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Why do we need to strengthen climate adaptations? Scenarios and financial lines of defense

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Abstract

Adaptation needs are vast, rising fast and difficult to determine in their entirety, especially with uncertain adverse scenarios due to climate inertia and implementation lags. Adaptation is hindered by a lack of a unified understanding of what it necessitates; the challenge in pointing out its costs, benefits, and residual risks; insufficiently prescriptive policy and legal frameworks; and the growing financing gap. Conversely, we now have better granular climate data to study the impacts of climate hazards and forecast climate risks; there is awareness that adaptation choices must be dynamic and reactive; and there is an increasing pool of case studies from which to learn. There is evidence that efficient adaptation investments can yield "triple-dividends" helping to close the financing gap. There is a need to absorb and smooth the impacts of rising extreme climate events. Innovative financial instruments, such as catastrophe bonds and climate bonds, might support challenged insurance coverages.

JEL classification: E52, Q54

Keywords: climate change, environmental economics, climate disasters, climate adaptation, resilience, climate financing.

Non-technical summary

This paper reviews several aspects of climate adaptation with a focus on Europe. Global temperatures are rising at an accelerating pace, especially in Europe, accompanied by growing extreme climate-related events, causing rising damages and losses. Consequently, in addition to climate mitigation efforts there is an urgent need for climate adaptation. Adaptation involves managing and reducing the impacts of climate change, aiming to build resilience across societies, economies, and ecosystems.

Climate Adaptation vs. Mitigation

While mitigation reduces greenhouse gas emissions to curb global warming, adaptation tackles the immediate and long-term effects of climate change. Adaptation strategies must be dynamic, context-specific, and multi-layered, considering regional, national, and local needs. Effective adaptation can minimize damages, support resilience, and reduce economic spillovers. However, significant trade-offs exist between adaptation costs, benefits, and residual risks.

Policy Framework and Legal Obligations

Internationally, the Paris Agreement introduced a "global adaptation goal" to enhance resilience, though adaptation commitments remain loosely defined. In Europe, the European Climate Law mandates progress toward adaptation goals by integrating them into governance structures and policies. The 2021 EU Adaptation Strategy outlines systemic, smarter, and faster approaches, emphasizing mainstreaming adaptation at all levels. Legal obligations are supplemented by rising climate litigation, with cases demanding accountability for insufficient adaptation measures.

Economic and Financial Dimensions

Adaptation financing needs are already vast, rising fast and at the same time difficult to determine in their entireness especially with evolving adverse scenarios stretched into an uncertain future. Adaptation financing is severely underfunded compared to mitigation. Public sector contributions dominate, but gaps persist in mobilizing private investments. Mechanisms like blended finance and innovative financial instruments, including catastrophe bonds (cat bonds) and green bonds, are emerging as potential solutions. Insurance coverage, critical for climate risk management, remains inadequate, especially in high-risk regions like southern Europe.

Benefits of Adaptation

Investments in adaptation generate triple dividends: avoided damages, economic gains, and socio-environmental benefits. For instance, strategies like building dikes and using nature-based solutions can significantly mitigate flood and coastal damage. However, cost-benefit analysis remains complex due to uncertainties in climate models and sectoral impact assessments.

Main findings

Cimate adaptation is hindered by several factors including: a lack of a unified understanding of what it is (should it be incremental or transformational?); the challenge in pointing out its costs, benefits and residual risks; its legal and policy framework are still loosely defined;

and the growing financing gap stemming also from a lack of a clear guidance for financial markets (there is no unified “adaptation taxonomy”). Conversely, in recent years there has been great progress on diverse fronts. We have better granular data to study the impacts of climate hazards and forecast climate risks, there is awareness that adaptation choices need to be dynamic and reactive due to shifting climate scenarios, and there is an increasing pool of successful case studies from which to learn. There is also empirical evidence that adaptation investments can be tremendously impactful and beneficial (adaptation might yield “triple-dividends”). This should facilitate private sector involvement in closing the adaptation financing gap. During the transition, we argue that there is a need to absorb and smooth the impacts of rising idiosyncratic climate hazards. Here, innovative financial instruments, such as catastrophe bonds and climate bonds, might support challenged insurance coverages. Aligning adaptation strategies with unfolding climate scenarios is essential to manage future climate risks and minimize economic and financial spillovers.

Conclusion

Climate adaptation is an urgent, multifaceted challenge that requires substantial coordination, investment, and continuing innovation. While progress is being made, gaps in financing, and implementation delays hinder effective action. Scaling up adaptation measures, supported by legal frameworks and financial innovation, is essential to minimize the socio-economic and environmental risks of a warming planet. Closing the adaptation financing gap, enhancing resilience, and developing comprehensive adaptation strategies are critical steps toward a sustainable and climate-resilient future. Local-specific strategies, and public-private partnerships are also critical for scaling adaptation efforts. A robust European Sustainable Finance Framework is needed to align financial flows with adaptation goals.

"Warning came, no one cared Earth was shakin', we stood and stared. When it came no one was spared. Still I hear 'Burn!'" Deep Purple, Burn 1974.

1. Introduction

Global temperatures are rising at an accelerating pace and so are climate extremes. According to the World Meteorological Organization, 2023 was the hottest year on record by a clear margin (WMO (2024)). On a moving averages basis, in December 2023, global mean temperatures (GMT) surpassed by an estimated 1.26°C pre-industrial levels (Copernicus Climate Change Service (2024)). The past decade has consistently witnessed the warmest years on record, underscoring the hastening pace of climate change. Rising global mean temperatures are accompanied by increases in climate extremes, such as heatwaves, droughts, wildfires, and floods. It also leads to accelerating sea-level rise, which represent an existential hazard for many low-lying coastal settlements in the long term (IPCC (2024) and EEA (2021).

Unabated climate change poses a contemporaneous need for climate mitigation and adaptation. Climate mitigation concerns the containment of GHG emissions that is necessary to slowdown the rise in temperatures, intensity of climate-related extreme events and environmental degradation (IPCC (2022) and UNFCCC (2022)). Larger geographical areas, assets and people become exposed to and vulnerable to climate hazards. Climate adaptation, instead, seeks to prevent and reduce the adverse social, economic, and financial impacts of climate change.[1] While successful mitigation limits further warming, rising climate extremes and environmental degradation, adaptation is indispensable to deal with its effects and minimize climate damages and losses. It also supports climate resilience and the ability of society, the economy and ecosystem to recover from extreme events. We need adaptation to cope with the effects of climate change.

The state of climate adaptation matters also for central banks in fulfilling their mandate(s). Without adequate adaptation, more and more people, urban as well as rural areas, infrastructures, buildings, factories, and farms can be damaged when exposed to climate hazards. All activities are affected such as crop yields, labor supply, employment patterns, electricity supply, etc. This can also have a pronounced and lasting impact on price fluctuations, as well as the level and volatility of inflation (Parker et al. (2024), Kuik et al (2024), and Ciccarelli et al (2024)), generate increasingly severe economic losses, affect the financial system and the transmission of monetary policy, and the ability of governments in supporting climate policies.[2] Rising climate extremes and the state of adaptation will increasingly be reflected in sovereign credit ratings impacting the sovereign-bank nexus (Bernhof et al. (2024)). The state of climate adaptation is also critical for assessing financial stability risks and risk management practices. Moreover NGFS (2024) surveys the links between adaptation finance, insurance protection gaps and the prudential risks that a failure to adapt could pose to the financial sector.

[1] In addition to mitigation and adaptation, there is also an emerging discussion pertaining to carbon dioxide removal (CDR, see Edenhofer et al. (2023)).

[2] The literature on the impact of adaptation on inflation levels and volatility is scarce. We might obtain some indirect inferences due to the lack of adaptation. Empirical studies are documenting that between 1961 and 2016, shifts in international food commodity prices, caused by harvest shocks, explain 30% of euro-area inflation volatility in that period (Peersman (2022)). Heat stresses might lower energy supply and require adaptation of power plants. Climate hazards and heat stress lower agricultural productivity and food supply and raise prices. Kotz et al. (2024) account for historical adaptations, which may have evolved via socio-economic development or prolonged exposure to different climate conditions, or through adjustment to warmer climatic conditions. They find limited effects.

Overlaps, but also differences, exist between mitigation and adaptation. In terms of time horizon, the impact of mitigation unfolds over time with lags, whereas adaptation measures are needed to make society more resilient to climate extremes in the short and medium term, they are cogent. In terms of verifiability, advancements in mitigation can be assessed with respect to quantifiable reductions in GHG emissions as well as slowing down further increases in global average temperatures (e.g., to below 1.5°- 2°C above pre-industrial levels). In contrast, climate change adaptation hinges on context-specific factors and needs to be adjusted and tailored to the specificities of national, regional, and local levels: these might evolve over time, i.e., there is *adaptation specificity*. In terms of its management, climate adaptation needs to be dynamic and flexible, as it will be driven by shifting climate risks of uncertain severity (it requires decision making under uncertainty). In terms of intertemporal policy choices, adaptation presents society and decision makers with a need to choose between how much to invest in it versus how much residual risk, and economic and financial losses, it is prepared to accept. Thus, there are *trade-offs among adaptations' costs, benefits, and residual damages*.

Climate change adaptation is not only a necessity, but also an obligation by law. The **Paris Agreement (2015),** which is a legally binding international treaty adopted by 195 signatory countries and the EU, included a 'global adaptation goal' among its objectives. However, the Paris Agreement did not introduce a uniform definition on climate adaptation, and the obligations imposed on the Parties focus on adaptation planning. Efforts were then made to implement this general goal into EU law. The **European Climate Law (2021)** established a duty for relevant EU institutions and Member States to ensure '*continuous progress*' towards adaptation by 2050 ('EU adaptation goal'). The European Climate Law requires the European Commission to formulate an EU strategy on adaptation, while regularly reviewing the collective progress made by the obliged EU institutions and Member States towards the EU adaptation goal. Moreover, relevant EU institutions and Member States are obliged to support the integration of adaptation measures in all policy areas, and Member States must adopt and implement national adaptation strategies and plans. To that end, the European Commission adopted a revised **EU Adaptation Strategy** in 2021, to promote adaptation strategies and actions in several key policy areas.

Climate change adaptation may also be driven by climate litigation based on alleged breaches of human rights law, international and national obligations, and tort law. A further source of legal obligations to plan and implement climate adaptation measures might be derived from human rights law, in particular **climate litigation based on human rights law**. Litigants are increasingly arguing that failure to plan and implement climate adaptation measures undermine their ability to enjoy a range of human rights. Litigants may also argue that states and/or private actors failed to fulfill their legal obligations established under international and national law where they fail to take sufficient adaptation action *('strategic' cases)*. Additionally, individuals who suffer harm due to climate related hazards may take initiate claims against state or private actors seeking damages due to their failure to implement adaptation measures *('polluter pays' cases).* An initial number of cases suggest that legal challenges centered or related to climate adaptation and human rights might increase in the future, driven by the worsening of climate scenarios.

We are mindful of a trilemma between damage restoration, mitigation, and adaptation efforts. The trilemma consists of three apexes: **damages and losses restoration** and compensation following climate-related extreme events, **mitigation** efforts

to slowdown climate change and rising climate extremes, and **adaptation** strategies and actions to reduce the impacts from climate hazards. A reactive approach relying principally on damage restoration and compensation, for example through public funds and insurance coverage, will become more costly for society, the economy and ecosystem, and fiscally unsustainable, if mitigation efforts are insufficient and adaptation actions are inadequate. Thus, underinvesting in adaptation might backfire in the short- and medium-term by draining public resources while shrinking the tax base. Instead, underinvesting in mitigation might backfire at any time.

Our aim is to review several aspects of climate adaptation. Although there is a considerable amount of literature on climate mitigation, there is a dearth of information on the drivers, climate zone specificities, state of implementation and transmission channels of climate adaptation. In this paper, we adopt a broad definition of adaptation which also includes enhancing climate resilience, widening climate insurance coverage as well as promoting financial instruments to either fund climate policies or absorb the impacts of climate change hazards. Climate hazards insurance and risk-sharing is needed to give mitigation and adaptation a chance to advance steadily. Thus, the concept of "adaptation" as referred to throughout this paper encompasses these aspects. The goal is to address topics relevant for central banks and the financial community.

The paper is organized in three broad parts. The first part is about geophysical processes. In **Section 2,** we examine the accelerating trends in climate change and global warming. In **Section 3,** we show how unabated climate change is exacerbating climate-related extreme events generating rising damages and losses. Such estimates are of overwhelming importance to study the need for mitigation and adaptation. The second part of the review discusses what adaptation entails and how it should be structured. In **Section 4,** we present a broad definition of climate adaptation and highlight its complexities underpinning policy decisions concerning where to adapt, how and to what extent, against a background of evolving climate risk. Adaptation is an obligation by law and in **Section 5** we and review recent international and European legislation and litigations. In **Section 6** we discuss how the European governance supports adaptation. In **Section 7** we consider to what type of world we are adapting. This section is dedicated to the analysis and comparison of the impacts of adaptation strategies based on the PESETA IV climate study: one of the main assessments of economic impacts of climate change. In the third part of the review, we direct our focus towards the enablers of adaptation: i.e., a shift in economic governance and financing of adaptation. We argue that adaptation financing needs are likely to rapidly rise in coming years. Unheeded, they might do harm faster than mitigation financing gaps and result in economic and financial adverse feedback loops. In **Section 8,** we review the role of the public sector which currently is the pivot and node of adaptation strategies. In **Section 9,** we argue that it is indispensable to raise various additional "lines of defense" including insurance coverage, Cat-bonds, and Climate Bonds. **Section 10** presents some final remarks and issues for further discussion.

"The lights go out and I can't be saved. Tides that I tried to swim against have brought me down upon my knees. Oh, I beg, I beg and plead." Coldplay Clocks, 2002.

