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The macroeconomic case for investing in climate adaptation

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Foreword

By the Hon. Matia Kasaija

Minister of Finance, Planning & Economic Development, Uganda

Co-Chair of the Coalition of Finance Ministers for Climate Action

As we confront the pressing realities of climate change, it is imperative for us to act with urgency and resolve. As Minister of Finance, I understand that it is critical to integrate climate action into macroeconomic and fiscal policies. The economic and fiscal vulnerabilities exposed by climate shocks are impacting our nations in profound ways. The evidence presented in this report highlights that climate policy and economic policy are intrinsically linked and provides the rationale for further action from Finance Ministries. Otherwise, economic growth is expected to contract, inequality to rise, labour productivity to diminish, unemployment to increase, and our citizens' welfare to deteriorate. This emphasises why we must develop robust analyses to make the best decisions at the policy level to harness resources: not just to mitigate risks, but to drive sustainable economic development.

Without the necessary investments in adaptation, climatic change will continue to impact national economic potential and individual livelihoods. Agriculture, the backbone of many countries' economies, is particularly vulnerable to erratic weather patterns and more extreme events. The knock-on fiscal implications exacerbate these challenges, as responses divert critical resources amid reduced revenues and heightened debt burdens.

Among these challenges, however, lies a significant opportunity. By prioritising investment in adaptation, we can convert challenges into pathways for transformative, resilient and inclusive growth and development. This report puts forward a powerful case for adaptation investments – not only as a necessary response to manage and reduce climate risks but as a proactive strategy to drive economic progress through resilience. We must advocate for resilient infrastructure and robust systems that engage the private and public sector, pooling resources for meaningful, planned and long-term adaptation solutions.

In Uganda we have embraced an integrated growth strategy that aligns economic objectives with our climate commitments. Our National Development Plan identifies critical areas for investment that not only respond to climate risks but also create a foundation for long-term prosperity. Drawing on innovative models, such as our Parish Development Model, we aim to drive community-level resilience while enhancing local ownership of adaptation measures.

As we move forward, this report offers an important guide for Finance Ministries to integrate climate risks into fiscal and macroeconomic planning, through the use of relevant analytical tools and decision-making based on rigorous assessments. The imperative to invest in resilience is not simply about avoiding losses: it is about providing for economic sustainability and prosperity.

In conclusion, I urge all of us to champion discussions around proactive adaptation and embrace the insights shared within this report. Our collaborative efforts can further strengthen the resilience of our economies and enrich the lives of our citizens.

Together, let us commit to a future where adaptation is at the heart of our economic strategies – paving the way for a sustainable and inclusive tomorrow.

Summary

This report provides a groundbreaking new synthesis of the economic and fiscal risks arising from physical climate change and the economic case for investing in adaptation to climate impacts. The report combines the results of nearly 300 studies and more than 6,000 unique estimates of the consequences of climate change and adaptation investment, and includes case studies from six countries.

The physical impacts of climate change are emerging rapidly across the globe, with consequences for human health, ecosystems and social well-being. The report shows that the macroeconomic and fiscal consequences of climate impacts are still difficult to quantify accurately but are already significant, growing, and likely to continue and intensify without further efforts to adapt and increase resilience. Our evidence shows that early and strategic adaptation investments can bolster economic stability, reduce debt levels and borrowing costs, and accelerate development.

Table S1. Summary of major quantitative results and their corresponding evidence base: climate impacts globally and in low- and lower-middle-income countries (LICs and LMICs) in 2050 – averages and ranges[1]

Climate indicator	Global impact	LIC and LMIC impact	Evidence base
Warming from pre-industrial average	2.5°C (2.2–2.8°C)	3.1°C (2.5–3.8°C)	IPCC (2021), Dietz et al. (2021)
Sea-level rise from level in 2000	230 mm (210–250 mm)	230 mm (160–310 mm)	FACTS (Kopp et al., 2023)
Macroeconomic impacts	**Global impact**	**LIC and LMIC impact**	**Evidence base**
Reduction in GDP per capita	8% (3–15%)	12% (8–18%)	85 econometric models
Welfare damages (% of GDP-equivalent loss)[2]	14% (8–19%)†	16% (8–23%)	105 estimates, synthesised by Howard and Sterner (2025); 3 integrated assessment models
Reduction in labour productivity	0.6% (0.0–0.7%)	1.4% (0.0–2.8%)	8 studies
Reduction in total factor productivity growth	0.03 pp/year (0.00–0.04)	0.03 pp/year (0.01–0.04)	3 studies
Increase in inflation rate	1.6 pp/year (0.6–2.0)	1.7 pp/year (0.7–2.2)	2 studies
Changes in unemployment rate	−0.23 pp (−0.9–0.7)†	0.1 pp (−0.5–0.7)†	Liu and Lin (2023)
Gini index	0.2 point (0.1–0.3)	0.3 point (0.2–0.3)	8 macromodels
Fiscal impacts	**Global impact**	**LIC and LMIC impact**	**Evidence base**
Reduction in credit rating	1.4 notch (2.0–0.5)†	1.0 notch (1.0–0.3)†	Klusak et al. (2023)

Cont. below

Summary of major quantitative results and their corresponding evidence base *cont.*

Adaptation benefits	Global impact	LIC and LMIC impact	Evidence base
Adaptation effectiveness ratio[3]	0.14 (0.03–0.47)	0.03 (0.02–0.17)	26 studies
Benefit–cost ratio	4× (3–6×)	5× (3–6×)	15 studies
Gini index	−1.2 point (−2.2–0.1 pt)	−2.6 point (−4.5 to −0.4 pt)	8 macromodels

Notes: 1. Estimates of the macroeconomic impacts of climate change are generally incomplete and do not capture all the consequences. Climate indicator, macroeconomic and fiscal estimates are projected under a high-emissions scenario consistent with the IPCC's SSP3-7.0 scenario and macroeconomic and fiscal estimates assume no further increases in adaptation and resilience. Global temperatures from tipping-point-corrected FaIR runs (Finite amplitude Impulse Response model v2.0); temperatures for LICs and LMICs use downscaling described in Appendix A.2, and assume temperatures had warmed 0.2°C by 1940–1960. Estimates marked with † are projected to match this report's baseline scenario but are not a synthesis performed for this report.
2. Welfare' is a composite measure of anything people value; welfare damages are often translated into a percentage of GDP loss for comparability.
3. The adaptation effectiveness ratio captures the portion of losses that are reduced thanks to adaptation. Units: pp = percentage points; pp/year = percentage points per year; notch = sovereign credit rate notch; point = Gini index point. References provided in Appendix A.7.

Key findings

Macroeconomic risks from climate impacts

The macroeconomic impacts of climate change are difficult to quantify accurately but are already significant, and they are growing rapidly. This study has synthesised the results from 85 models of the impacts of local temperature change and sea-level rise on economic growth, assuming no further increases in adaptation and resilience. All these model results, most of which have been produced in the past five years, are based on a robust, data-driven approach, and the resulting synthesis includes quantified scientific uncertainty. We fill in some key gaps on climate tipping points, sea-level rise and trade spillovers, and express the findings in terms of effects on gross domestic product (GDP) per capita.

