this century, demonstrating that timely, science-based multilateral cooperation can reverse severe environmental damage.

Moreover, collective action has successfully addressed other threats in the past. To address concerns about the Year 2000 software bug, airplanes were grounded and hospitals were secured. Faced with COVID-19, societies mobilized at unprecedented speed and on a life-saving scale. In the context of past global challenges history shows that solutions are possible, given adequate policy responses. However, while these examples could be addressed with targeted measures and without overhauling the entire economy, climate change might be more arduous. It requires more structural changes to the economy and a widespread shift in global awareness, cognition and behavior. A large number of similar successes, both big and small, would be needed simultaneously.

12. Closing the climate action gaps: final remarks

A decade after the Paris Agreement, global greenhouse gas emissions have not yet begun a decisive decline, and both the "ambition gap" and "implementation gap" remain substantial. Yet the picture is not one of failure, but of partial progress, uneven learning, and rapidly expanding capabilities that can still be harnessed at scale. Understanding why collective action has lagged is essential to accelerating the transition. Several barriers have constrained momentum. Outdated mental models of how economies, technologies, and ecosystems interact have limited recognition of systemic climate risk, contributing to an awareness gap among decision-makers and the public. Concurrent shocks—health, financial, and geopolitical crises, as well as war—have repeatedly displaced climate from the top of policy agendas. Regulatory fatigue has emerged in some jurisdictions, where calls for "less red tape" can slow the deployment of effective instruments. Attitudes toward climate policy have also become more polarized in places, and in some societies, disillusionment has grown about the feasibility of coordinated global action. Addressing these layers together is crucial if climate policy is to match the scale and urgency of the challenge.

At the same time, physical climate risks have become more visible. The increasing frequency and severity of extreme events, together with the emergence of chronic risks, now provide direct evidence of a warming world. Scientists warn of climate inertia, tipping points, and planetary boundaries that, if transgressed, could trigger irreversible and nonlinear changes in Earth systems. Nevertheless, the Paris framework remains a central pillar of global climate governance and can still anchor stronger collective action. Over the last ten years, it has also catalyzed important advances: a growing role for private actors, new policy and financial tools, and rapid innovation in low-carbon technologies.

Two temporal dimensions now define effective climate risk management: reaction time and intervention time. Reaction time is the delay between scientific warnings and the implementation of robust policy responses, including the time required for negotiation, legislation, and deployment. Intervention time is the shrinking window in which those responses can still prevent crossing critical tipping points. Aligning these two clocks is a central task for climate governance. Even in jurisdictions skeptical about climate risks, reducing emissions is a risk-management strategy: it preserves flexibility under uncertainty, allows societies to adapt as evidence evolves, and lowers the probability of irreversible damage (van Wijnbergen and Willems, 2015).

History shows that coordinated responses to systemic threats are possible. International action to curb acid rain, the Montreal Protocol on ozone-depleting substances, preparations for the Year 2000 software risk, and the rapid mobilization against COVID-19 all demonstrate that when risks are clearly communicated and policy design is credible, collective action can be swift and effective.

Recent years have also seen strong private-sector advances. Innovation in renewables and related technologies has driven down costs and created globally competitive industries. Remaining constraints—including access to critical minerals, smart-grid deployment, and affordable storage at household, regional, and seasonal scales—are increasingly well-defined engineering, financial, and governance challenges. Targeted investment, streamlined permitting, and secure supply chains for key materials such as lithium, cobalt, copper, aluminum, and rare earths can unlock further acceleration. Free markets, when effectively incentivized, can serve as powerful catalysts for the green transition, fostering competition and driving technological innovation. Mechanisms like carbon pricing, tradable permits, and sustainability-linked financial tools internalize environmental costs and align business incentives with climate goals. Historical examples, such as the rapid cost declines in solar and wind energy, demonstrate the transformative potential of market-driven solutions. By mobilizing private capital and enabling decentralized innovation, markets can support a sustainable and economically efficient global energy transition.

Public policy remains pivotal. Reinvigorating global climate governance, clarifying national targets and harmonizing approaches are essential to restore credibility and predictability. Achieving net-zero emissions requires coherent policy packages that combine instruments, account for their interactions and sequencing, and draw on systematic ex-post evaluation of what works in different contexts. Simplified and coordinated permitting, together with better resolution of land-use conflicts, can reduce delays in deploying low-carbon infrastructure.