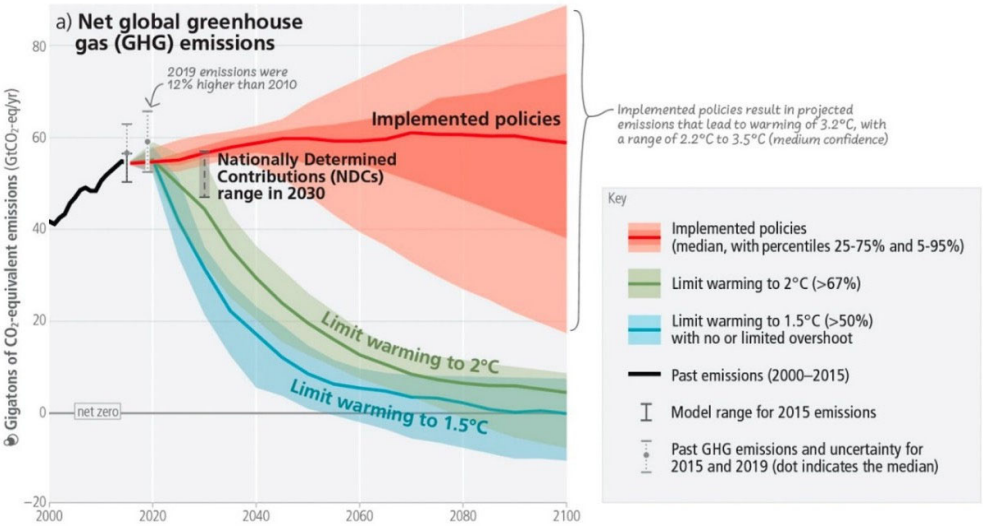
2. Recent empirical evidence on climate change

The urgency of addressing climate change cannot be overstated. Empirical evidence shows that global temperatures are rising at an accelerating pace, propelled by cumulated

GHG emissions. Thus, we are close to breaching the objectives set in the 2015 Paris Agreement, to limit global warming to below 2 °C, but preferably below 1.5 °C, compared with preindustrial levels (1850-1900).[3] A worrisome feature is that Europe is the fastest warming continent, with certain macro-regions expected to experience disproportionately severe impacts. Rising temperatures are increasing the risk of concurrent climate hazards and intensify feedback loops in the climate system, which could lead to crossing tipping points (McKay et al. (2022)), such as the potential collapse of the Atlantic Meridional Overturning Circulation (AMOC). Without timely and effective mitigation efforts, these changes may become irreversible.

Global net GHG emissions are not yet declining, they are at best plateauing. While European GHG emissions have been declining for a while, global GHG emissions are still on an upward trajectory (Figure 1). Recent data from the Global Carbon Project confirms a worrying trend: carbon emissions from fossil fuels are still increasing globally, albeit at a declining pace, by 1.1% in 2023 compared to the previous year. This extends a decade-long plateau in global CO2 emissions, deviating from the necessary trajectory that would be essential to achieve climate objectives. As a result, temperatures are accelerating.

Figure 1. Net Global GHGs Emission Pathways and Resulting Future Warming Levels



Source: IPCC AR6 Synthesis report (2023).

Two opposing developments stand out: a collapse in land carbon sinks and a sharp decline in the cost and deployment of renewables. In 2023, the amount of carbon absorbed by land has temporarily collapsed. Forests, plants, and soils absorbed almost no carbon. Thus, terrestrial ecosystems are losing their carbon store and uptake capacity, and oceans are also showing signs of instability (see Ke et al. (2023)). On the other hand, we are witnessing more rapid technological advancements and declines in sustainable energy prices (LCOEs falling rapidly). The dramatic growth in clean energy investments supports the transition. It offers a counterbalance to slow mitigation progress in other areas. In 2024, solar energy alone is expected to attract US$ 500 billion in investments, surpassing all other energy sources combined (IEA World Energy Investment (2024)). In addition, the electrification in transportation is progressing rapidly, with global electric car sales reaching nearly 14 million

[3] See Article 2 of the Paris Agreement.

in 2023—18% of all cars sold, up from 14% in 2022. This means that over 250 000 electric cars were sold every week in 2023, more than the number sold in a year just a decade ago (IEA Global EV Outlook (2024)).

Where are we heading? Towards higher temperatures sooner than expected and uncertain future temperature ranges. The current trajectory suggests an inevitable progression towards exceeding 1.5°C -2.0°C of warming at earlier dates than initially projected. The reason is that there is both a widening of the ambition gap as well as the delivery gap (Mongelli (2023 a and b)).[4] Without a substantial acceleration of climate policies, global temperatures could surpass this threshold as soon as the early 2030s. At the same time there might be a downward correction of endpoint 2100 projected temperatures: which remain in any case threatening. In 2015, global average temperatures were projected to rise nearly 5°C above pre-industrial levels by 2100 if existing policies persisted (UNEP Emissions Gap Report 2015). Recent climate pathways projected based on current nationally determined contributions (NDCs) until 2030, and assuming no further increase in climate mitigation strategies, thereafter, predict a global warming trajectory of about 3.2 °C by the end of the century, with an uncertainty range spanning between 2.2°C and 3.5 °C (IPCC, 2023). Conversely, very latest publications provide numbers that range between 2.5°C (EA (2023), peak temperature rises in the WEO-2022 scenarios) and just over 3°C (UNEP Emissions Gap Report 2024) under current policies.[5] Despite this modest downward correction, still none of these scenarios meets the Paris Agreement's goal of limiting warming to below 2°C.

What do such levels of global warming levels imply across continents? Europe stands out by warming disproportionately. Global warming captures average trends, across all countries and over certain periods to account for temperature oscillations. Such measures typically span 30 years, relative to Earth's average temperature during the preindustrial era (1850-1900). Yet there is also evidence that continental temperature trends can diverge significantly from global averages. According to the latest report from the World Meteorological Organization (WMO, 2022), Europe is the fastest-warming continent globally, experiencing double the average global warming since the 1980s.

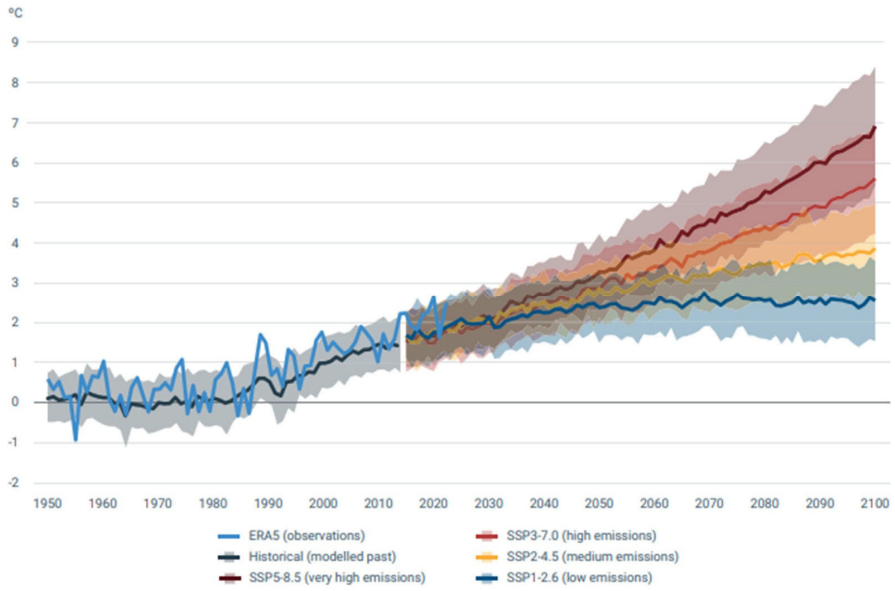
Under existing policies and GHG emissions trajectories, the most recent projections suggest that temperatures across Europe could surge by 5 °C and beyond by 2100 (Figure 2).[6] The most pronounced temperature increases are anticipated in Eastern and Northern Europe (EEA (2024)).[7] Extreme climate events are expected to worsen due to climate change, affecting various sectors, including ecosystems, food security, health, infrastructure, and the economy (Figure 3). For example, extreme weather events such as heatwaves, droughts, wildfires, and floods are expected to become more frequent and intense in the coming decades. The impacts of climate change reveal a distinct north-south divide in Europe, with southern regions facing significantly greater challenges due to extreme

[4] Policies enacted up to the end of 2020 are anticipated to yield even higher global GHG emissions in 2030 compared with emissions implied by current NDCs.
[5] See The Economist November 16th -22nd 2024 briefing on the cost of decarbonization and references therein.
[6] These "Shared Socioeconomic Pathways" (SSPs) look at five different ways in which the world might evolve in the absence of climate policy and how different levels of climate change mitigation could be achieved when the mitigation targets of RCPs are combined with the SSPs.
[7] The European Climate Risk Assessment identifies thirty-six major climate risks for Europe within five broad clusters: ecosystems, food, health, infrastructure, and the economy. Over half of the identified risks demand more robust action now and eight of them are particularly urgent to conserve ecosystems, protect people against heat, protect people and infrastructure from floods as well as wildfires (EEA (2024)).

heat, water scarcity, droughts, forest fires, and agricultural losses. Northern Europe may experience mixed impacts, including some potential benefits from warmer temperatures but also increased flood risks (Feyen et al. (2020)). Furthermore, increased climate variability due to global warming is projected to significantly intensify droughts also across central and northern Europe. Events like the extreme drought of 2018 are expected to become more frequent and severe in these regions, especially under the high-end emission scenario (Toreti et al., 2019).

Due to climate inertias in the geophysical system, additional warming in coming decades is already locked in. Climate change inertia is the phenomenon by which a planet's climate system shows a slowness to deviate away from a given dynamic path.[8] Mitigation policies impact the net flow of GHGs while the climate is steered by the outstanding stock of GHGs that will take longer to stabilize and reduce. This implies that climate risks and extreme climate events will continue rising even with successful mitigation. Damages and losses restoration will also continue rising. Yet, at present we are witnessing underinvestment in both mitigation and adaptation, as recent damages and losses are still absorbed by the private and public sector and a sense of urgency is lacking. This is also known as the "tragedy of the horizon" (Mark Carney (2015)): climate worsening might become irreversible if not mitigated in time.

Figure 2. Historical and future European warming trends under different future SSPs



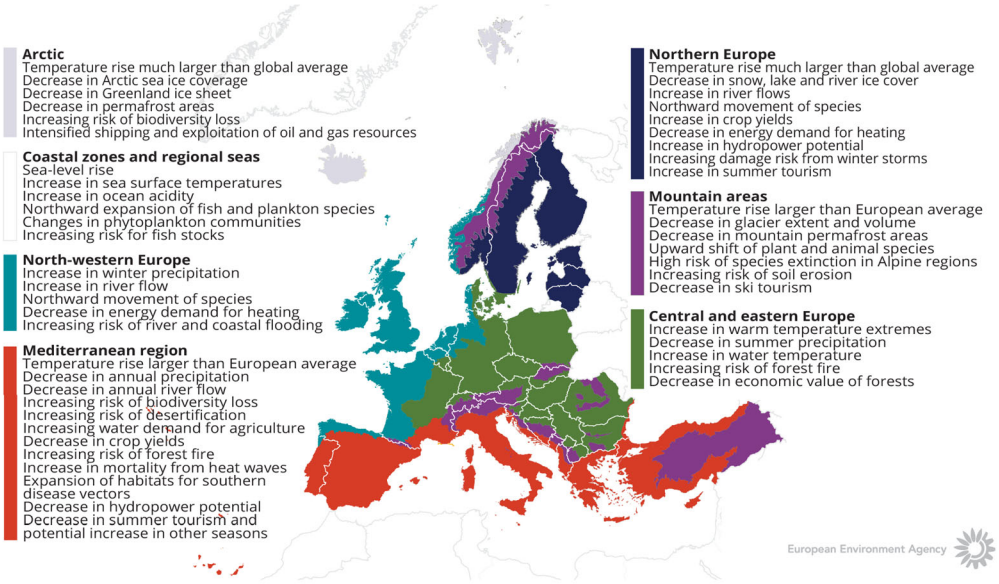
Source: Copernicus Climate Change Service and EEA (2024). Note: **SSPs** are Shared Socioeconomic Pathways looking at different ways in which the world might evolve in the absence of climate policy and how different levels of climate change mitigation could be achieved when the mitigation targets of representative concentration pathways (RCPs) are combined with the SSPs. SSP1-2.6 is considered as Paris aligned scenario, while currently we are on a pathway of the high-emission scenario SSP3-7.0.

Science warns us that each incremental rise in global warming can aggravate compound and concurrent climate hazards. Compound climate extremes occur when multiple climate-related events (e.g., heatwaves, fires, droughts, and floods) occur simultaneously or consecutively, intensifying their impacts. These hazards can exacerbate vulnerabilities in ecosystems, economies, and societies, leading to cascading and amplified risks.

[8] See: https://archive.ipcc.ch/ipccreports/tar/vol4/011.htm

Due to climate change, they are becoming more frequent and severe (EUCRA (2024), IPCC (2023) and Raymond et al. (2023)). Compound risks are characterized by complex, non-linear interactions, making their effects on society and the economy difficult to predict. Unlike individual shocks, the impacts of compound events cannot simply be quantified. These interactions can amplify the severity of climate-related shocks, creating disproportionate consequences. Such amplification poses significant challenges for financial stability and monetary policy, as traditional models struggle to account for the cascading and interconnected nature of these risks. This may lead to the underestimation of their impacts (NGFS (2023)).

Figure 3. Climate change impacts in Europe (EEA (2020)).



Summing up, *several studies concur that the climate is changing at a faster pace than envisaged even a few years ago. Global warming is propelled by GHGs emissions which are still rising, albeit at a slower pace. Due to climate inertias in the geophysical system, additional warming is already locked in. Europe is warming faster than other continents and there is considerable heterogeneity of impacts across European climate zones. This highlights the urgent need for societies to adapt to the reality of higher temperatures and the increasing frequency and intensity of extreme climate events, which are expected to result in more significant damages and economic losses.*

"Video flagrare omnia res. Audio clamare homines. Nunc extinguitur mundi et astrorum lumen. Nunc concipitur mali hominis crimen. Tristitate et lacrimis gravis est dolor.
Cat Stevens, Catch Bull at Four, O'Caritas 1972.