Our findings show:

- **By 2050, climate change could reduce income for the average person, measured in terms of GDP per capita, by between 3 and 15%** due to rises in local temperatures, sea-level rise and some tipping points, based on the plausible worst case scenario of a rise in global average temperature of 2.2–2.8°C relative to a pre-industrial climate, and assuming no further increases in adaptation and resilience. People in low- and lower-middle-income countries are expected to be disproportionately affected by climate impacts, experiencing a loss of 8–18% of GDP per capita on average, with some likely to face losses exceeding 20% of GDP per capita by 2050.
- **People in the low- and lower-middle-income countries (LICs and LMICs) are today already 4 to 12% poorer** in terms of GDP per capita due to local temperature changes and sea-level rise, the same analysis suggests.
- **In addition to these outcomes are the substantial impacts expected from changes in the frequency and severity of other extreme climate-related events, such as flooding, wildfires and drought.** As such, the figures above are likely to constitute significant underestimates of the overall impacts of climate change on GDP per capita.
- **There are also important non-market impacts of climate change that are missed when the focus is solely on GDP.** Non-market losses from climate change, such as well-being lost due to higher risk of death, cultural heritage loss and the disamenities of a harsher

climate, are important components of total 'welfare', but are not reflected in GDP per capita.

- **Losses of aggregate welfare – both market and non-market losses, expressed as a percentage of GDP per capita – are projected to reach 8–19% by 2050,** driven by changes to global average temperature of 2.2–2.8°C, which accounts for some tipping points and assumes no further increases in adaptation and resilience. Losses are projected to be felt in all regions. Welfare in low- and lower-middle income countries is projected to be 8–23% lower in 2050 than it would have been without warming due to climate change on average and assuming no further increases in adaptation and resilience, with some regions facing a central estimate of losses above 20% of their welfare. Almost 50% of damages are attributable to catastrophic impacts, represented by climate and economic tipping points.
- **Labour productivity – which is influenced significantly by temperature increases – is expected to be lower due to climate change**, assuming no further increases in adaptation and resilience, especially in regions that are reliant on weather-exposed labour. Total factor productivity growth rates will likely decline in warmer climates, further exacerbating economic vulnerabilities.
- **A rise in the occurrence of extreme weather events could cause persistent upward pressures on inflation** in the absence of further increases in adaptation and resilience – including through impacts on interest rates.
- **Climate change is also expected to increase unemployment and drive up inequality** in the absence of further increases in adaptation and resilience.

Without much larger reductions in greenhouse gas emissions, these impacts are likely to continue to intensify or even accelerate in the latter half of the 21st century. **In contrast, under a scenario that approaches 2°C of temperature rise by the end of the century, GDP per capita and welfare impacts stabilise by mid-century.**

The studies underlying these estimates are not comprehensive. Because they exclude many important impacts, such as flooding and the full impacts of tropical cyclones, cascading and compounding risks and tipping points, **they are likely to be significant underestimates of the potential consequences**, assuming no further increases in adaptation and resilience.

Fiscal risks from climate impacts

Demands on fiscal spending from responding to climate impacts are already significant in some countries, and in the absence of further increases in adaptation and resilience, they are expected to rise in the future, increasing government expenditures and decreasing revenues. However, analytical assessment of fiscal risks is notably thin.

Sovereign credit ratings are increasingly at risk due to climate change impacts in the absence of further increases in adaptation and resilience, which will affect borrowing costs and fiscal stability:

- **High-income countries may face larger relative downgrades** due to higher baseline ratings, with over a dozen at risk of downgrades of two credit rating notches or more by 2050 in the absence of further increases in adaptation and resilience. Poorer countries are intrinsically more vulnerable and have higher absolute risk and welfare losses.
- **Downgrades to credit ratings can lead to a vicious cycle in which vulnerable economies face escalating borrowing costs**, hindering their ability to finance crucial climate adaptation measures and other vital public services.

Adaptation measures to reduce risk are inadequately captured and rewarded within sovereign credit risk assessments, despite evidence that climate impacts are starting to materially impact the fiscal positions of governments.

Benefits of adaptation

Adaptation investments can yield substantial returns at the macroeconomic level, especially because of the broad co-benefits and opportunities created:

- **Adaptation investments can yield a 'triple dividend',** preventing losses, stimulating economic activity and providing social and environmental co-benefits.
- **Economic metrics indicate median economic benefit–cost ratios of around 4:1 and economic internal rates of return of about 25%:** representing substantial returns on adaptation investment.
- **There are many adaptation actions that can provide rapid benefits.** Focusing on these interventions, accumulated benefits are expected to exceed costs after approximately three years for the average project.

Early and strategic adaptation investments bolster fiscal stability by reducing expenditures on losses from climate change impacts, maintaining government revenues, supporting economic stability, reducing future borrowing costs, improving debt-to-GDP ratios and mitigating credit rating impacts.

The broader economic returns from adaptation are typically higher than financial ones, since some benefits are not priced by the market. This highlights the need for government intervention and partnerships with other actors to avoid underinvestment in adaptation.

While it is clear that investments in increasing adaptation and resilience have significant economic benefits, these should not be regarded as alternatives to investments in efforts to reduce greenhouse gas emissions. There are likely to be limits to the level of climate impacts to which adaptation and resilience can provide a cost-effective response; beyond that threshold, economic losses and damages would rise substantially.

While this report focuses on the benefits of domestic adaptation, the evidence also clearly points to the returns on investments in adaptation and resilience overseas, particularly in lower-income countries. In addition to the benefits to the country receiving the investments, there are returns for investors as well. For instance, it is more cost-effective to invest in adaptation measures that reduce loss and damage in lower-income countries than to provide emergency aid after weather-related disasters made more frequent and intense by climate change. Investments in resilience also counter the potential for rising political instability and conflict in vulnerable countries, and can thus contribute to reducing flows of refugees and migrants escaping climate change impacts. They can also help to protect global supply chains, enhancing the security of food and other essential goods and services. For these reasons, investments in adaptation and resilience overseas can be viewed as based on 'enlightened self-interest'.

Role of the public sector, Ministries of Finance and the international research community

Public sector leadership will be crucial to help countries manage the economic and financial risks of climate change proactively and push for investment in adaptation. In the latter case, public sector involvement is critical to overcome market failures, which lead to underinvestment. The public sector can, for example, create an environment for private investment and implement adaptation measures that are public goods.

Strategic adaptation investments led by the public sector require effective governance, collaboration with the private sector and integration into national economic and development planning processes to maximise resource allocation and impact. This includes integrating climate data into macro-fiscal and sector economic models, crafting strategic plans for mobilising private finance around public priorities, addressing private risks, scaling up adaptation goods and services, and establishing policies and regulations that create the right incentives and environment for public and private capital.