Crucially, climate- and nature-related risks are inseparable. Rising temperatures, shifting precipitation and more frequent extremes are accelerating land degradation, water stress and ecosystem disruption, eroding biodiversity and weakening ecosystem services such as pollination, water regulation, coastal protection and carbon sequestration. Crossing ecological tipping points — including the collapse of key ecosystems — would send powerful shocks through food systems, health outcomes, migration patterns and asset values. Integrated strategies that jointly address mitigation, adaptation, and ecosystem restoration, supported by robust assessment and disclosure frameworks, are therefore indispensable.

The future of humanity under climate change is not predetermined. It will be shaped by how fast policy catches up with science, how effectively public and private actors collaborate, and how ambitiously societies expand mitigation, adaptation, and innovative finance. Acting now—cutting emissions decisively while building resilience—not only reduces future harm but also preserves strategic options, stabilizes expectations, and keeps orderly transition pathways open. The window is narrowing, but it remains open, and the tools at our disposal have never been more powerful. Remaining adaptive in the face of uncertainty is critical to navigating the complex and evolving challenges posed by climate change. Deep uncertainties surrounding tipping points, ecosystem responses, and the pace of technological breakthroughs underscore the need for policies and strategies that can evolve as evidence and conditions change. Adaptive approaches preserve flexibility, allowing societies to recalibrate efforts as scientific insights deepen and risks become clearer. They also prevent lock-in to ineffective or overly rigid pathways, ensuring that options for mitigation, adaptation, and restoration remain open. Climate governance must embrace this adaptability, integrating robust monitoring systems, iterative policy design, and contingency planning to manage risks and capitalize on emerging opportunities. In the face of uncertainty, adaptability becomes a cornerstone of resilience and long-term climate governance.

We finish with three lessons that follow from the Paris Agreement reached ten years ago. First, the Paris Agreement demonstrates the anchoring effect of a long-term global goal. The Paris Agreement's central objective—limiting temperature rise to well below 2°C and pursuing 1.5°C—has proved indispensable as a shared reference point. It has guided national strategies, corporate planning, and financial risk assessment, and helped align expectations about the direction of travel, even where implementation is incomplete. Second, international cooperation changes trajectories, even if it falls short of stated aims. Global emissions have not yet peaked, but their growth has slowed to around 0.3% per year, less than one-fifth of the rate recorded in the preceding decade. This suggests that coordinated commitments, combined with technology and policy diffusion, have materially altered the baseline path. The world would likely be in a far more precarious position without the Paris Agreement. Third, pledges must be coupled with credible implementation systems. The "ambition gap" has been joined by an "implementation gap." Paris has shown that bottom-up nationally determined contributions can mobilize participation, but durable progress requires robust domestic policies, transparent tracking, and mechanisms to regularly ratchet up ambition and delivery.

A climate policy paradigm shift is needed, and many of its elements already exist. Yet the narrowing window for implementing timely and effective mitigation and adaptation measures starkly reveals a persistent deficit of urgency in practice. A new climate policy paradigm should therefore not be understood as a rejection of existing instruments—carbon pricing, regulation, public investment, innovation policy, disclosure, adaptation finance, or international coordination—but as a change in the logic that organizes them. The old paradigm treats climate policy largely as a problem of marginal emissions abatement under known risks, to be optimized through discrete instruments and gradual adjustment. The new paradigm starts instead from deep uncertainty, tail risks, tipping points, policy inertia and geophysical inertia, and the possibility of catastrophic outcomes. It therefore requires a systemic, precautionary, adaptive, and incentive-compatible framework that can “tilt the odds” away from irreversible climate damage even when probabilities are poorly known.

In this new climate policy paradigm, climate policy is not an environmental add-on to economic policy. Instead, it becomes a core organizing principle of macroeconomic, financial, industrial, energy, trade, and security policy. Existing levers remain necessary, but they must be deployed as mutually reinforcing elements of a long-term transformation strategy: accelerating the transition to net-zero greenhouse gas emissions, scaling clean-energy infrastructure, strengthening resilience, aligning private incentives with public objectives, and maintaining political legitimacy through a just and equitable transition.

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Dirk Broeders

European Central Bank, Frankfurt am Main, Germany; Maastricht University, Maastricht, The Netherlands;
email: dirk.broeders@ecb.europa.eu

Francesco Paolo Mongelli

Goethe University Frankfurt, Frankfurt am Main, Germany; email: mongelli@econ.uni-frankfurt.de

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

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