3. Rising GHGs and warming exacerbate climate hazards with rising damages and losses.

Data on past damages and losses attributable to climate-related extreme events is heterogeneous and fragmented. Such estimates, obtained from various sources, are of overwhelming importance to the argument for stepping up both mitigation and adaptation efforts because they show where damages and losses occur and how urgent it is to act.[9] In

[9]Including, statistical agencies (e.g., concerning economic and equipment losses), insurances and re- insurances (e.g., properties losses), financial institutions (e.g., collateral and credit losses), and other entities.

this section we review the backward-looking micro- and macro-based evidence and then turn to their possible trends and to forward-looking scenarios and model-based projections.

3.1 Climate hazards and the damages they cause are on the rise.

Data on past physical hazards point towards an increasing trend in the frequency and especially in the intensity of extremes weather events. In the case of low-income countries, according to Newman and Noy (2023), the cost of extreme weather events attributable to climate change already represented about 1% of GDP per year on average between 2000 and 2019. In the case of Europe, from 1980 to 2022, extreme weather and climate events – such as floods, storms, heatwaves, and droughts -- led to asset-related economic losses totaling around EUR 650 billion in EU Member States (Figure 4).[10] An increase of 41% in damages was observed over the 2009 to 2022 period, or a compounded increase of 2.5% per year. In 2021 only, these losses amounted to EUR 59.4 billion, and in 2022, they reached EUR 52.3 billion (this represents about 0.3% of GDP per year). A significant portion of economic losses can be attributed to a limited number of events: 5% of the most impactful climate-related events account for 59% of total losses, and a mere 1% of these events contribute to 28% of the losses (EEA, 2024).

Analyzing trends in past financial losses poses challenges due to significant year-to-year variability (thus the 30-years moving averages in **Figure 4**). Nevertheless, there is consensus about a general upward trend in economic losses. Worldwide, natural disasters in 2022 and 2023 resulted in losses of around US$ 250bn per year (UNDRR (2024).[11] The UNDRR (2024) warns that diverse impacts from natural disasters are not included in these estimates, *"…such as the impact of slow-onset and small-scale events, the knock-on effects of broken supply chains, losses in productivity, compromised physical and mental health, and the enduring impacts of disrupted education."*[12]

European countries should start to systematically collect and report data on climate hazards and disasters. The newly revised **EU Economic Governance Framework (2023)**[13] requires that member states collect and publish information on the fiscal cost of past natural disasters and climate related events. The aim is to support ("green budgeting"), i.e., assess the fiscal impact of climate change and enhance countries' adaptive capacity in national budgets, thus enhancing macro-fiscal resilience (more in Section 6).

A concern is that future fiscal and financial damages from climate hazards might continue rising, possibly at an accelerating pace. Bova et al. (2019) analyze contingent liability realizations in a sample of 80 advanced and emerging economies for the period

[10] Similarly, the World Bank estimates that between 1980 and 2020, natural disasters affected nearly 50 million people in the European Union and caused, on average, economic losses of €12 billion per year (about €500 billion cumulatively). See: https://www.worldbank.org/en/news/feature/2021/06/04/economics-for-disaster- prevention-and-preparedness-in-europe

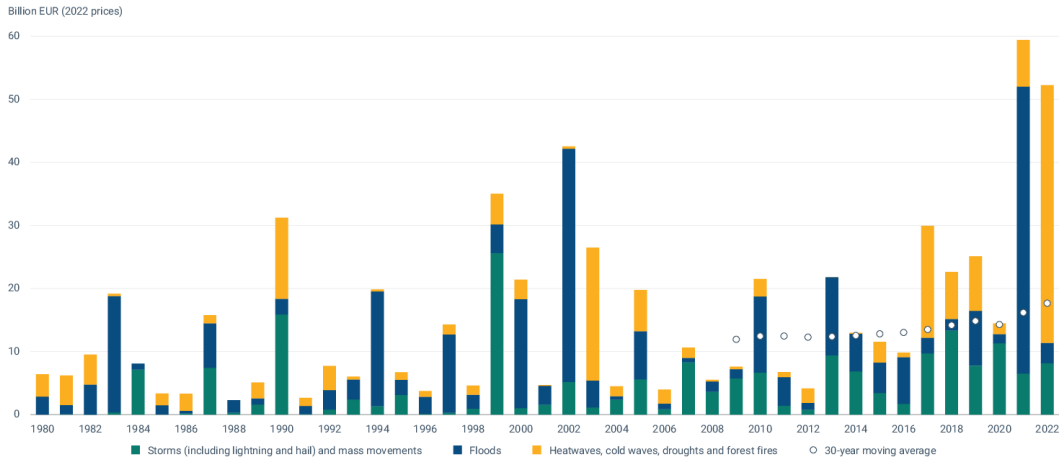
[11] See: https://www.munichre.com/en/company/media-relations/media-information-and-corporate- news/media-information/2024/natural-disaster-figures-2023.html

[12] see: https://www.undrr.org/explainer/uncounted-costs-of-disasters-2023

[13] "The economic governance framework refers to a system of institutions and procedures that the EU has set up to coordinate member states' economic policies and to achieve its economic objectives. The framework comprises an elaborate system of policy coordination and surveillance. It relies on the principles of monitoring, preventing, and correcting economic trends that could weaken individual member states' economies or cause spillovers to other economies". Climate change impacts all layers of governance, see: https://www.consilium.europa.eu/en/policies/economic-governance-framework

1990–2014 showing that natural disasters, including geophysical events, are one of the most important sources of contingent liabilities, the realization of which can be a substantial source of fiscal distress. The public budget is indirectly affected by changes in the tax base (via hysteresis effects and sectoral spillovers) and, thus, also tax revenues (Bachner et al. (2019)). By using a model of sovereign default, Mallucci (2022) shows that natural disasters reduce governments' ability to borrow from abroad, depress welfare and moreover that climate change will further restrict governments' access to financial markets.

Figure 4. Annual Economic Losses Caused by Climate-Related Extreme Events



Source: EEA (2023)).

3.2 Quantifying future impacts of rising climate hazards presents several challenges.

Climate hazards are likely to continue increasing in frequency and intensity, thereby distressing the supply as well as demand side of the economy. On the supply side, climate shocks disrupt output, affect physical capital, and hamper future growth (Ciccarelli et al. (2021)). In addition to negative supply shocks in the decades to come, climate change has the potential to lead to widespread disruption of the economic and financial system and have demand-side implications (Andersson et al. (2020)). The World Bank estimates that the economic impact of major floods, but also earthquakes, might range between 7 to 17 percent of GDP in some European countries[14]. Future damages and losses will not depend solely on the frequency and intensity of events, but also on the value of exposed assets and climate adaptation measures in effect by that time.

According to some forecasts, within the next 26 years, the world economy might face an income reduction of 19%. Such damages, due to historical carbon emissions and socioeconomic inertia, would outweigh the mitigation costs required to limit global warming to two degrees by sixfold. Thereafter damages diverge strongly depending on emission choices (Kotz et al. (2024)). Both, advanced and emerging countries are adversely impacted by global climate risk shocks (Byrne et al. (2024)). For Europe, the 2021 PESETA IV study (see next section) has shown that the climate related damages will be heterogeneous across European countries[15]

[14] https://www.worldbank.org/en/news/feature/2021/06/04/economics-for-disaster-prevention-and-preparedness-in-europe

[15] Southern Europe is expected to experience higher damages than Northern Europe. Damage assessments can also

Damage functions provide indispensable insights about projected future damages stemming from rising climate hazards. We briefly review two recent specifications of damage functions. Kalkuhl and Wenz (2020) assume *"level effects without persistence"* in their damage estimates. This means that damages only occur in the year in which a climate shock occurs. Once the climate stabilizes, no more damages occur. An interpretation of this finding would be that after a climate shock, society immediately adapts, and hence, resumes its original growth rate once climate stabilizes. A second specification is in Kotz, Levermann and Wenz (2024) that assumes instead a *"level effects with lags"* in its damage estimates. This means that damages manifest themselves for several years after the climate shock. Even if the climate stabilizes, damages can continue to occur for several years according to this damage function. An oversimplified interpretation of this finding would be that after a climate shock, society requires multiple years to adapt, and hence, it requires some time before it can fully revert to its original growth rate, even when the climate has stabilized.[16] The two specifications lead to quite different projected future damages, especially when it comes to adaptation. When comparing the severity in damage estimates based on high estimates for both damage functions Kotz et al. (2024) projects damages which are almost 50% higher than in Kalkuhl and Wenz (2020) by end-2100.[17]

Data over the last 120 years shows that damages and losses from climate hazards might be underestimated. Bilal and Kaenzig (2024) assemble a novel global dataset of the climate as well as the economy spanning the last 120 years. They estimate that the macroeconomic damages from climate change are six times larger than previously thought. A 1°C increase in global temperature leads to a 12% decline in world GDP and a business-as-usual warming scenario leads to loss equivalent to a present welfare loss of 31% (Bilal and Kaenzig (2024)). They argue that global temperature shocks correlate more strongly with extreme climatic events than the country-level temperature shocks commonly used in panel analysis. This also implies a significantly higher Social Cost of Carbon of $1,056 per ton of carbon dioxide.

3.3 Reckoning possibly extreme impacts of rising climate hazards presents challenges.

Severe adverse financial feedback loops may result, raising climate risks. Climate change could severely threaten livelihoods and the livability of large regions through extreme events such as heatwaves, fires, droughts, and flooding. These escalating risks may lead to the breakdown of governance systems, heighten regional tensions, and pose serious threats to both regional and global security, with clear implications for the financial system. In narrow terms, climate risks can be understood as the interplay between occurrence of climate hazards, exposure, and vulnerability (UNEP Adaptation Gap Report (2023)). Climate hazards are the climate related natural disasters.

A growing body of research shows that climate-related hazards are indeed

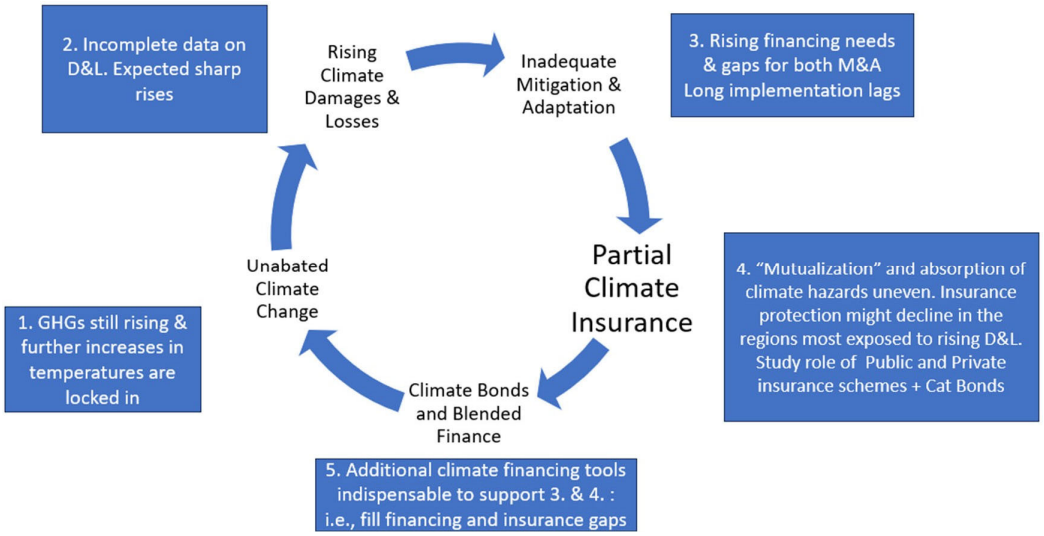
be conducted based on Integrated Assessment Models (IAMs). The projected damages vary widely -- see "Nordhaus versus Dietz debate" – and is highly sensitive to population growth, innovation, and discount factors assumptions.

[16] Several caveats apply. There are more methodological differences in the specifications, including a different set of climatic variables: e.g., the impact of temperature variability is accounted for in Kotz et al., (2024), but not in Kalkuhl and Wenz (2020). Moreover, the two papers use a different dataset to estimate their regressions. Thus, only part of the difference in loss estimates can be attributed to persistence effects.

[17] At the same time, both specifications neglect some aspect of adaptation. For example, long-terms adaptation goals are only partly reflected in damage functions. For a discussion see Aufhammer (2018) and to gauge the terms of the quantification of adaptation impacts see Hsiang and Narita (2012) on adaptation to cyclone risks.

increasingly affecting the financial sector (Altavilla et al. (2023)). Climate risks could accelerate, causing the financial system to spiral out of control "just as fast and with even greater impact than the [global] financial crisis" (Bateson et al (2024)). There is nascent literature on the adverse relationship between rising climate risks and cost of sovereign debt. A recent IMF Debt Sustainability Analysis (2022) corroborates these findings showing – using the examples of Peru and Colombia -- that climate shocks lead to significant increases in public debt. In some cases, climate shocks, increase a country's probability of incurring a significant financial sector stress event. This is reminiscent of the doom-loops during the euro area crisis (**Figure 5**).

Figure 5. Breaking the climate financing doom-loop



A wide spectrum of predictions and scenarios concerning future climate-related damages exist. These range from significant but manageable damages and losses to catastrophic outcomes by the end of the forecast horizon (EEA (2024)). In addition, there are correlations of climate related risks that are still not discussed in mainstream research publications, including, compounded climate hazards, concurrent events and risk multipliers that might become increasingly unmanageable in more exposed climate zones.

Climate alerts. The European Environment Agency in its first European Climate Risk Assessment (EUCRA) alerts us about "*…catastrophic and urgent dangers from a warming planet*" (EEA (2024)).[18] The report further states that climate change intensifies existing risks, with impacts cascading across *"...systems and regions leading to widespread societal challenges..."* Moreover, climate hazards can *"…compromise food and water security, energy security and financial stability, and the health of the general population and of outdoor workers; in turn, this affects social cohesion and stability".* Work on climate change is shrouded in uncertainties and hidden threats). A wide spectrum of potential outcomes exists in different guises such as non-linearities and planetary boundaries. This is an area in which a vast array of experts is cooperating and providing new insights.