The role of Ministries of Finance and other economic decision-makers in proactively incorporating climate risks and opportunities to invest in adaptation within their macroeconomic and budget projections and capital investment planning processes is especially important. This will be essential to help countries plan for the rising fiscal demands from climate change and invest in adaptation measures to offset the risks and unlock economic opportunities.

All countries are different, and targeted and context-specific adaptation strategies are essential for maximising the long-term economic benefits and addressing local socioeconomic and climatic needs. For some countries, adaptation projects can help to unlock sources of international financing, including concessionary finance, technical assistance and capacity-building measures.

The evidence base strongly indicates the need for proactive action rather than a wait-and-see strategy, to take full advantage of potential co-benefits and to ameliorate outcomes in the worst-case scenarios.

Ministries of Finance and other economic decision-makers must invest in building their analytical capabilities to identify and assess physical climate risks and benefit from the opportunities of leveraging proactive adaptation.

The research community and international organisations must improve the data and quantitative approaches used to assess the economic and fiscal impacts of both climate risk and investing in adaptation to address the clear gaps in existing approaches.

A particular emphasis should be placed on grounding economics in the latest science *and* the experience of successful adaptation.

It is also essential to address knowledge gaps for low- and lower-middle-income countries, which are often found to be impacted the most by physical climate risks. These gaps are not an excuse to delay adaptation investment, but unless they are addressed, they will continue to slow down the urgent and decisive action needed for adaptation and for the rapid decarbonisation of the global economy necessary to accelerate growth and development.

Adaptation and low-carbon development

The growing economic costs of climate impacts demonstrate the continued need to accelerate action to decarbonise the global economy. Not all these climate impacts can be adapted to cost-effectively, and there will be increasing limits to adaptation, underscoring the need to pursue mitigation, adaptation and development concurrently.

Fortunately, synergies from investments in adaptation and low-carbon development can be leveraged to minimise climate damages and maximise economic opportunities. There are abundant opportunities for adaptation, decarbonisation and development to work effectively together, particularly where actions provide both immediate and long-term benefits, such as with reduced rates of deforestation and better pollution control. Policies that address challenges related to coordination, market dynamics and crowding-in private finance can support locally-driven sustainable development.

This report includes case studies illustrating key points and set out as boxes across the chapters. These are summarised in Table S2.

Table S2. Summary of case studies in the report

Country	Context/area	Key outcome from adaptation
Bangladesh	Adaptation planning coordination	The integration of climate adaptation and economic development requires cross-ministerial coordination
Brazil	Nature-based solutions (NbS)	NbS drive agricultural productivity, reduce greenhouse gas emissions and enhance resilience to climate change
Kenya	Household resilience to climate change	Identifying household resilience factors guides effective public investments for climate resilience and economic development
Nigeria	Integrated resources water management (IWRM)	Investing in IWRM reduces flood risk, protects infrastructure and supports economic stability
Rwanda	Institutional frameworks	Strong institutional arrangements and enabling conditions enhance the integration of climate adaptation into macroeconomic and fiscal policies
UK	Government role in climate adaptation	Government intervention is crucial in overcoming market and policy failures to manage macroeconomic and fiscal risks through adaptation

Research gaps

Current assessments of the economic impacts of climate change capture critical climate risks and non-market welfare losses inadequately and are largely limited to assessing marginal losses. Systemic risks, structural shifts in the economic system, and climate and economic tipping points are rarely represented and poorly understood. These may lead to significant underestimates of the economic impacts of physical climate risk, especially for mid- and late-century impacts, in turn limiting their insights into future economic challenges.

A better understanding of systemic risks is a priority. It is currently impossible to fully estimate the impact of future climate scenarios that have transboundary, cascading effects across sectors within and between countries and economies, such as food supply chains and impacts on insurance markets. Some analyses suggest that governments can take steps to build resilience to such systemic risks but the field is still nascent.

Improved data on adaptation is critical. Assessments of both planned and completed adaptation investments contain significant gaps, often missing post-implementation costs and benefits, macroeconomic consequences, the fiscal consequences of adaptation or the importance of timing for adaptation investments. Coordinated data collection efforts are needed to inform decisions and share insights.

The insufficiency of robust assessments and data, particularly for emerging markets and developing countries, underscores the need for enhanced investment in expanded and diverse macroeconomic and adaptation analyses. It is important not to fixate on individual data points or figures without considering the underlying assumptions, scope and uncertainties in the analyses. Combining different tools and methods increases robustness: there are a range of analytical approaches to inform decision-making, from quantitative modelling to scenario-based reasoning, ex-post case studies, stakeholder engagement and iterative decision-making processes.

In light of the large uncertainties, governments should also combine flexibility in their decision-making to respond to new information, exercising the precautionary principle, which demands rapid increases in adaptation investment and planning in the face of the significant and growing climate risks highlighted by this report. Continued underinvestment is not an option.

1. Introduction

This report provides a groundbreaking new synthesis of the economic and fiscal risks arising from physical climate change and the economic case for investing in adaptation.[1] It reviews nearly 300 studies and over 6,000 unique estimates, combined with case studies from six countries – Bangladesh, Brazil, Kenya, Nigeria, Rwanda and the UK – to provide a meta-synthesis of the macroeconomic and fiscal impacts of inaction on climate change and the benefits of investing in adaptation and resilience. It pays particular attention to the risks and opportunities facing emerging markets and developing countries.

The nature of the threat and the role of adaptation

The frequency and intensity of various extreme weather events have shifted in recent years. According to the Intergovernmental Panel on Climate Change's (IPCC's) *Sixth Assessment Report* (AR6), weather and climate events such as heatwaves, heavy rainfall and droughts are occurring more often and with greater impact in many parts of the world, though the trends for others, such as tropical cyclones, remain more complex and uncertain (IPCC, 2022). Many of these changes align with earlier climate predictions, while some impacts are exceeding previous estimates.

Shifting weather patterns are already affecting millions of lives and livelihoods, increasing mortality and morbidity, displacing communities and disrupting ecosystems and the economies that depend on them. Even localised disasters can have far-reaching macroeconomic consequences, reducing productivity levels and undermining national economic growth. Climate impacts ripple through national economies, exacerbating poverty and inequality, and stalling development efforts.

Climate change threatens more than current economic stability, however: it also poses measurable risks to government finances by increasing public expenditures for disaster relief and recovery efforts, while simultaneously reducing revenue streams and potentially lowering sovereign credit ratings. There is an urgent need for robust measures to limit and reduce these growing threats.

Fortunately, strategic investments in adaptation and resilience can help manage the risks. Countries can significantly reduce the potential damages they face by implementing adaptive measures. Innovative resilience-building approaches are already being employed across different regions in national adaptation plans (NAPs).

National adaptation case studies for six countries are highlighted in boxes in Sections 3 and 4. From infrastructure modifications to ecosystem-based approaches, these examples demonstrate that proactive adaptation is both feasible and effective. They reflect the diversity of resilience-enhancing measures, encompassing both targeted investments and enabling policy environments in national contexts. However, the underlying studies on which our analysis draws largely focus on the effects of adaptation and resilience investments, rather than the full spectrum of supporting policy measures.

Studies consistently demonstrate high rates of return on investments in adaptation. Beyond reducing vulnerabilities, these investments frequently yield substantial co-benefits, such as support for economic development and provision of social and environmental advantages – a concept often termed the 'triple dividend' of adaptation (Surminski et al., 2016). Incorporating avoided losses and costs into long-term planning can demonstrate the economic value of proactive adaptation relative to post-disaster action. This is particularly important given that

[1] Only the physical and economic impacts of climate change are studied in this report; it does not consider transition risk or the interface between physical and transition risks.

adaptation projects often have low and uncertain short-term financial returns that can disincentivise investment (Surminski et al., 2025).

What this report does

There is growing evidence for the macroeconomic and fiscal risks of a changing climate – and the potential for adaptation – from advances in modelling and econometrics. This report assesses the economic costs of climate change inaction and the benefits of adaptation investments through a global review and synthesis of the academic and grey literature. It focuses on macroeconomic and fiscal outcomes at the national level, rather than individual or local risks and adaptation opportunities. In doing so, it highlights the critical importance of proactive public policy measures to address climate impacts, paired with mitigation action to keep further temperature increases as low as possible.

The report contains three core elements:

- Review of the evidence: The existing literature examining macroeconomic and fiscal outcomes related to climate inaction and adaptation is reviewed, drawing on both global and country-specific analyses. This includes quantitative evidence of impacts in a diverse set of regions, aiming to provide a holistic view of these topics.
- Meta-synthesis: The report extracts key outcomes of interest from the literature review, drawing together multiple lines of evidence where possible. Analytical and knowledge gaps that might hinder potential action are identified and results from studies that bridge these and illustrate emerging insights in adaptation investments are highlighted.
- Case study development: Examples of adaptation outcomes are explored for six countries: Bangladesh, Brazil, Kenya, Nigeria, Rwanda and the UK. These countries were chosen to provide a diverse range of geographical regions, economic conditions and climate adaptation challenges. The case studies focus on success factors, financing mechanisms and national-scale benefits in each region. They offer insights into the importance of government investment in adaptation and resilience.

The report also provides an integrated perspective across multiple indicators of risk and returns. Climate change impacts numerous macroeconomic outcomes, including gross domestic product (GDP) per capita, total factor productivity, inflation, unemployment and inequality, among others. Government finances are also affected in numerous ways, particularly through increased spending, decreased revenues and increased borrowing costs. While a comprehensive view of these changes remains out of reach, the report draws on recent developments across multiple methodologies to provide a clearer picture of what is known – and what remains uncertain – about the risks governments face and what they can do about them.

Recognising the need for actionable insights, the report places a special emphasis on how its results are relevant to Ministries of Finance, which oversee public financing exceeding US$30 trillion per annum globally, along with other economic decision-makers, such as central banks and regulatory bodies. Ministries of Finance play a crucial role in shaping national economic policies and resource allocation, making them pivotal in addressing climate change. Their responsibilities encompass crafting fiscal policies that dictate where public funds are directed, as well as managing national budgets to prioritise investments in climate adaptation and resilience initiatives. However, as the work of the Coalition of Finance Ministers for Climate Action highlights, there are gaps in integrating physical climate risks into the tools used and the decisions made by these ministries (CFMCA, 2025a).

By integrating adaptation strategies into budgetary frameworks, Ministries of Finance can promote economic and fiscal stability against climate-related impacts, ultimately safeguarding public finances while contributing to national development objectives. The findings in this report emphasise the significant advantages of this approach, empowering Ministries of Finance to champion effective climate action.

The three elements of the report provide Ministries of Finance and other economic decision-makers with actionable insights that integrate adaptation into economic and fiscal planning. The results make clear the critical importance of proactive public measures in addressing climate impacts and highlight how adaptation can unlock international financing and bolster national development objectives.

This report does not intend to provide analysis on how to prioritise specific adaptation strategies to maximise welfare. The results presented are generally at the macroeconomic scale, and some (such as GDP impacts) do not admit a clear unpacking of the specific channels and hazards that drive these macroeconomic outcomes. Moreover, the report does not focus on within-country heterogeneity in climate change scenarios, which could guide sector-specific adaptation investment. Rather, it offers a useful review of the benefits of adaptation at the macroscale. Furthermore, the report does not provide tools for defining the optimal level of adaptation needed to maximise net benefits. National planning for the sectoral and regional specifics of adaptation should be performed in consultation with multiple stakeholders and with consideration of the national organisation structure, as explored in the Bangladesh and UK case studies in Section 4.

Report structure

The remainder of Section 1 provides background on the principles for understanding quantitative outcomes outlined in the report and an overview of our methodology and the available evidence (further detailed in Section 2 and the Appendix). Section 2 examines the macroeconomic and fiscal risks driven by climate change impacts. Section 3 presents the evidence for adaptation's benefits and Section 4 makes a call for action based on the economic case. Section 5 concludes and highlights methodologies for further progress and how Ministries of Finance can cement their role.

Principles for understanding climate risks and the potential for adaptation investment

Climate risks are multifaceted, emerging from sudden events, gradual trends, and cascading and simultaneous impacts. Realised impacts come from the interaction between hazards, the population and capital exposed, and multiple forms of socioeconomic vulnerability. Even as climate change continues to disrupt the world, economies will continue to evolve.

Adaptation action encompasses both reactive and anticipatory strategies designed to reduce physical climate risks. Reactive adaptation, such as households' use of air conditioning during heatwaves and increasing irrigation or sinking new groundwater wells in response to drought, are typically immediate responses to climate stressors. In contrast, anticipatory adaptation involves proactive and strategic initiatives, such as investing in coastal defences, implementing comprehensive soil management practices and committing to managed retreat from vulnerable areas. Such actions require extensive planning and potentially substantial capital investment. Importantly, many of these adaptation choices have consequences that extend far beyond the specific locales in which they are enacted, influencing broader ecological, economic and social systems.

This report is mainly concerned with policy-driven adaptation, but this is only part of the necessary action. Along with any public policy measures, individuals and firms will make adaptation investments for their private benefit. Rising incomes in many regions will also confer significant benefits, in the form of reduced vulnerability and greater adaptive capacity. To date, most documented adaptation strategies and their benefits have been fragmented and localised, with limited assessment of risk reduction (Berrang-Ford et al., 2021). However, even when private action is possible, it may be overpriced and face underinvestment. In fact, finance for adaptation is more complex than for mitigation because it is challenging to define, evaluate and scale-up investments. Policy-driven adaptation investment is crucial for achieving economic goals and creating financial incentives that encourage further adaptation investment (Gautam et al., 2024).

One of these economic goals is to take advantage of all the actions for which benefits exceed implementation costs. This is a basic economic tenet: both economic growth and the greatest good can often be pursued just by identifying such actions. Economic growth can be boosted by reduced losses in labour productivity, capital, output and total factor productivity. Benefits priced in the economy include not only growth, but also a better distribution of income as adaptation may contribute to reducing the impacts of climate change on inequality. These benefits may later translate into fiscal policy, potentially creating opportunities for further economic growth and reducing income inequality.