[18] See: https://www.eea.europa.eu/publications/european-climate-risk-assessment

3.4 Compound and concurrent hazards

Compound shocks present rising threats to the economic and financial system. Climate change is a risk multiplier that can exacerbate existing climate risks and precipitate extreme weather events. Every uptick in global warming is expected to magnify concurrent changes in multiple climatic impact drivers in a non-linear manner. For example, the frequency of ***compound hazards*** such as droughts and heatwaves are projected to escalate, including the occurrence of ***concurrent events*** spanning multiple geographical locations (Kornhuber et al. (2023), Toreti et al. (2021)). Concurrent shocks, deeply interconnected risks, and diminishing resilience can lead to the emergence of polycrises, where multiple crises interact in ways that amplify the overall impact, making it far greater than the sum of its individual parts. Therefore, better understanding and incorporating the effects of compound shocks on the macroeconomy and financial sector into risk management is essential, especially for central banks and supervisors (NGFS, 2023). Climate risks are expected to compound and present concurrent hazards if global warming continues.

Cross-border and emerging risks must be accounted for. Understanding and managing cross-border and emerging risks, including environmental, health, and technological threats, is essential to increase societal resilience (Corbane et al. (2024)). Interconnectedness of these risks emphasizes the importance of integrated approaches and improved data sharing to better anticipate and prepare for potential disasters. Additionally, incorporating transboundary considerations into risk management strategies is vital to address the complex and interconnected risks we face today.

Summing up, *assessing current and expected damages and losses from unabated climate change is indispensable to prepare and advocate for robust climate adaptation and mitigation. There is a dichotomy. Past data, that might be underreported, suggests a general but still contained upward trend in economic damages and losses from extreme climate events, globally and in Europe. Conversely, several forward-looking studies and reports concur on the possibly aggravating detrimental effects of unabated global warming on the economy.*

"Can whisper tales of gore of how we calmed the tides of war. [ ] So now you'd better stop and rebuild all your ruins." Led Zeppelin, Immigrant Song 1970

4. The political economy of adaptation

Adaptation needs are likely to be already vast, rising fast and at the same time difficult to determine in their entirety, e.g., for a country, region, or sector. Also, vast and manifold are the barriers to adaptation. In Section 2 and 3 we discussed uncertainty about future climate paths which might lower current incentives to mitigate and adapt. Inertias, lags, and long horizons might discourage robust strategies and actions. Information and adjustment costs are high for the public, firms, and decision-makers: e.g., for the effects on welfare, health, the ecosystem, and so on. Thus, Europe will be faced with more frequent and intense climate events that stretch preparedness and response capacity and will need to promote structural changes to deal with systemic impacts on all economic sectors (EEA (2024)). In this section, we embrace a widely accepted definition of adaptation, review its main benefits and principal approaches, and explain that the information and

computational burden of deciding about how to adapt is burdensome and presents trade-offs. Choosing how, where, to what extent, and when to adapt is complex and a demanding process for society.

4.1 Economic approaches to adaptation and resilience-enhancing strategies.

As a start, diverse definitions of climate adaptation exist. According to Mendelsohn adaptation encompasses any change in behavior to reduce the harm or increase the gains from a given climate change (Mendelsohn (2012). According to the IPCC, adaptation captures "*the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."* Instead, climate resilience captures "*the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions"* (IPCC (2022).

We adopt instead the Sendai Framework for Disaster Risk Reduction ("Sendai"). This comprises a non-binding set of guidelines formulated by the United Nations' Office for Disaster Risk Reduction (UNDRR) which embraces both adaptation and resilience. The goal is to reduce vulnerabilities and enhance the capacity of social, economic, and environmental systems to deal with the impacts of natural hazards and climate change.[19] Sendai comprises two interconnected pillars. *Climate adaptation* is the process of adjusting practices, systems, and structures to moderate potential damages and losses and cope with the consequences of natural and climate-related hazards.[20] This includes adjusting socio-economic and environmental practices to limit damage (UNDRR (2015)). *Climate resilience* concerns the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including the preservation and restoration of its essential basic structures and functions through risk management (UNDRR (2015)).

4.2 The colors and shades of climate adaptation

While the general concept of adaptation is intuitive, when it comes to its implementation, nothing about it is straightforward. There is a great amount of intertemporal and intergenerational choices to make. Adaptation presents society and decisionmakers with a need to choose between how much to invest in it versus how much residual risk it is prepared to accept. Thus, there are trade-offs among adaptation costs, its benefits, and the residual damages and losses after adaptation strategies and actions have been implemented. What renders such a choice complex is that the costs of adaptation are not set or global. Whereas they change with the rise in climate hazards and damages and losses, the level of ambition or the objective and whether an objective can be met from the perspective of economic efficiency or risk levels (as we discuss next). Intertemporal and

[19] See: https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

[20] Adaptation to climate change might include building resilient infrastructures, increasing the resilience of urban areas, developing early warning systems to alert against forthcoming extreme weather events, implementing water management and agricultural practices that can withstand changing conditions, protecting natural habitats that can serve as climate refuges, and acquiring needed climate insurance.

intergenerational dilemmas must be considered. Timing matters. The longer climate policies, including adaptation, are postponed the less effective and costly they might become.

The degree of ambition matters: incremental or transformational? *Incremental adaptation* maintains the integrity of a social-economic system or process at a given scale. Some examples include: **"no-regret actions"** such as early warning systems to alert the population of looming climate hazards; "climate-smart designs" which foster infrastructures that are climate resilient and might prove cost-effective over longer periods; and "low-cost preparatory and early actions" which provide option value for more transformational adaptation over time. Instead, *transformational adaptation* envisages changes in the fundamental attributes of a system in anticipation of further climate change and more severe impacts (World Bank (2024) and Möller et al. (2022)).

4.3 Net benefits of investing in climate adaptation

By reducing systemic risks in the economy, adaptation actions are expected to generate triple dividends in terms of *avoided losses and damages*, *economic benefits*, and *socio-environmental (non-market) benefits* (see Allan et al. (2019) and report for Global Commission on Adaptation (CGA, 2019) and PESETA IV)).

(A) Avoided losses and damages are one of the central dividends of adaptation investments. The materialization of climate risks affects public finances both directly and indirectly. Responding to climate change implies disaster relief or reconstruction of damaged public infrastructure from extreme climate events, relief payments for farmers affected by drought or flooding, etc. Thus, fiscal space for contingency planning is required. Bachner et al.(2019) developed a modelling framework to assess cost and benefits, showing the budgetary implications of adaptation with data from Austria. They show that public adaptation already involves considerable costs for the Austrian federal budget (15% of the pre-selected budget is adaptation-relevant). However, it is difficult to quantify avoided damages and losses due to a need for either counterfactual or panel studies.

(B) Economic benefits are the accrued dividends through investments in adaptations that decrease risks or improve outcomes. Some examples include reduced risk of flooding, lower costs of insurance, lower maintenance and repair costs, and increased income (WRI, 2022). As such, some adaptation investments may translate into revenue for governments' budgets. Interestingly, Bachner et al. (2019) find that public adaptation in Austria has the potential to increase government revenues because of higher economic activity as compared to a scenario with only the impacts of climate change and lower disaster relief expenditures.[21]

(C) Socio-environmental effects also include effects that result in deeper structural changes in the economy, such as greater social inequalities, which may occur (and intensify) over time and yet not be immediately visible. Nonetheless, these effects are likely to have a profound impact on public finances.

4.4 Asymmetric perceived costs and benefits of climate policies.

Diverse asymmetries influence the perception of the trade- offs from undertaking decisive climate adaptation and mitigation policies. Costs might be largely perceived as clear

[21] However, Bachner et al. (2019) note that, although applicable to all countries, their framework is hard to implement broadly as it requires considerable time and effort with respect to data collection, preparation, and stakeholder consultation. Yet, learning from experiences is fundamental and is discussed next.

and present, and yet they might be quite diverse heterogeneous such as losses of competitiveness, job- leakage, and transfer of activities, slowing economy activity, rising prices, and free riding by other countries. Plus, the costs might even seem unwarranted by climate change sceptics. Benefits might instead be seen as too far-off in the future and uncertain, especially in the case of mitigation. Benefits of slowing and reversing climate change might be underestimated, despite rising evidence that any short-term costs will be dwarfed by the long-term benefits. Examples might include health improvements thanks to cleaner air that reduces mortality and morbidity rates from local air pollution, more stable GDP, financial stability, and safeguarding biodiversity (Adrian et al (2022), IMF WEO (2020) and IPCC (2022)). We shall return to these considerations in a later section.

4.4 Top-down, bottom-up or hybrid adaptation?

Assessing the needs for adaptation must bring together several perspectives, expertise, and backgrounds. It's important to proceed on various parallel tracks, learn from and compare experiences across countries and tailor to local needs.

"Science-first" adaptation studies start with climate model projections, then model climate impacts in the medium to long terms, for example until 2050, and then model technical adaptation options and their costs based on some cost assumptions.[22] For example, the PESETA IV study follows this approach. Such a top-down approach raises awareness and provides headline estimates of the costs and benefits of adaptation. It also highlights the costs of climate policy inaction. This type of analysis supports high-level planning.

"Policy-first" adaptation studies support adaptation decisions in the short-term. They are based upon policy or project decisions and thus are also labelled as bottom-up. Examples include the actions in national adaptation plans for the following five years, or the evaluation of specific project investment decisions (such as for a new hydropower plant). They are based on specific cost estimates and allow an assessment of investments financial flows (IFFs or their variation), and disaster management (DM) support tools.

Adaptive management, or "hybrid adaptation," considers both science- and policy-based adaptation assessments, based on expected future climate risks, adaptation roadmaps, and pathway frameworks. According to the report of the World Bank (2024), there can be several types of approaches such as:

- Studies looking at the medium- and long-term needs for selected infrastructure or those that consider short-term no regret measures first, while more information on adaptation options for different sectors become available;
- Adaptive management, also called iterative risk management, envisaging an iterative cycle of monitoring, research, evaluation, and learning—that is, a process to improve future adaptation management strategies; and

[22] Model projections are generally based on Integrated Assessment Models (IAM) and sector integrated assessments and costs of damage, computational general equilibrium models (CGE), macrostructural and econometric models for economic modelling of the impacts of climate change. Examples include the studies of coastal or river flood adaptation reported in numerous European and national studies.

- Dynamic adaptation route maps focussing on *Decision-Making Under Uncertainty* (DMUU) and identifying adaptation tipping points at which actions are no longer adequate (requiring transformational adaptation).

4.5 The prerequisites of adaptation to climate hazards are high.

The need for data granularity and computational burden of adaptation to climate hazards can be very high. The World Bank lists several choices that decisionmakers might face when setting an adaptation objective (World bank (2024)). Below we make a reference to investment for protection from coastal or river flooding:

- **Business as usual with maintenance of existing infrastructures.** This involves facing current and future maintenance costs for upkeep but with no additional enhancement or new infrastructure envisaged. In this approach to adaptation, the costs are low, but residual damage in the case of climate hazards can be high and increases over time with unabated climate change;
- **Stepping up flooding protection to a constant relative risk level** that is deemed as acceptable risk. This might involve setting a standard for risk protection to protect, for example, against a 1-in100-year event. With unabated climate change, the costs of protecting to this same level of risks increase over time. This is because additional infrastructure investment is needed to deliver the same protection under a changing climate;
- **Maintenance of a constant absolute risk level from flooding**. This approach may involve, for instance, maintaining a constant level of residual damage, which involves more protection and higher adaptation costs, resulting both from socioeconomic change (and with a rise in assets at risk) and increasing climate change;
- **Protection to a risk-intolerant level**. This approach may entail for example, reducing average annual losses to very low levels, leading to very low residual damage but involving very high adaptation costs; and
- **Protection to an economically optimal level of adaptation**. This would involve investing in adaptation to the point where the marginal costs equalize marginal benefits. Such an adaptation strategy might lead to lower levels of overall adaptation or even maladaptation.[23]

Overall, cost differences in such adaptation strategies can be significant: e.g., the costs for protecting from river floods can vary by a factor of four between the economically optimal action and that which results in the least residual damage (World Bank (2024)).

4.6 Managing expectations and sustaining efforts matters.

Climate policies will inevitably encounter significant lags before results are evident and, in the meantime, rising climate damages and losses must be absorbed. In previous sections we argued that higher temperatures are already locked in for the next years and that in fact climate damages might be severely underestimated at present but might soar soon. Because investments in climate adaptation (as well as mitigation) must be boosted from relatively low levels of funding, as argued in a later section, and entail implementation lags, in the transition phase, we also need to absorb the impacts of rising

[23] The reason is that investments might not be in highly costly actions, and residual damage might be higher. Moreover, finding such an optimal level is very difficult, because of the wide range of potential impacts from climate change.

climate hazards and spread the risks and costs of resulting damages. This requires acquiring the necessary private and public insurance against climate risks/hazards, issuing climate hazards bonds, and changing human behaviors (e.g., more efficient water-use, farmers expanding their use of climate-resilient crops).[24]

4.7 Barriers to adaptation financing in the private sector

The barriers to private investment and financing are higher for adaptation projects than for mitigation. The main reason for this is that several factors contribute to the complexity of securing private funding for adaptation initiatives. These factors include:

Public good, large adaptation projects usually provide public goods and the barriers to private investment and financing are particularly high. For example, disaster prevention infrastructure such as dikes that protect against flash floods or the general rise in sea-levels are prime examples of a public good. Such endeavors can generate widespread and prolonged collective benefits across vast regions and/or sectors. Yet, it could be unattractive – or outright impossible – for individual actors to assume the costs of adaptation projects (even those with large externalities). Consequently, this might lead to an under-provision of specific adaptation projects;

Uncertain returns: In cases where the public good argument does not hold, returns of adaptation investments over time might be uncertain.[25] These issues are aggravated by little data coverage and are reflected in the fact that there are no markets that would provide incentives for investing in adaptation initiatives, as carbon markets do in the case of mitigation. Adaptation initiatives typically require investment into unproductive capital (e.g., dykes), which represent deadweight costs, lowering the path of GDP compared to a case where resources were directed towards growth enhancing projects;

Moral hazards: Private funding for adaptation is hampered by moral-hazard dynamics. This is particularly true for the sub-field "disaster prevention". The consequences of disasters are borne out ultimately by taxpayers, especially those that are not insured against or uninsurable as we discuss in a later section. Thus, the incentive structure for private actors to hedge against climate risks through adaptation is distorted and shifts these risks onto the public sector.