The benefits of adaptation are not restricted to financial returns. Many climate impacts reduce 'welfare' – a composite used by economists to reflect impacts on anything people value – more than a reduction in economic production. For example, heatwave-induced health risks represent a significant threat to welfare, but the elderly who are most at risk do not contribute directly to the economy. Because these 'non-market' risks and the non-market benefits of adaptation are included in this measure, governments can only expect a portion of the benefits to accrue to their balance sheets. The value added to people's lives by reducing these risks is real, nonetheless, and creative policies can capture part of this value in monetary terms and still leave people better off – for example, health benefits can lead to increased productivity and larger tax receipts.

Welfare damages are often translated into a percentage of GDP loss – which indicates the extent of welfare loss in a comparable unit – to make them more comprehensible. For example, a welfare damage of 14% of GDP-equivalent suggests that the loss in welfare corresponds to what would occur if individuals lost 14% of their consumption. It is important to note that this method of normalisation does not imply that these welfare losses translate directly into a reduction in GDP; rather, it provides a framework for understanding the significant impacts of non-market factors on human well-being, emphasising that the non-economic effects can be just as damaging as measurable declines in economic output.

Understanding of the relationship between welfare damages, adaptation and mitigation has a long history. Watkiss et al. (2015) show that welfare damages as a percentage of global GDP are lowest when adaptation and mitigation strategies are combined and implemented simultaneously. Adaptation action, which reduces the consequences of climate impacts, is complementary to climate mitigation action, which reduces greenhouse gas emissions, and both are needed. New investments and policies have the potential to achieve both goals. Further, while the national scale is central for coordination, it is complementary and depends on the planning that is needed at the local and international scales.

Section 4 of this report develops a case for action, building on basic principles with a well-established rationale. Some of these basic principles are as follows:

- **First, national-level adaptation should be driven by robust policy frameworks.** Clear governance structures establish risk ownership and set out objectives and goals, helping to prioritise actions that combine high potential impact with the greatest urgency. This involves developing strategic pathways that integrate adaptation into broader development and economic plans.
- **Second, adaptation needs to be seen as a process.** The inherent uncertainties in climate projections and risks necessitate decision-making approaches that are flexible, adaptive and precautionary. Policies should incorporate adaptive management techniques to adjust action as new information becomes available.
- **Third, adaptation strategies must be tailored to specific local contexts,** accounting for unique hazard, geographical, cultural and economic characteristics. This report focuses on impacts and adaptation at the national level. However, this is only one piece of the

climate action puzzle. Engaging local communities and stakeholders in planning and implementation processes helps to ensure that solutions are relevant, effective and supported by those directly affected.

Body of evidence, methodological approach and limitations

The long tradition of studying global-level macroeconomic and welfare outcomes is now supported by meta-analysis (Barrage and Nordhaus, 2024; Howard and Sterner, 2025), and this can be used to evaluate the social cost of greenhouse gas emissions (e.g. EPA, 2023). However, national decision-makers require evidence that is specific to their regions and economies.

At the same time, evidence on adaptation tends to be highly local and context-dependent, with much of it coming from evaluations of individual adaptation projects (e.g. Brandon et al., 2025). While this is crucial and provides a much-needed basis for new investments, it is too localised for many national-scale decisions. This report helps close the gap by providing national-scale information for decision-makers.

These results are founded entirely on the existing evidence base in the academic and grey literature. The data come from evaluation studies of adaptation investments, modelling studies of future risks and adaptation potential, and econometric statistical studies of current impacts. Each of these brings important evidence to the table.

Some of these results come from sophisticated engineering and natural science models, in some cases integrated into macroeconomic models, such as dynamic stochastic general equilibrium (DSGE) and dynamic-recursive computable general equilibrium (CGE) models. These models incorporate assumptions made before the fact (ex-ante) and their results can diverge significantly from evaluations conducted after investments have been made (ex-post), reflecting observed impacts and adaptation benefits. Outcomes in the real world can be smaller than predicted when unmodelled shifts in the economy or behaviours diminish the effects, or larger than predicted when non-marginal changes in the economy emerge.

Econometric studies use observed data to study outcomes in the real world. While these often reflect ex-post economic realities, they typically capture only simple relationships. Extrapolating these beyond the observational datasets is prone to error and bias. This also means the use of these functions to assess future climate change risks is subject to considerable uncertainty.

Many of the key results presented in this report represent a synthesis of many studies or models, often using diverse methodologies. Meta-analysis of this kind provides two main benefits. First, it offers a more robust estimate of the median outcome, since that median is across different datasets, different approaches and different author biases. Second, it better constrains the multiple dimensions of uncertainty, with this report including both within-study and across-study uncertainty. These uncertainties are represented with an interquartile range (25th to 75th percentile) across all estimates. In some cases, there is a basis for weighting different studies (e.g. for GDP growth results) or limiting the sample to higher-quality results (e.g. for integrated assessment models). The report also provides results from existing syntheses where possible (e.g. for welfare and inequality). Even where these are not available, using multiple studies improves the overall quality of the evidence.

Nevertheless, this approach has drawbacks. Different studies use different assumptions, include different factors and are projected under different scenarios. In some cases, later studies specifically call into question the work of earlier studies, as the science and economics have improved. We try to account for this by excluding questionable studies and by limiting the synthesis to a coherent set of scenarios. Moreover, we systematically record the differences in model types, key assumptions, scenarios and outputs to enable reasonable comparisons. However, we may have missed some dimensions required to capture a broader spectrum of possible results. Additionally, where results are seen as under- or overestimates, this is explained.

The report combines a review of 116 academic and grey literature studies with an artificial intelligence-based evaluation of over 40,000 additional studies identified using Scopus and Web of Science (see Appendix A.1.2). Quantitative estimates of macroeconomic and fiscal risks and the potential for adaptation have been extracted from 286 studies, resulting in more than 6,500 distinct estimates. The evidence base for the report primarily consists of papers and reports from the last decade (since 2015), with 60% of studies undertaken during the last five years (since 2020). The publication years of these studies are shown in Figure 1.1 below, showing the rapid rise in macroeconomic evidence.

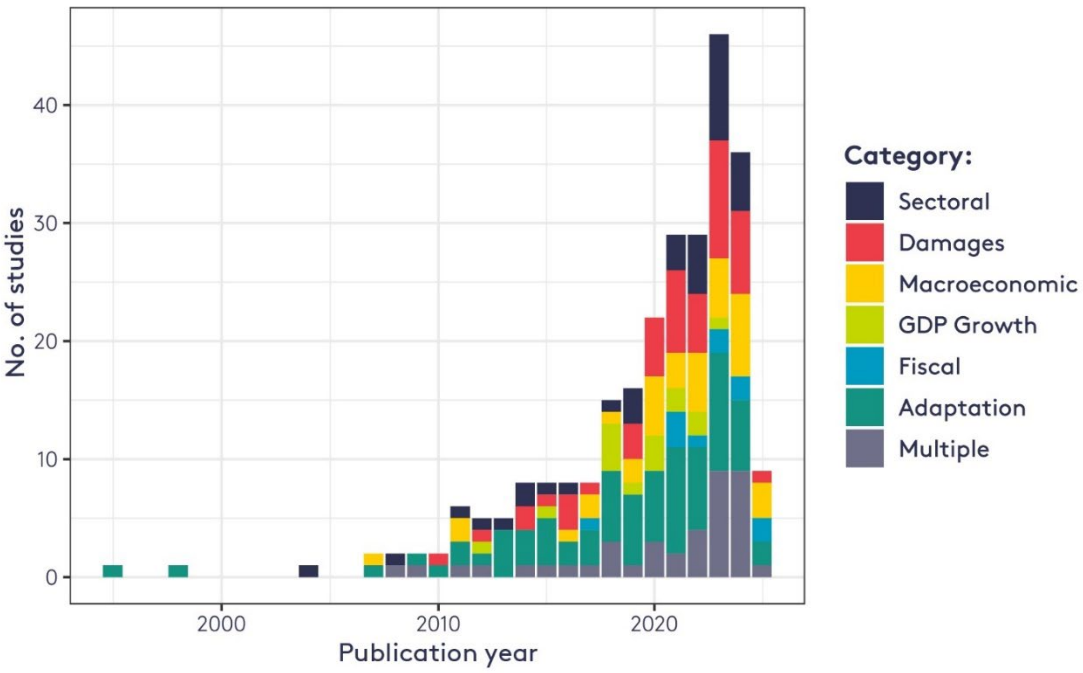
The evidence base used in the report is provided as an online data archive. The archive includes the human and AI-generated review materials, cleaned inputs into the synthesis analyses, and outputs reflecting the results and figures below.

While the evidence on macroeconomic impacts arising from physical climate risks has evolved rapidly in recent years, our knowledge of the socioeconomic consequences of climate change and the potential for adaptation remains highly uncertain, sorely incomplete and noticeably biased towards certain countries. For example, tipping points in the climatic and economic systems are largely missing from assessments, likely resulting in a significant underestimation of risks (see 'Research gaps' in Section 2).

Despite this, the evidence on climate impacts and the value of targeted adaptation is unequivocal and compelling, highlighting the urgent need for concrete responses. The socioeconomic impacts of climate change will be highly disruptive across the globe, from the individual to the macroeconomic levels. Known adaptation actions offer large benefits across a wide range of sectors. The presence of uncertainty in this context contributes to the rationale for strong precautionary action to avoid the worst outcomes (see 'The economic case for adaptation' in Section 4).

This is the motivation for both large-scale mitigation action to transition the economy away from greenhouse gases and for investment in adaptation projects at every level. The evidence provides a strong basis for action today, because every additional year that large-scale mitigation and adaptation investments are delayed will result in more losses and presage even greater ones.

Figure 1.1. Publication years for the academic and grey literature studies reviewed for this report



Baseline warming of the climate

This report's findings focus on projections for 2050 under various scenarios, as reflected in the existing literature. Where possible, the results are translated according to a baseline future climate scenario that combines the baseline high-emissions climate projections from the Intergovernmental Panel on Climate Change (IPCC) with estimates of the effects of some tipping points from Dietz et al. (2021) (see Appendix A.2.1). The Dietz et al. resource is used to represent the added effect of tipping points because it provides a meta-analytical model that integrates all climate tipping points physically represented in economic models. Our tipping point temperature corrections, from Dietz et al. (2021), capture permafrost melting, ocean methane hydrates, Arctic sea-ice/surface albedo and Amazon dieback, as well as interactions between these tipping points.

The baseline high-emissions scenario in this report is based on the IPCC's Shared Socioeconomic Pathway (SSP) 3-7.0. This scenario represents a divided world, with a lack of global coordination and persistent inequality. While some signs suggest that the current challenges in international coordination will not derail the energy transition, SSP3-7.0 provides an appropriate adverse scenario to use for adaptation planning. It has higher warming and lower growth than the most likely scenarios but is nonetheless a plausible future that decision-makers should hedge against.

Under a high-emissions baseline scenario, the world is projected to warm by 2.5°C on average (within a range of 2.2–2.8°C) above pre-industrial levels by 2050 and by 3.9°C (3.5–4.3°C) by 2100. This results in much greater damages than the low-emissions SSP1-2.6 scenario, which has 2°C (1.8–2.3°C) of warming by 2050. These warming levels are higher than those in the results from the IPCC for the same scenarios because the effects of tipping points are missing from the original analyses.

The average person already lives in a country that is 1.9°C warmer in 2025 than it was under pre-industrial conditions (see Table 1.1 and Appendix Figure A.2.1). Unless emissions are rapidly reduced, on average the next 25 years are projected to result in 50% as much additional warming as the past 250 years.[2]

Table 1.1. Global temperature levels for 2025 and 2050, relative to pre-industrial temperatures

	2025		2050	
	Average	Range	Average	Range
IPCC AR6[1]	1.39°C	(1.2–1.6°C)	2.08°C	(1.8–2.3°C)
+ Dietz et al.[2]	1.62°C	(1.4–1.8°C)	2.49°C	(2.2–2.8°C)
+ Population-weights[3]	1.88°C	(1.8–2°C)	2.93°C	(2.8–3.1°C)

Notes: 1. Warming levels projected under the IPCC's SSP3-7.0 scenario. 'IPCC AR6' shows warming from the AR6-calibrated FaIR model (Finite amplitude Impulse Response model v2.0), reported in IPCC Sixth Assessment Report, Working Group 1. 2. '+ Dietz et al. ' includes the effects of global tipping points, using the emulation relationship found in Dietz et al. (2021). These are used in this report where custom projections are performed at the global level (e.g. welfare impacts). 3. '+ Population-weights' apply population weighting to the tipping-point-corrected temperatures. These are used in this report where custom projections are performed at the national level (e.g. GDP impacts).

This person-weighted warming level is projected to increase to about 2.9°C in 2050 under the high-emissions baseline scenario. The additional warming is expected to come with a variety of regional and global tipping points exacerbating the climate problem. Across the world, such rapid warming will drive heat-related mortality, widespread labour productivity loss, crop failures, flooding, droughts, wildfires, ecosystem disruption and many other direct impacts. How countries respond to these impacts could amplify or avoid their worst consequences.

[2] This is higher than the globally averaged warming level in 2025 because human populations experience temperatures on land which warms more quickly than the oceans.

Further resources

There are useful tools and guides to assess the climate risks and benefits of adaptation at the project level that can be consulted if there is a need to evaluate the effectiveness of adaptation strategies in the conceptualisation, preparation and implementation of specific projects. To date, development banks and financial institutions have designed their own resilience metrics to assess projects. It was only at the COP30 UN climate change summit in Belém, Brazil, in late 2025 that a set of standardised metrics for adaptation was defined at the international level.