Summing up, *while the concept of adaptation is intuitive, deciding where to adapt, how, to what extent given residual risks, and at what speed can be rather complex. There is a lack of standardization and need for quantifiable targets and steps, a shared classification system and approaches to climate adaptation, which embraces trade-offs, shares best practices, and learns by doing. Adaptation will also require substantial data and computational power, building synergies and adjusting to changing risks and scenarios. The potential and limits of combining digitalization and artificial intelligence, to analyze what works and how it could be scaled up should be explored. Moreover, clarity and enforceability in the applicable legal framework, to which we turn next, is critical.*

[24] https://sustainablefinancecenter.org/wp-content/uploads/2023/04/Theme-02-Public-Finance-for-Climate-Change-Adaptation-1.pdf

[25] Contrastingly, there are some mitigation activities, which bring a more immediate and certain financial return (e.g., EV manufacturing, sustainable energy projects, solar panels, etc.). Moreover, areas with low climate resilience and a greater need for adaptation tend to be unstable also in economic and political terms.

5. Overview of the international and European Union legal frameworks on climate adaptation.[26]

In addition to being increasingly necessary - due to unabated climate change and rising damages and losses – climate adaptation may also be a legal requirement, borne out of the international and EU legal frameworks and case law. The international legal framework makes provision for climate adaptation whilst the EU legal framework prescribes more concrete obligations regarding climate adaptation. Additionally, climate adaptation has become a focal point in an emerging number of climate litigation cases.

5.1 International obligations on climate adaptation

The Paris Agreement has introduced a global adaptation goal. Article 7 of the Paris Agreement sets out the goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerabilities to climate change". This is also referred to as the 'global adaptation goal'. Both the EU and its Member States are Parties to the Paris Agreement. The global adaptation goal under the Paris Agreement specifies and strengthens the non-binding Adaptation Principle introduced in the 1992 United Nations Framework Convention on Climate Change (UNFCCC).[27] However, the Paris Agreement commitments on adaptation are formulated in a less stringent and verifiable manner than the commitments on mitigation: i.e., they are less enforceable (Brus et al. (2023)). In addition, the Paris Agreement does not reflect any agreed definition of climate adaptation among Parties (Zahar (2024)), nor does it prescribe specific targets to be reached. As such, the provision is framed as a process-based obligation, mandating Parties to follow some specific procedural steps with the caveat 'as appropriate', while leaving wide discretion as regards the outcome. Thus, the literature characterizes the adaptation provisions of the Paris Agreement as *"soft obligations"* (see Bodanski (2016), Werksman (2019), and Rajamani (2016)).

International or regional human rights treaties may create obligations for states to ensure adaptation measures are adopted, where the failure to do so undermines the ability to enjoy a variety of human rights. International or regional human rights treaties, such as the European Convention of Human Rights (ECHR),[28] the International Covenant on Civil and Political Rights (ICCPR),[29] and the International Covenant on Economic, Social and Cultural Rights (ICESCR)[30] might create obligations on States to ensure that adaptation measures are put in place. The lack of climate adaptation planning and action might undermine the ability to enjoy a variety of human rights, such as the right to life, food, housing, health, social rights of workers, and the right to a healthy environment. As further indicated below, climate litigation may play an important role in specifying States' human rights obligations in relation to climate adaptation. For instance, following the recent ruling of the European Court of Human Rights (EctHR) in the *Verein Klimaseniorinnen Schweiz v. Switzerland* case, litigants may

[26] We are grateful to Marguerite O'Connell, Martina Menegat and Ava O'Connor for their extensive contributions to Sections 5 and 6.
[27] Article 3 UNFCCC.
[28] Verein Klimaseniorinnen Schweiz & ors v Switzerland [2024] ECtHR App no53600/20.
[29] HRC (2019), General comment No. 36 on Article 6 of the International Covenant on Civil and Political Rights, on the right to life and CESCR (2022), General comment No. 26 on land and economic, social, and cultural rights. Daniel Billy et al. v. Australia; "Torres Strait Islanders case."
[30] CESCR (2022), General comment No. 26 on land and economic, social and cultural rights.

argue that Articles 2 and 8 ECHR, which protect the right to life and the right to private and family life, imply obligations for states to adopt climate adaptation measures.[31]

The importance of nature-based solutions (NBS). The importance of climate adaptation is also emphasized in the 2022 Kunming-Montreal Global Biodiversity Framework (GBF)[32], which recommends Parties to minimise the impact of climate change on biodiversity and increase its resilience, inter alia through adaptation and disaster risk reduction actions. Whilst unlike the global adaptation goal enshrined under the Paris Agreement, the GBF includes specific targets and metrics to measure Parties' progress but follows the weaker form of a COP decision and lacks an implementation mechanism.[33] The adaptation targets prescribed under the GBF therefore do not legally bind the contracting parties.

5.2 The EU legal framework on climate adaptation

The EU legal framework requires continuous progress towards adaptation. The 2021 European Climate Law,[34] which incorporates the Paris Agreement into the EU legal framework, imposes a duty on relevant Union institutions and the Member States to a ensure 'continuous progress' towards adaptation. The EU adaptation goal includes: (i) enhancing adaptive capacity, (ii) strengthening resilience and (iii) reducing vulnerability to climate change in accordance with the Paris Agreement's global adaptation goal.[35] The European Climate Law also obliges the Commission to adopt a Union strategy on adaptation, and regularly review it.[36] Relevant Union institutions and Member States are obliged to support the integration of adaptation measures in all policy areas, while Member States are required to adopt and implement national adaptation strategies and plans.[37] In 2023, the European Commission adopted a revised set of non-legally binding Guidelines to assist Member States in updating and implementing national adaptation strategies, plans and policies.[38] Most notably, the Guidelines call for Member States to adopt legal frameworks on climate adaptation rather than the implementation of soft policies.[39]

Like the Paris Agreement, the European Climate Law does not contain quantitative elements or annual targets. Rather, it contains procedural-based obligations for the Commission to assess the collective progress of the Union and the Member States towards the EU adaptation objective. Pursuant to the European Climate Law, the Commission

[31] Verein Klimaseniorinnen Schweiz & ors v Switzerland [2024] ECtHR App no53600/20, para. 552.
[32] See Target 8 of UNEP Decision 15/4 on the Kunming-Montreal Global Biodiversity Framework under the Convention on Biological Diversity (19 December 2022).
[33] For further discussion on this topic, see Ekdart, F. (2023) Legally binding and ambitious biodiversity protection under the CBD, the global biodiversity framework and human rights law and Streck C, (2023) Synergies between the Kunming-Montreal Global Biodiversity Framework and the Paris Agreement: the role of policy milestones, monitoring frameworks and safeguards.
[34] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'), (9.7.2021) OJ L 243.
[35] Article 5(1) of the European Climate Law.
[36] Article 5(2) of the European Climate Law.
[37] Article 5(3) and (4) of the European Climate Law.
[38] Notice of the European Commission on Guidelines on Member States' adaptation strategies and plans (OJ C 264, 27.7.2023, p 1).
[39] See page 3 of Notice of the European Commission on Guidelines on Member States' adaptation strategies and plans (OJ C 264, 27.7.2023, p 1).

published its 2021 EU Adaptation Strategy, which identifies four high-level objectives to strengthen EU adaptive capacity: smarter, systemic, faster, and international adaptation in several key policy areas. The Commission emphasized the need to streamline adaptation actions and investments at the local, regional, and national levels in the coming years.[40]

In line with the GBF, the EU Nature Restoration Law also recognizes the importance of adaptation policies for nature protection objectives.[41] The Nature Restoration Law is a key element of the EU Biodiversity strategy, aiming at restoring at least 20% of the EU's land and sea areas by 2030 and all ecosystems in need of restoration by 2050. The Law specifies that restoring ecosystems also contributes to the Union's climate change mitigation and adaptation objectives.[42] In the preparation of national restoration plans, Member States are required to identify synergies with climate mitigation and adaptation, land degradation neutrality and disaster prevention and prioritise restoration measures accordingly.[43] A dedicated section of such plans is expected to set out "the potential of restoration measures to minimise climate change impacts on nature, to prevent or mitigate the effects of natural disasters and to support adaptation", as well as synergies with national adaptation strategies or plans and national disaster risk assessment reports. [44]

5.3 New avenues to spur adaptation: climate litigation.

Climate adaptation also has been the focus of an emerging number of cases of climate litigation (other than human rights). Such cases may heighten awareness of climate adaptation needs within civil society and among policymakers, potentially influencing the development of new legislation and regulations in the EU, as well as their implementation and enforcement. Some of these cases allege that a government or company has a responsibility to adopt adaptation measures or has failed to implement necessary measures, leading to reasonably foreseeable harm for which the plaintiff seeks compensation: i.e., *'failure to adapt'* cases (see Setzer et al. (2024)) These cases have also coined the term *strategic cases.* A limited number of cases seek monetary damages from companies based on their alleged contribution to harm caused by greenhouse gas emissions, aiming to fund the cost of adaptation: i.e., '*polluter pays'* cases (see UNEP (2023)).

***Summing up**, international and European climate laws are beginning to address climate adaptation. However, these regulations lack clear targets and objectives, partly due to scientific uncertainties surrounding the best approaches to climate adaptation. Meanwhile, climate litigants may increasingly pressure governments and businesses to take adaptation measures to safeguard fundamental rights from the adverse effects of climate change, both in the Global North and in the Global South. The abovementioned legal framework and trends in climate litigation begs the questions of what role can litigations effectively play? How are climate laws and regulations referring to adaptation transposed in European governance?*

[40] Communication "Managing climate risks – protecting people and prosperity" (2024) COM/2024/91 final, p.4.
[41] Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869 ('Nature Restoration Law'), OJ L, 2024/1991, 29.7.2024.
[42] Article 1(1) of the Nature Restoration Law.
[43] Article 14(9) of the Nature Restoration Law.
[44] Article 15(3)(t) of the Nature Restoration Law.

6. The European Union Governance framework and its interplay with climate adaptation

The following sections only focuses on the governance of the European Union.

6.1 Europe (I): the Economic Governance Framework ('green budgeting')

Unabated climate change is expected to amplify the intensity and frequency of extreme weather events weighing on national budgets. Governments generally cover a large share of the uninsured costs of relief, recovery and reconstruction which poses a challenge for public finances. Climate change has significant implications for national budgets as well as the Union's budget and financial facilities. Adaptation efforts require substantial investments in infrastructures (see next section), technology and innovation, and other measures to mitigate the adverse effects of climate change.

The recent reform of the Economic Governance Framework is encouraging the use of proactive "green budgeting" tools and practices to enhance countries' adaptive capacity. To improve budgetary planning and redirect public revenue and expenditure to green priorities, the Council Directive on national budgetary frameworks has been updated.[45] the new provisions introduced into the Council Directive on national budgetary frameworks requires Member States to report current and past macro fiscal risks from climate change, climate-related contingent liabilities, and fiscal costs of disasters. In their national budgetary strategies, Member States should pay attention to the macrofiscal risks of climate change and their impact on public finances and limit and manage these risks that can have environmental and distributional impacts. Moreover, under the new Stability and Growth Pact (SGP) Preventive Arm Regulation,[46] Member States are required to prepare national medium-term fiscal structural plans. These plans must, inter alia, explain how Member States will address the objectives set out in the European Climate Law through the planned reforms and investments included in their national plans.

6.2 European Union (II): the Union budget and Next Generation EU program

In recent decades the European Union has created a significant number of financial facilities to address various worthy policy priorities. Over time these initiatives might be aimed at addressing challenges stemming from the impact of unabated climate change. In its long-term budget for 2021 – 2027, the European Union has increased the spending target for climate actions to 30% including funding that supports climate adaptation and resilience building. Financial support for climate adaptation as well as other climate policies is becoming available via, inter alia the Recovery and Resilience Fund, the Just Transition Fund and the European Structural and Investment Funds.

(A) The **Recovery and Resilience Facility (RRF),** which was adopted in 2021 as part of the EU's post-pandemic '**Next Generation EU'** program, requires that 37% of the total allocation of funding under Member States' national plans include measures that effectively contribute to the green transition, or address the challenges resulting from the green transition. The RRF aims to improve resilience, crisis preparedness, adjustment

[45] Council Directive 2011/85/EU of 8 November 2011 on requirements for budgetary frameworks of the Member States, OJ L 306, 23/11/2011, p. 41.
[46] Regulation (EU) 2024/1263 of the European Parliament and of the Council of 29 April 2024 on the effective coordination of economic policies and on multilateral budgetary surveillance and repealing Council Regulation (EC) No 1466/97, OJ L, 2024/1263, 30.4.2024.

capacity and growth potential of Member States to contribute to the Union's 2030 climate targets and comply with the objective of EU climate neutrality by 2050.

(B) The **Just Transition Mechanism (JTM).** Following the **European Green Deal of 2019**, to ensure that the transition to a climate neutral economy happens in a fair and equitable way, the EU adopted the JTM, consisting of the following three pillars:

- **The Just Transition Fund** enables regions and people to address the social, employment, economic and environmental impacts of the transition towards the Union's 2030 targets for energy and climate and a climate-neutral economy of the Union by 2050, based on the Paris Agreement.
- The **InvestEU program** consists of the InvestEU Fund -- which provides EU guarantees supporting investment across several policy areas to address market failures or suboptimal investment situations -- the InvestEU Advisory Hub, and the InvestEU Portal; and
- The **Public Sector Loan Facility** for additional investment to be leveraged by the European Investment Bank. This facility may be used to support investment in infrastructure aimed at enhancing resilience to withstand ecological disaster, accentuated by climate change. However, the facility is not limited to supporting climate adaptation measures.