One of these guides is the *World Bank Climate and Disaster Risk Screening Tools*, which integrates climate and disaster risk into project design to support decision-making and project planning under uncertainty (World Bank, n.d.). Another useful guide is the *Principles of Climate and Risk Management for Climate Proofing Projects* (Watkiss et al., 2020), in which a methodology for climate risk management processes and the identification of adaptation options is presented for projects developed by the Asian Development Bank (ADB). The Inter-American Development Bank's *Disaster and Climate Change Risk Assessment Methodology for IDB projects* provides a methodology to assess climate change risks and resilience opportunities at the different stages of project planning and implementation (Barandiarán et al., 2019). Lastly, the *Identification of Climate Resilience Opportunities and Metrics in Financing Operations: A Technical Reference Document for IDB Project Teams* provides a conceptual framework to identify adaptation opportunities and define indicators at the project level to assess climate resilience (Grunwaldt et al., 2021).

2. Macroeconomic and fiscal risks to economic stability and growth

This section draws out the macroeconomic and fiscal outcomes related to climate inaction and climate adaptation revealed by our evidence review and meta-synthesis.

Indicators of macroeconomic and fiscal risks

Macroeconomic risks are generally assessed using key indicators such as GDP per capita and GDP per capita-equivalent loss of welfare, which serve as the primary metrics for assessing economic performance and societal well-being. A decline in GDP per capita signals stagnation, while welfare loss quantifies the broader impacts of economic stressors, highlighting the relationship between economic stability and quality of life.

However, macroeconomic outcomes such as GDP per capita loss only reflect *some* of the damaging market consequences of climate change (Stern et al., 2022). Climate change is expected to undermine health and human capital, reduce ecosystem stability and natural productivity, and disrupt communities and cultures. GDP per capita and macroeconomic indicators do not capture many of these non-market effects. Alternatives, such as inclusive wealth accounting and welfare calculations, provide a more comprehensive picture, but no single measure is sufficient for basing decisions on.

Nevertheless, GDP per capita loss remains a vital indicator for some important processes. First, as a measure of consumption, investment and exports, GDP per capita is a strong predictor of government revenues. While the elasticity of tax revenue with GDP varies depending on the structure of a country's economy and its tax policies, declines in GDP usually result in corresponding declines in tax revenue. Second, while consumption is a poor predictor of well-being at higher income levels, it is an important input at lower ones. Outside high-income countries, GDP correlates with life expectancy and many other indicators of well-being.

In addition to these primary indicators, secondary measures such as total factor productivity (TFP) (Letta and Tol, 2019) and labour productivity (Zhao et al., 2021) can shed light on the productive foundation of the economy. High productivity levels indicate a robust economy, while declines suggest underlying problems. Other important factors include capital depreciation, which affects productive capacity, as well as interest rates, inflation and unemployment, all of which can have a significant influence on economic growth and public finances.

This section also covers fiscal risks, which encompass the potential challenges that can undermine a government's financial stability and its ability to fund public services. Understanding these risks is essential for maintaining fiscal health and ensuring sustainable economic growth (CFMCA, 2025b).

Primary indicators of fiscal health include public expenditures, revenues, borrowing costs and debt-to-GDP ratios. High borrowing costs, influenced by sovereign credit ratings, can strain public finances and limit a government's ability to finance essential services or infrastructure projects (Klusak et al., 2023). Furthermore, the growth of sovereign debt can signal potential future challenges related to repayment and fiscal discipline.

Governments also need to understand their contingent liabilities. As impacts emerge, governments can face unexpected expenditures or losses, further complicating their fiscal landscape.

A summary of macroeconomic and fiscal impacts revealed by our analysis is provided in Table 2.1, with additional details in the sections below.

Table 2.1. Summary of major macroeconomic and fiscal impacts from climate change and their corresponding evidence base: globally and in low- and lower-middle-income countries (LICs and LMICs) in 2050 – averages and ranges

Macroeconomic impacts	Global impact	LIC and LMIC impact	Evidence base
Reduction in GDP per capita	8% (3–15%)	12% (8–18%)	85 econometric models
Welfare damages (% of GDP-equivalent loss)	14% (8–19%)†	16% (8–23%)	105 estimates, synthesised by Howard and Sterner (2025); 3 integrated assessment models
Reduction in labour productivity	0.6% (0.0–0.7%)	1.4% (0.0–2.8%)	8 studies
Reduction in total factor productivity growth	0.03 pp/year (0.00–0.04)	0.03 pp/year (0.01–0.04)	3 studies
Increase in inflation rate	1.6 pp/year (0.6–2.0)	1.7 pp/year (0.7–2.2)	2 studies
Change in unemployment rate	−0.23 pp (−0.9–0.7)†	0.1 pp (−0.5–0.7)†	Liu and Lin (2023)
Gini index	0.2 point (0.1–0.3 pt)	0.3 point (0.2–0.3)	8 macromodels
Fiscal impacts	**Global impact**	**LIC and LMIC impact**	**Evidence base**
Reduction in credit rating	1.4 notch (2.0–0.5)†	1.0 notch (1.0–0.3)†	Klusak et al. (2023)

Note: Estimates of the macroeconomic impacts of climate change are generally incomplete and do not capture all the consequences. Macroeconomic and fiscal estimates are projected under a high-emissions scenario consistent with the IPCC's SSP3-7.0 scenario and assume no further adaptation and resilience.

Estimates marketed with † are projected to match this report's baseline scenario, but are not a synthesis performed for this report. Units: pp = percentage points; pp/year = percentage points per year; notch = sovereign credit rate notches; point = Gini index point. References provided in Appendix A.7.

Estimated impacts of climate change across categories

Impacts on GDP per capita

Methodology and literature

The impacts of climate change on GDP per capita at the national level are assessed here using a subset of studies concerned with top-down macroeconomic impacts. The results are based on a meta-analysis of 85 econometric models from 15 macroeconomic studies of the impacts of temperature on GDP growth (the models are listed in Appendix Figure A.3.3). All 85 of these models use a consistent, robust, data-driven approach, and they represent the majority of econometric work on this topic.

Per capita GDP growth rates represent a composite of market impacts across an economy. Recent developments in econometric analysis have exposed a strong relationship between temperature and GDP growth, providing an important new lens through which to view the top-down impacts of climate change. This work has empowered new data-driven science on the scale of impacts and areas of vulnerability, with significant and growing losses being identified, particularly for equatorial low- and middle-income countries (Piontek et al., 2021). However, the literature also reflects deep uncertainties: the inclusion of climate hazards, representation of unobserved variables and role of adaptation vary widely. As a result, the estimated impacts can vary by differing orders of magnitude. This meta-analysis attempts to offer coherent assessments across this disorganised literature.