(C) Climate funding also has been incorporated into the **European Structural and Investment Funds (ESIFs).** For the financial period 2021 – 2027, there are five ESIFs' whose objectives include the promotion of climate change adaptation, risk management and prevention. All ESIFs pursue the EU's goal of economic, social, and territorial cohesion (Article 3 of the Treaty of the European Union and Article 174 of the Treaty of the Functioning of the European Union). They are:

- The **European Regional Development Fund (ERDF)** aims to promote balanced development in the different regions of the EU;
- The **European Social Fund (ESF)** supports employment-related project across the EU;
- The **Cohesion Fund (CF)** aims to finance transport and environment projects in countries where the gross national income per inhabitant is less than 90% of the EU average;
- The **European Agricultural Fund for Rural Development (EAFRD)** focuses on resolving specific challenges in rural areas; and
- The **European Maritime, Fisheries and Aquaculture Fund (EMFAF)** helps facilitate the adoption of sustainable fishing practices and improve quality of life along European coasts.

Three additional facilities also support recovery after natural disasters and climate policies and adaptation:

- The **European Solidarity Fund** provides financial assistance to Member States to enable a rapid and flexible response, to emergency situations, such as a natural disaster or public health emergencies. Operations to be financed by the fund must fall in the fields of environmental protection, natural disaster risk prevention and management and climate adaptation;
- The **Emissions Trading System (EU ETS**) is a carbon emission cap and trade trading scheme. It was launched in 2005 to lower GHGs emissions. Revenues generated

from the auctioning of allowances can contribute to: (a) Global Energy Efficiency and Renewable Energy Fund and to the Adaptation Funds; (b) supporting the protection and restoration of land-based ecosystems and other forms of adaptation, and (c) financing climate action in vulnerable LDCs; and

- **Horizon Europe** is a framework program for research and innovation during the 2021 – 2027 multiannual financial framework. It consists of four parts: excellent science; global challenges and European industrial competitiveness; innovative Europe and widening participation and strengthening the ERA.

6.3 An EU Sustainable Finance Framework

In recent years the EU has developed a novel Sustainable Finance Framework with several key legislative measures that may enhance private sector funding of climate adaptation. The aim of the framework is to support the objectives enshrined in the 2019 European Green Deal as well as the EU's international climate commitments. [47] As described by the European Commission's action plan on financing sustainable growth,[48] the EU's Sustainable Finance Framework is composed of three pillars: (i) reorienting capital flows towards a more sustainable economy; (ii) mainstreaming sustainability into risk management; and (iii) fostering transparency and long-termism. At present, only five components of the EU's Sustainable Finance Framework seek to directly and indirectly incentivize the channeling of private funds towards climate adaptation measures:

- **Taxonomy Framework:** The Taxonomy Regulation[49] and Commission delegated act[50] put forward a classification system for sustainable activities in the EU. The Taxonomy framework establishes 'climate change adaptation' as one of the six environmental objectives to which an economic activity should substantially contribute, for it to be considered 'environmentally sustainable' under the regulation;[51]
- **EU's Green Bond Standard Regulation**:[52] The Regulation lays down uniform requirements for issuers of bonds who wish to use the designation ''European Green Bond'' (''EuGB''). Through its link with the Taxonomy framework, the Regulation may encourage companies to undertake climate adaptation measures. To be able to use the designation EuGB, issuers must invest the proceeds from these bonds in full, before the bond reaches maturity, in sustainable economic activities deemed 'environmentally sustainable' in accordance with the Taxonomy Regulation, which include climate adaptation ('gradual approach'). Issuers can alternatively allocate the proceeds from

[47] Sustainable finance is about financing both what is already environmentally friendly today (Green Finance), and what is transitioning to become environmentally friendly over time (Transition Finance). See European Commission, Overview of Sustainable Finance, website page.

[48] European Commission, Renewed sustainable finance strategy and implementation of the action plan on financing sustainable growth, updated on 5 August 2020.

[49] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment and amending Regulation (EU) 2019/2088 [202] OJ L 198, 22.6.2020, ('The Taxonomy Regulation').

[50] Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives, OJ L 442, 9.12.2021.

[51] Articles 2(6), 3 and 9, and 11 of the Taxonomy Regulation.

[52] Regulation (EU) 2023/2631 of the European Parliament and of the Council of 22 November 2023 on European Green Bonds and optional disclosures for bonds marketed as environmentally sustainable and for sustainability linked bonds (30.11.2023) OJ l 2631 (''The Green Bond Standard Regulation'').

these bonds to a portfolio of fixed assets or financial assets in accordance with the Taxonomy Regulation's criteria ('portfolio approach');

- **Corporate Sustainability Reporting Directive (CSRD)**:[53] The CSRD imposes disclosure requirements on companies, including their policies and targets in respect of climate change adaptation. Such information must be reported in accordance with European Sustainability Reporting Standards (ESRS).[54] ESRS 1 include disclosure requirements regarding climate-related hazards that can lead to physical climate risks for the undertaking and its adaptation solutions to reduce these risks. The CSRD will enter into force in a staggered manner from 2025;
- **Sustainable Finance Disclosures Regulation (SFDR):**[55] The SFDR adopted in 2019, specifies asset managers' and institutional investors' duties regarding sustainability. While not requiring disclosure of climate adaptation measures *per se*, it provides indirect incentives for climate adaptation, by increasing transparency about sustainability risks and adverse sustainability impacts; and
    - **Environmental, Social and Governance (ESG) Ratings Regulation:** The proposed Regulation introduces a common regulatory approach to enhance the integrity, transparency, comparability, good governance, and independence of ESG rating activities.[56] ESG rating providers are required to publish methodologies, models and key rating assumptions used in ESG rating activities on their website. It underpins adaptation measures, by increasing investor understanding of the methodologies underpinning (ESG) ratings, and thus whether adaptation measures in place.

6.4 Other legal obligations and developments regarding climate adaptation under EU law

Other areas of EU policy require to consider climate adaptation and resilience aspects during planning or licensing application processes and when performing impact assessments. Key examples include the Environmental Impact Assessment Directive,[57] the Energy Performance of Buildings Directive[58] and the Critical Infrastructure Directive.[59]

[53] Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC, and Directive 2013/34/EU, as regards corporate sustainability reporting, OJ L 322, 16.12.2022, (The Corporate Sustainability Reporting Directive).
[54] Commission Delegated Regulation (EU) 2023/2772 of 31 July 2023 supplementing Directive 2013/34/EU of the European Parliament and of the Council as regards sustainability reporting standards, OJ L, 2023/2772, 22.12.2023.
[55] Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector, OJ L 317, 9.12.2019, p. 1. (''Sustainable Finance Disclosure Regulation'').
[56] The Commission published its proposal in June 2023 and the European Council and Parliament reached a provisional agreement on the 5 February 2024 which resulted in the final compromise text and awaits approval of the Permanent Representatives Committee with a view to reach an agreement of at first reading with the European Parliament. Environmental, social and governance (ESG) ratings: Council and Parliament reach agreement - Consilium (europa.eu).
[57] Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment (28.1.2012) OJ L 26/1.
[58] Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (8.5.2024) OJ L 2024/1275.
[59] Directive (EU) 2022/2557 of the European Parliament and of the Council of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC (27.12.2022) OJ L 333/164.

***Summing up**, adaptation together with mitigation, are the main policy avenue to address risks emanating from climate change. They are needed to minimize and manage climate risks, reduce vulnerabilities, and enhance the capacity of social, economic, and environmental systems to deal with the impacts of climate change. A key feature of adaptation is that it might take place in a diffused and context specific manner. In addition to being increasingly necessary, there are mounting legal obligations to undertake climate adaptation. It will be important to see how legal risks will support climate adaptation. At this point some relevant questions are: how might adaptation play out and to what type of world (in terms of global warming) are we adapting?*

"***Well, if I can do something, you can do something. If I could do anything but can you do something out of this world?"*** Supertramp, Crime of the Century, 1974

7. How effective might adaptation strategies be?

Climate adaptation should be commensurate to past as well as expected future damages and losses from climate hazards. Adapting to a sea-level rise of 30 centimeters versus 3 meters involves vastly different investments in adaptation. However, planning for various scenarios is a complex exercise due to multiple uncertainties about assumptions underlying the path of GHG emissions and global warming. It is entirely plausible that reality could unfold differently making current choices ineffective. Climate adaptation needs to be dynamic and reactive in response to changing climate scenarios.[60] This section is grounded on the PESETA IV study, i.e., the Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis.

7.1 What world are we adapting to?

The PESETA IV study assesses economic and non-economic impacts of future climate change on Europe, and for selected impacts also the benefits of adaptation measures.[61] It is based on a systematic evaluation of the diminished impact of natural hazards on overall economic development, biodiversity conservation, greenhouse gas emission reductions, and public health and well-being. PESETA IV assesses the effects of both GHG emissions reduction and the implementation of adaptation measures at the EU sectoral level (Ciscar et al. (2021))). This quantitative assessment entails an examination of the sectoral-level impacts of climate change under future scenarios where both mitigation and adaptation policy actions are enacted, in contrast to scenarios where no policy actions are pursued.[62] In the absence of policy actions, impacts were assessed under a global warming scenario of 3° C with no adaptation measures. Conversely, the mitigation benefits of achieving the warming targets outlined in the Paris Agreement were evaluated by estimating impacts at global warming levels of 1.5°-2 °C.[63]

[60]It is important to know when the 30 centimeters versus 3 meters might be reached along global warming trajectories. https://www.financeministersforclimate.org/sites/cape/files/inline-files/Climate%20Change%20Adaptation%20and%20Role%20of%20CFMCA.pdf

[61] The PESETA IV study aims at understanding the effects of climate change on Europe and how these effects could be avoided with mitigation and adaptation policies, see: https://joint-research- centre.ec.europa.eu/peseta-projects/jrc-peseta-iv_en

[62] Given the inertias in climate dynamics, the "benefits" from climate policies (mitigation and, in the case of this paper, adaptation) are assessed in terms of avoided negative impacts (under less favourable scenarios).

[63]The PESETA IV study includes categories such as human mortality attributed to heatwaves, droughts, river and

7.2 Rising costs and benefits

With inadequate mitigation and adaptation efforts, projections indicate substantial impacts on ecosystems, societies, and the EU economy. Notably, a discernible North-South disparity emerges within Europe, with southern regions bearing a disproportionate burden due to heightened heat stress and constrained water availability **(EUCRA (2024), IPCC (2023) and (Feyen et al. (2020))**. The PESETA IV study unequivocally demonstrates that climate mitigation measures can substantially attenuate the adverse effects of climate change across the EU. Additionally, the implementation of climate change adaptation strategies has been shown to effectively reduce unavoidable impacts in a cost-efficient manner. This conclusion is of overwhelming importance, given that even under scenarios in which global warming is constrained to well below 2 °C, Europe will still face significant climate impacts.

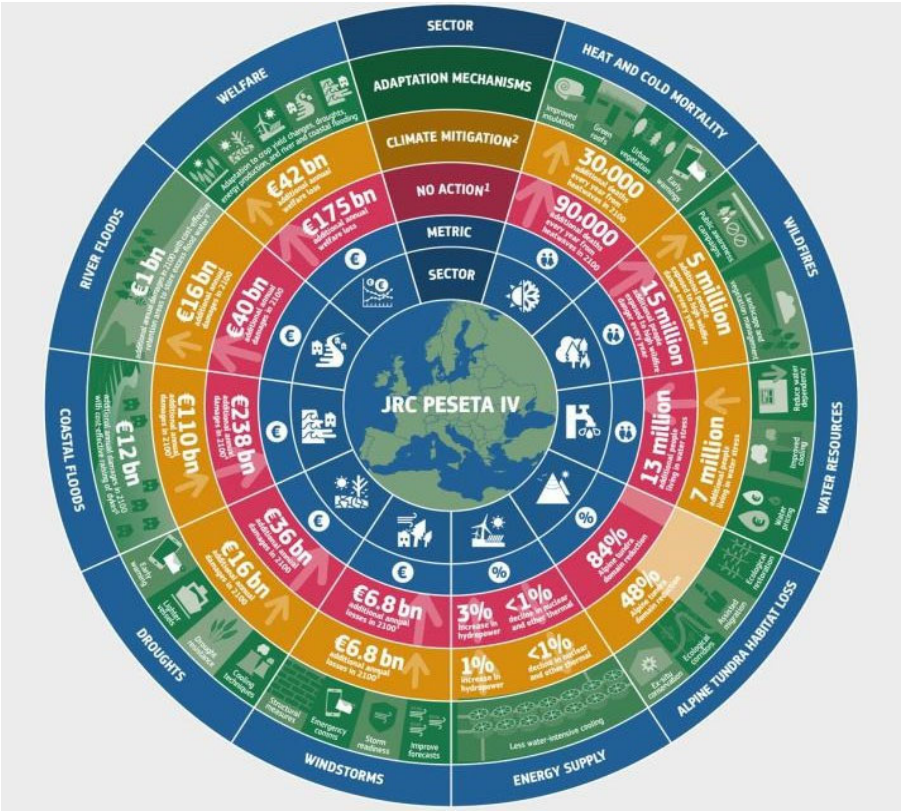
From our viewpoint, effective adaptation efforts generate significant benefits and buy time for mitigation efforts to display their effects. The benefits of adaptations measures are underscored by their capacity to mitigate escalating climate change damages over time, particularly in the face of increasing global warming. For instance, under a scenario of 3 °C global warming by 2100, the projected river flood damage in the EU and UK would amplify sixfold compared to current losses, amounting to €48 billion annually, and posing a threat to nearly 500.000 individuals annually, compared to the current 170,000. However, limiting global warming to 1.5 °C could halve adverse economic impacts and reduce the number of people exposed by an estimated 230,000. Adaptation strategies hold the potential to significantly curtail future flood impacts in a cost-effective manner, with associated co-benefits. For example, implementing retention reservoirs to diminish river flood peaks could slash projected damages by nearly €40 billion annually by 2100, while concurrently enhancing ecosystem quality. Furthermore, in the absence of mitigation and adaptation measures, annual damage from coastal flooding in the EU and UK could surge from the current €1.4 billion annually to nearly €240 billion by 2100. However, PESETA IV argues that around 95% of these impacts could be averted through moderate mitigation efforts and strategic bolstering of dykes in areas of human settlement and economic significance along coastlines. **Annex 2** addresses how nature preservation can support adaptation.

7.3 The cost-benefit analysis

Cost-benefit analysis plays a pivotal role in comprehending the economic ramifications of different adaptation options and their implications for the financial system. It requires cutting- edge biophysical impact models to quantify sector-specific effects, robust assessment of uncertainty through consideration of diverse climate models and emission scenarios, and evaluation of welfare impacts by integrating direct human and economic consequences into economic models to estimate corresponding welfare losses. However, the current state of knowledge presents challenges in accurately comparing the costs and benefits of adaptive actions across various economic sectors: this requires substantial efforts and coordination highlighting the importance of further data and modelling advancements to support climate pathways analysis and cost-benefit assessments. A discussion of the principles of EU adaptation in agriculture is in **Annex 1**.

coastal flooding, disruptions in energy supply, and wildfires.

Figure 6. Summary of PESETA IV – climate change impacts and adaptation in Europe



Summing up, *the approach to adaptation in the PESETA IV report is reliant on a "common understanding" of adaptation as in the EU Treaties and Directives[64]. In the approach of the European Environmental Agency (EEA (2023)), climate change adaptation measures are those critical to increase climate resilience and reduce disaster risks for all EU citizens. Hence, these approaches are based on a general concept of adaptation to minimize unavoidable impacts from climate change in a cost-effective manner. The question of "adaptation to which level of global warming?" has not yet been answered. In the next section, we bring together various sources and types of adaptation and resilience enhancement measures.*

8. The financing of adaptation (I): the role of the public sector

Thus far, data on the various sources of adaptation financing is fragmented and less systematic than data on mitigation financing. However, there is some evidence that adaptation financing is currently dwarfed by mitigation financing, and that the public sector is the principal source of adaptation financing.

8.1 What evidence do we have about financing of climate adaptation?

Estimated adaptation financing needs. According to a meta study by the IMF,

[64] In this approach, adaptation to climate change would further minimize its unavoidable impacts in a cost- effective manner, with considerable co-benefits from nature-based solutions.

global adaptation needs in 2030 are estimated to reach approximately 0.25% of world GDP per year, but with very large disparities across countries and high uncertainty.[65] The estimated global total is the equivalent of US$260 billion per year. Given that the EU and the UK represent a bit less than 20% of global GDP, a tentative ballpark estimation for EU + UK could be circa € 50 Billion annually based on the IMF meta-study. To put these figures into perspective, the UNEP 2023 Adaptation Gap Report estimated that annual costs of adaptation in Developing Countries alone could range from about US$215 billion to US$387 billion annually by 2030 and significantly rise further by 2050. According to UNEP these projections represent 10-18 times more than current financing flows. Moreover, this gap is expected to increase to US$ 315-565 billion by 2050.

At present, the public sector is the principal source of (still modest) adaptation finance. According to the World Resource Institute (WRI) current adaptation investment projects are overwhelmingly financed by the public sector (98%), with development finance institutions accounting for almost 80 %of total adaptation financing (WRI (2022)). Thus, development investments, that are in large part public, and adaptation are closely related, according to the World Resources Institute.[66] Private adaptation finance flows, as recorded by the Climate Policy Initiative (CPI) demonstrates that on average, around US$ 300 billion is invested in climate mitigation and only US$ 1 billion in adaptation.[67]

When considering all publicly known climate investments, the share of adaptation fundings is relatively small. According to the UNDRR less than 10 %of all climate finance is currently allocated for adaptation (UNDRR (2024)). According to CPI estimates, total adaptation financing amounted to around US$63 billion (annual average over 2021 and 2022). Although this represents an increase of over 29 percent from US$49 billion in 2019/2020, at about 5.3% it pales in comparison with mitigation financing, which amounted to over US$1.2 trillion over the same period.

However, we know less about the allocation and timing of future funding for mitigation and adaptation. For example, the Multiannual Financial Framework 2014-2020 mandates that at least 20% of the European budget be allocated to climate-related expenditure, encompassing both adaptation and mitigation efforts. But clear distinctions or attributions are missing. Concerning the timing of investments in mitigation and adaptation there is also a lack of specificity. The framework merely states that they should advance jointly until 2050.

How much should the European Union invest in adaptation? One fundamental difficulty lay in the lack of assessments of the effective costs of various forms of adaptation. This impedes raising and allocating adequate financing, and thus ultimately hinders undertaking effective climate change adaptation across Europe. Although it is not clear how much countries, regions and sectors should invest in adaptation, several complementary

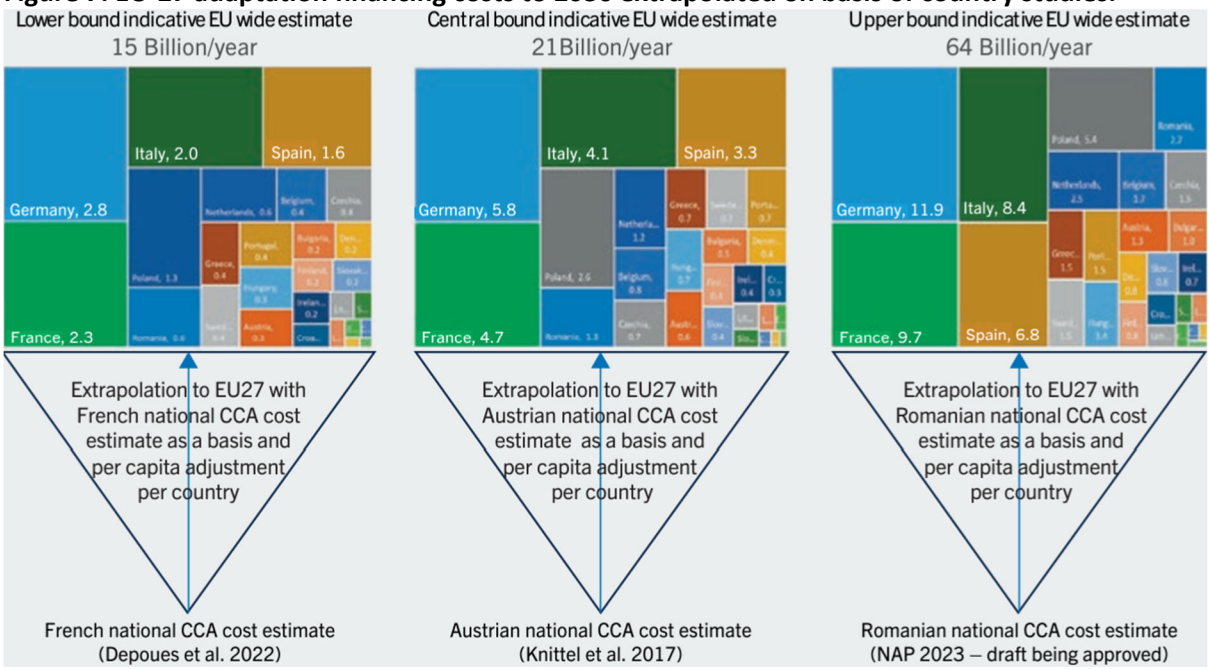
[65] A broad range of climate adaptation measures is captured by the IMF. It addresses risks from changes both in average conditions and in the frequency and intensity of extreme weather, by improving resilience to droughts in agriculture, changing where and how crops are grown, managing water resources, addressing sea-level rise, and rendering infrastructures more resilient to extreme weather (Bellon et al (2022 a and b), Aligishiev et al (2022) and see: https://www.elibrary.imf.org/view/journals/066/2022/002/article-A001-en.xml).

[66] "Building a road may enhance resilience for a community by making it easier for people to access markets, hospitals, and other sources of assistance during extreme weather and other times of trouble. To count as adaptation finance, however, the road needs to be deliberately built with climate impacts and the needs of vulnerable people in mind." See: https://www.wri.org/insights/adaptation-finance-explained

[67] https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2021/

approaches are progressing based on several recent country studies (World Bank (2024)).

Figure 7. EU-27 adaptation financing costs to 2030 extrapolated on basis of country studies.



Source: World Bank (2024).

Three ranges of EU-wide costs estimate of incremental **"no-regret" adaptation measures** (see Page 25) are extrapolated on a per capita basis from three country specific adaptation studies (Figure 7). The left panel shows a lower-bound estimate of yearly costs of adaptation extrapolated from a French assessment, i.e., €15 Billion EU-wide. The central panel is based on a per capita basis from the Austrian PACINAS study, i.e., €21 Billion (Knittel et al. (2017)). Instead, the right panel presents an upper-bound estimate of adaptation costs based on the Romanian National Adaptation Strategy and Action Plan, i.e., €64 Billion (which is still preliminary, as the National Adaptation Plan was not yet finalized). These estimates can only be considered as indicative as they do not take account of vulnerabilities or impediments in scaling up from the national level (World Bank (2024)).

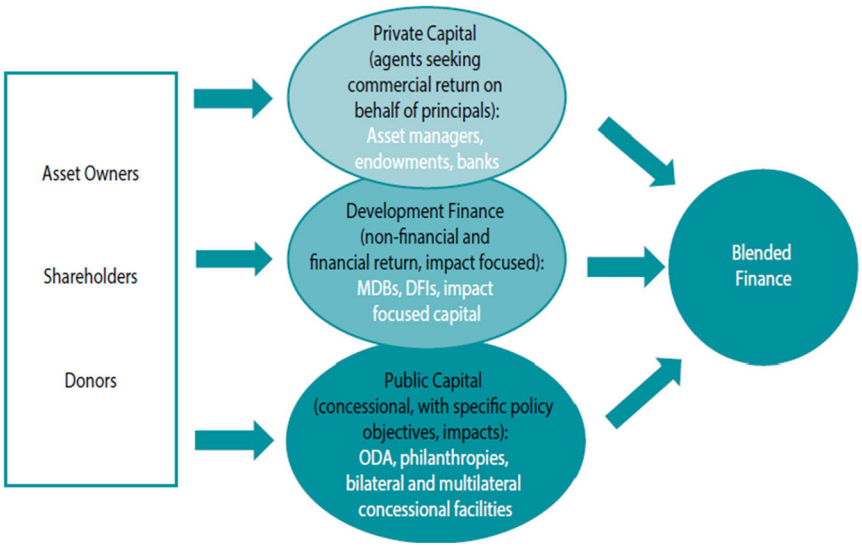
Is adaptation advancing jointly with mitigation? The scant empirical evidence suggests not. Yet there is paucity of data to plot the trends and components in the case of European countries. For example, in the case of developing countries, when correcting for inflation, adaptation investments have barely changed over the last 30 years (UNEP (2023)).

8.2 Are additional public-private approaches to climate adaptation financing being tested?

Given the paucity of financing of climate adaptation, are there additional approaches being tested? Yes, by means of a blended finance approach. The NGFS defines blended finance as "*… the strategic use of a limited amount of concessional resources to mobilize financing from public and private financial institutions to achieve climate impacts." (NGFS (2023)).* Since its early adoption, a growing number of new initiatives have been supporting the mainstreaming and scaling up of blended finance as a tool to attract private financing. According to the OECD, blended finance needs to attract commercial

capital towards projects that contribute to sustainable development, while providing financial returns to investors. The aim is to enlarge the total amount of resources available to developing countries to fulfil their adaptation and mitigation goals.

Figure 8. Blended Finance Ecosystems



Source: NGFS (2023). Blended finance initiatives and platforms, include Convergence and G20 initiative on Blended Finance. Information intermediaries include Credit Rating Agencies, and ESG data and product providers. Concerning ethical standards see UN, ICMA, and OECD.

Summing up, *climate adaptation will require considerable financial resources. Thus far, the picture on the role of the public sector in financing adaptation is twofold. On one hand, the empirical evidence on financing of climate adaptation is patchy and fragmented. Adaptation financing is currently dwarfed by mitigation financing and the public sector is today the principal source of adaptation financing. As we discuss in the next section the contribution of private financing must rapidly rise to meet the challenge. On the other hand, the EU has over the decades created several financial facilities to address various policy priorities such as cohesion, convergence, solidarity and so on. Over time these initiatives might be aimed at also addressing challenges stemming from the impact of unabated climate change! It is remarkable that investments in adaptation can generate high rates of return.*

9. The financing of adaptation (II): a sustainable finance framework, insurance contributions, Cat-bonds, and other lines of defense.

In previous sections we argued that climate change is worsening unabated, that mitigation plans are not ambitious enough, and that public investments in adaptation is fragmented and inadequate to face rising climate hazards. As mitigation and adaptation are stepped up, it is indispensable to raise various financial market-based "lines of defense" grounded on a sustainable finance framework, insurance coverage, Cat-bonds, Climate Bonds and strengthen other financial safeguards for mitigation and adaptation to be successfully implemented.

9.1 Insurance coverage needs to play an increasing role.

There is a significant insurance protection gap in the EU. Joint work by the ECB and EIOPA show that currently, on average, only 25% of climate-related disaster losses in the European Union are insured and that the insurance gap is expected to widen as the impact of climate change becomes more severe (see EIOPA (2024), ECB-EIOPA (2023) and Rousova et al. (2021)). A particular concern is that some of the climatic zones more exposed to future rising climate hazards (such as the Mediterranean climate zone in Section 3) are among those with the lowest insurance protection at present.[68]

A gradual decline in insurance protection, against the background of slow mitigation and adaptation, and locked in continued warming and extreme events, may have an impact on the economy. For example, disruptions in the global value chains (GVC) and financial stability (due to the decline in value of insured assets) may ensue. Thus, assessing the state and prospects of the insurance gaps is critical. The international association of insurance supervisors (IAIS) is advocating for a framework to promote public private insurance programs against climate hazards with joint involvement from the IAIS and OECD.

Wider insurance coverage should protect rising shares of households and firms from the damages and losses originating from extreme weather events and even climate-related disasters. At one extreme, several governments are already looking to privatize the financing and incentivization of climate adaptation through insurance markets. In a pure *market approach to insurance for extreme weather events*, individuals become responsible for ensuring that they are adequately covered for risks to their own properties, and governments no longer contribute funds to post-disaster recovery (Lucas and Booth (2020)).

Yet, the insurance sector's contribution to climate adaptation might be neither unbound nor unlimited. Unabated climate change might see an increase in both the frequency and/or the intensity of extreme weather events (hazards) which over time might potentially limit the future availability or affordable insurance (OECD (2023)). Insurances firms might bear losses which then might have knock on effects on reinsurances (thus the debate on cat-bonds below).

Adverse incentives? Might insurance coverage of climate related risks provide a false sense of safety and discourage adaptive behaviors? Insurance premiums signal the level of climate risk faced by households, firms, and governments. This should incentivize investments in adaptive actions for risk-proofing, such as retrofitting, drainage work, and fire proofing, to reduce premiums. Where risk is considered too high by insurance markets, housing is devalued or firms value is dented, in theory leading to a retreat from risky areas and or activities. Yet there is also evidence of moral hazard behavior and insufficient risk-proofing and adaptive behavior.[69]

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[68] For a dashboard on insurance protection gaps for natural catastrophes in the EU see: https://www.eiopa.europa.eu/tools-and-data/dashboard-insurance-protection-gap-natural-catastrophes_en. For the EIOPA's Final Single Programming Document 2024-2026 see: https://www.eiopa.europa.eu/document/download/73ad1211-1cbd-475f-883b-cbc864afb447_en?filename=EIOPA%20Final%20SPD%202024-2026.pdf

[69] There is a role for financial literacy. Evidence shows a mismatch between social understandings of responsibility for facing climate risks, and the market-based home insurance products offered by private insurance markets. Moreover, market-based models of insurance for extreme weather events erode the solidaristic and collective

Insurance coverage is likely to play an increasingly important role in climate adaptation. The challenges of moral hazards and poor micro adaptive behaviors by households and firms should be acknowledged and addressed. Policyholder risk reduction can be both encouraged and supported. The IMF and OECD have identified approaches that policymakers, regulators and supervisors could consider supporting such as a greater contribution of the insurance sector to climate adaptation (Ando et al. (2022) and OECD (2023)). Possible areas for further work concern re-insurance, supporting a market for catastrophe bonds, and interactions between private and public insurance schemes. Eventually it might be useful to conceptualize the medium- and long- term interactions between adaptation and mitigation.

9.2 Catastrophe bonds are insurance linked securities.

Catastrophe bonds (cat bonds) are securities which are linked to natural disaster risks. Their purpose is to transfer the burden of climate related risks from an issuer (generally an insurance company) to investors (generally bond markets): i.e., wholesale investors, not retail. When such professional investors purchase cat bonds, they take on the risk of the occurrence of a predefined natural hazard/disaster in return for payments. If the adverse event occurs, investors will lose part, or all, of the capital invested, and the issuer will use the proceeds to cover the damage. Cat bonds were created in the mid-1990s, after Hurricane Harvey in 1992 brought 11 insurance companies into bankruptcy. A detailed description is in Polacek (2018)).

The market for cat bonds is still relatively undeveloped, especially outside the US. There might be an ESG angle to this asset class. "*Over 60% of Schroders Capital ILS assets are classified as Article 8 under the EU's SFDR. In addition, there are some cat bonds which use ESG-friendly collateral (such as IBRD bonds) thus further increasing the ESG credentials. Cat bonds are also increasingly used with a development angle such as the Chile earthquake bond*." European project Medewsa ties into these mechanisms. The idea of the Medewsa project that started in July 2024 is to explore innovative risk transfer solutions to reduce the climate insurance gap.

9.3 Green Capital Market Unions need to come to the rescue!

A European climate bond and a Global Climate Fund. Monasterolo et al. (2024) propose issuance of a European climate bond. To close part of the EU's climate investment gap, they propose the joint issuance of European climate bonds by the European Stability Mechanism (ESM). Climate bonds would be funded by the sale of GHG emission allowances, traded on the EU Emissions Trading System, extended to cover all sectors (ETS2). Access to the resulting funds would be conditional onMember State's green performance with respect to the implementation of climate projects. The climate bonds would meet the demand for a safe, liquid, and green asset, while increasing the speed and efficiency of EU climate investing, resilience to sovereign crises, and the greening of investors' portfolios and monetary policy. Hochrainer-Stigler et al. (2014) instead propose a **Global Climate Fund** *"…covering different risk layers to be in the lower billions of dollars annually, compared to estimates of global climate adaptation which reach to more than USD 100 billion annually*."[70]

practices that support adaptive behaviour (Lucas and Booth (2020)).

[70] https://www.sciencedirect.com/science/article/abs/pii/S0959378014000259

Summing up, *while mitigation and adaptation are stepped up, it is indispensable to raise various financial market-based "lines of defence". There are already strong foundations such as the EU's evolving* ***Sustainable Finance Framework*** *which can be a game changer for climate policies including adaptation, with its Taxonomy Regulation, EU's Green Bond Standard Regulation, the Corporate Sustainability Reporting Directive, the Sustainable Finance Disclosures Regulation, and the proposed ESG Ratings Regulation. However, there are concerns about uneven and possibly declining insurance coverages. Insurance coverage is both limited at present and is not a final solution to unabated climate change, escalating climate hazards and rising damages. New financial instruments are being considered such as Cat-bonds, Climate Bonds, and a global climate fund. These instruments would strengthen other financial safeguards for mitigation and adaptation to be able to unfold.*

10. Some final remarks and open issues

Unabated climate change confronts us with a wide spectrum of climate scenarios as well as paths of damages from more frequent and stronger extreme events. Predictions range from significant but manageable damages by the end of the forecast horizon, i.e., 2100, all the way to catastrophic outcomes. Compounded hazards, concurrent events and risk multipliers that might become increasingly unmanageable (especially in more vulnerable exposed climate zones (EEA (2024)). As significant damages are uncertain but highly probable, it would be prudent to immediately frontload robust climate adaptation measures.

We should be mindful of a trilemma between damage restoration, mitigation, and adaptation efforts. The trilemma consists of three apexes: **damage restoration** and compensation following climate-related extreme events, **mitigation** efforts to slowdown climate change and the occurrence of climate hazards, and **adaptation** strategies and actions to reduce the negative impacts from climate hazards. A reactive approach relying principally on damage restoration and compensation will become increasingly costlier if mitigation efforts are insufficient and adaptation actions are inadequate. Thus, underinvesting in adaptation might backfire by draining public resources, while simultaneously shrinking the tax base.

A serious drawback in climate research is the paucity of granular data on past damages and losses. A common thread throughout the paper is that we face uneven and inadequate data coverage concerning past and current damages and losses considering, amongst others, actual damages, financial needs, financing options, and so forth. On the other hand, we have considerable amount of new granular weather data and projections. Effective adaptation, that is specific for countries and regions, will likely require substantial coordination between central, economy-wide measures and local or sector-specific actions (which involves administrative costs for sharing best practices and building expertise, see World Bank (2024)).

Climate adaptation presents us now with difficult choices with intertemporal consequences: i.e., we need to tackle the barriers and political economy challenges. While the concept of adaptation is intuitive, deciding where to adapt, how, to what extent given residual risks, and when over long time periods can be rather complex. There is a need for quantifiable targets and steps, a shared classification system and approaches to climate adaptation, which embraces trade-offs, shares best practices, and learns by doing.

Another paradigm shift is that addressing climate change requires a wholistic transformation of economic governance as well as existing financial facilities such as the sustainable finance framework. There are opportunity costs as adaptation financing competes with mitigation financing as well as other policy goals within a given budget. On one hand, adaptation investments support development goals. "*However, we still see widespread underinvestment in adaptation due to electoral cycles, definitional ambiguity surrounding what adaptation entails; complexity associated with quantifying the negative economic consequences of climate change and the positive economic returns to investment in adaptation. Future election cycles" (Allen et al. (2019).*

While adaptation might be costly, not all adaptive measures are necessarily expensive. Some require raising awareness, education, information, and collecting, analyzing, and sharing more granular data concerning climate hazards and vulnerabilities, as well as a requalification of existing budget items. Public awareness and support are pivotal. Thus, a key question is: *how might private support for climate adaptation be enhanced at the level of households and firms?* Reassuringly, overwhelming evidence shows that the benefits from early adaptation and vigorous mitigation generate significant net benefits.

Possible impacts from climate change adaptation, or the lack thereof, for central banks (I). Unabated climate change and weak adaptation has the potential to impact all tasks of central banks through various direct and indirect channels. While these concepts are broad, they can increasingly be captured by measurable financial risks such as liquidity, market, and credit risks. Inevitably, this may affect central banks' price stability mandate,[71] the ability to define and implement monetary policy and perform tasks related to prudential supervision and financial stability.

Possible impacts from climate change adaptation, or the lack thereof, for central banks (II). Heterogeneity and inequality effects of unabated climate change and rising extreme events are among the things we still do not know much about. Adaptation needs can be highly specific to regions and sectors. Local climate data and tailored adaptation strategies are essential (e.g., *Florida versus Montana*, or *Puglia versus Tyrol*). However, there are also spillover effects where actions in one area can impact other. The wide heterogeneity and dispersion of climate impacts necessitate a strong role for risk-sharing and cross-regional and sectoral insurance, especially during the implementation of mitigation and adaptation policies which have lags. Lack of local adaptation can generate increasingly important economic and financial spillovers of various kinds, e.g., by interrupting trade and global value chains GVC (not to be mixed with global "climate spillover").

Climate adaptation is among the most complex challenges in economics, finance, and political economy. This paper has outlined several reasons to be very concerned about its urgency. Conversely, we now have better granular climate data to study the frequency and impacts of climate hazards and thus forecast climate risks; there is awareness that adaptation choices must be dynamic and reactive; and there is an increasing pool of case studies from which to learn. There is evidence that efficient adaptation investments can yield "triple-dividends" helping to close the financing gap. Solving the adaptation puzzle and mosaic will require substantial data and computational power, building synergies and adjusting to changing risks and scenarios as they unfold. The potential of combining digitalization, artificial intelligence, and sustainable energy to support efficient and effective adaptation should be explored.

[71] In the case of the ECB, see respectively Articles 127(1) TFEU, Article 127(2) TFEU, and Article 127(5) TFEU.

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Annex 1. Principles of EU adaptation: the agricultural sector as a case study.

The goal of the EU Adaptation Strategy is to ensure that adaptation considerations are integrated into all relevant EU policies. This entails promoting enhanced coordination, coherence, and information sharing (EEA, 2024). Moreover, the strategy acknowledges the pivotal role of improved access to funding in building a climate- resilient Europe.

Among the many sectors and activities in Europe, agriculture and tourism are among those most exposed to climate change impacts and the need for adaptation. Moreover, not only is agriculture a significant contributor to climate change, but it is also profoundly affected by its

impacts. Consequently, policy efforts are directed not only towards mitigating climate change within agriculture but also towards bolstering the sector's resilience and minimizing the adverse effects of climate change.

In this regard, the EU Adaptation Strategy, the Land Use, Land Use Change and Forestry Regulation (LULUCF), and the EU Common Agricultural Policy serve as pivotal instruments for promoting adaptation solutions and enhancing the resilience of the agricultural sector to climate risks. Additionally, adaptation knowledge and networks of practitioners have emerged, facilitating information exchange and capacity building, largely supported by various EU-funded research programs. Monitoring, reporting, and evaluating agricultural measures at the EU level heavily rely on the formal reporting mechanisms established under the reformed Common Agricultural Policy.

Building a resilient and sustainable future for agricultural production requires the development and implementation of tailored climate change adaptation strategies (Ceglar et al., 2024; Toreti et al., 2022; Ceglar et al., 2021). These include, among others, introduction of resistant crop varieties, changing production patterns, improved irrigation infrastructure and efficiency, development of early warning systems and others. While the whole of Europe is facing adaptation need, the worst situation has been emerging in the southern parts of the continent, where non-linear decline of climatically suitable growing regions is expected.

Annex 2: How can nature preservation support adaptation?

As climate change effects such as droughts, flooding, and extreme temperatures become more pronounced, the urgency for adaptation measures increases. Nature preservation supports adaptation to climate change through **nature-based solutions (NBS),** which utilize natural ecosystems to mitigate and adapt to climate impacts. These solutions are cost-effective, provide multiple co-benefits, and are crucial for building resilience in both human and natural systems[40]. Ecosystem-based adaptation focuses on restoring and enhancing ecosystem services to shield society from the negative impacts of climate change.

NbS encompass a range of ecosystem-based approaches designed to enhance resilience to climate change. These solutions typically include coastal zone protection, wetland restoration, river and floodplain restoration, agroforestry, close-to-nature forestry, (peri)urban greening, and soil protection. NbS provide essential services such as erosion control, drought and flood prevention, carbon sequestration, cooling, and wildfire prevention. With 72% of European companies critically depending on these services, the importance of implementing NbS for economic stability is further underscored (Boldrini et al., 2023).

Forests act as carbon sinks, absorbing CO2 from the atmosphere and thereby reducing the greenhouse effect that contributes to global warming. Protecting and restoring forests not only helps to sequester carbon but also preserves biodiversity and ecosystem stability, which are vital for resilience against climate impacts such as extreme weather events and changing precipitation patterns. Wetlands, including marshes and mangroves, serve as natural buffers against storms and flooding by absorbing excess water and reducing erosion. Preserving these ecosystems therefore ensures they can continue to provide crucial protective functions. Furthermore, preserving natural habitats supports agricultural productivity by maintaining soil fertility, pollination services, and pest control mechanisms. These ecosystem services are critical for food security and sustainable agriculture in the face of climate variability and change.

The EU Adaptation Strategy, updated in 2021, highlights the importance of ecosystem-based approaches, especially nature-based solutions. Relevant EU policy frameworks include

not only the EU Adaptation Strategy but also the Green Infrastructure Strategy and the Biodiversity Strategy. The Nature Restoration Law[41], enacted by the European Council in June 2024, explicitly recognizes the indispensable role of nature in climate change adaptation. By mandating comprehensive ecosystem restoration and conservation efforts, the law aims to bolster the resilience of natural landscapes, ensuring they continue to provide vital services that mitigate climate impacts and support human well-being. This legislation reflects a commitment to leveraging nature-based solutions as a fundamental strategy in addressing the challenges posed by a changing climate.

[40] https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/key-eu-actions/NbS
[41] https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

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