The meta-analysis method combines outputs from each of the models, weighting them according to how well each one predicts future GDP per capita growth shocks beyond the period on which it has been calibrated (see Appendix A.3.4). We run the models from 1940 to 2100, including the effects of some tipping points on global temperatures (see Dietz et al., 2021). Since these models structurally miss crucial dynamics that also affect GDP, and in particular the market losses from sea-level rise and storm surges (Depsky et al., 2023) and an estimate of the effects of trade spillovers (Rising, 2023), these are applied to the final outputs. Dietz et al. (2021) represents the most complete meta-synthesis of tipping points from economic modelling studies, while Depsky et al. (2023) is a significant update to the forward-looking coastal adaptation model CIAM.

Some vital elements are missing from this meta-analysis of macro-econometric results, largely because of the limitations of current econometric methods. Importantly, these models do not account for non-market welfare losses, such as impacts on health, biodiversity and ecosystem services, which are expected to be large; they are outside the models' intended scope. Total economic damages (including market and non-market losses) are expected to be considerably higher than these estimated market losses.

The synthesis of results in this report also misses:

- Impacts that are not strongly driven by temperature shocks[3] (i.e. unexpected temperature changes), such as slow onset effects (except for sea-level rise, which is included); water supply and demand impacts; and the impacts of other extreme events, such as extreme precipitation, surface and river floods, droughts and wildfires.
- Regional-scale tipping points such as the Atlantic Meridional Overturning Circulation (AMOC), sea-level rise tipping points, and future changes in the occurrence of tropical cyclones.
- The impacts of future adaptation measures and the results of broader undermining of the economy by climate change, beyond what is reflected in the historical record.

These are included in some form in various macroeconometric studies, but this study does not project these aspects of the models in its reanalysis. Nonetheless, we find large losses to GDP worldwide.

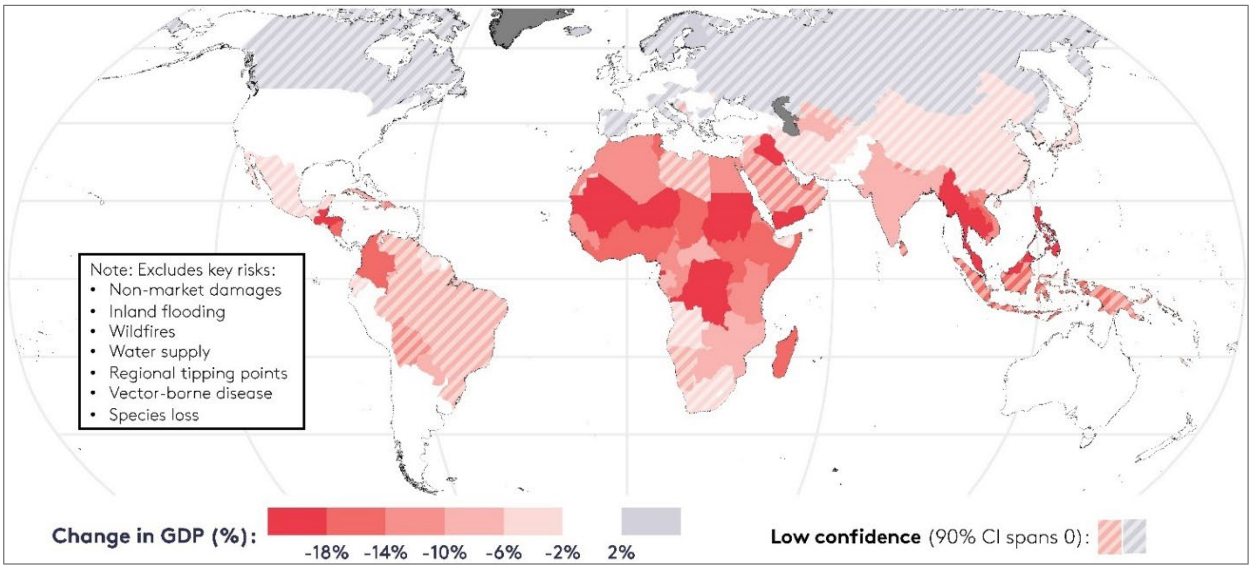
Results

GDP per capita is reduced by 8% by the temperature changes and sea-level rise, and some tipping points, associated with climate change by 2050 under the baseline high-emissions scenario, as a population-weighted average. Using this evidence base, under the high-emissions scenario, the average person lives in a country that is projected to be 8% (3–15%) poorer in 2050

[3] See Appendix A.2.1 for further explanation.

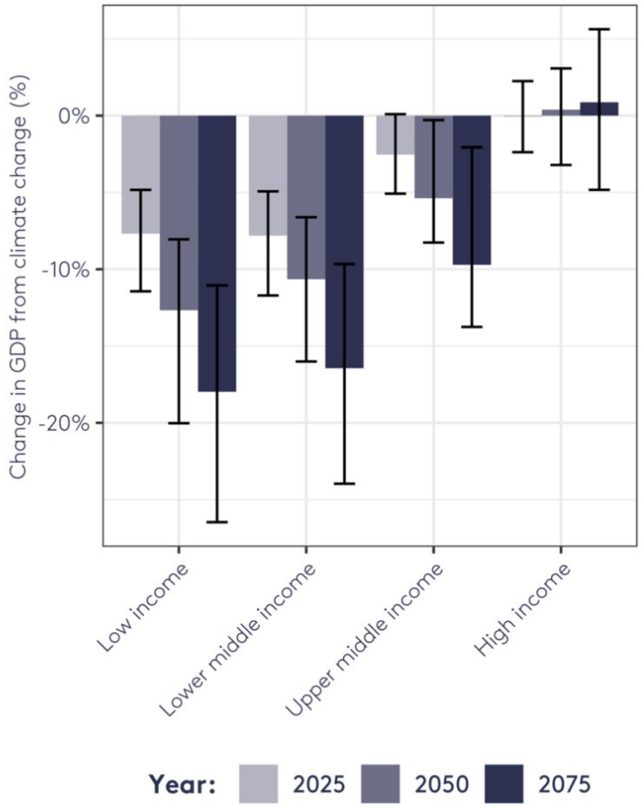
than it would have been without climate change, in terms of GDP per capita. As shown in Figure 2.1, the greatest losses are across low- and lower-middle income countries and at low latitudes.

Figure 2.1. Percentage losses in GDP from temperature changes and sea-level rise in 2050 under the high-emissions scenario



Notes: Colours show the loss in GDP due to warming from 1960 to 2050, under a high-emissions baseline scenario, as a percentage of each country's counterfactual GDP without climate change. The estimate is based on 85 econometric models and only accounts for temperature changes and sea-level rise. Countries for which the 90% uncertainty range includes 0 are shown with diagonal white lines.

Figure 2.2. Loss in GDP due to warming since 1960, under a high-emissions baseline scenario, by income group and year



Notes: The estimate is based on 85 econometric models and only accounts for temperature changes and sea-level rise. See Figure 2.1 for key excluded risks. Error bars show the interquartile range

Sub-Saharan Africa and Southeast Asia face the largest losses, with some countries expected to lose 20% of their GDP on average by 2050 because of climate change.

The loss estimates in some individual studies – such as those of the Network for Greening the Financial System (NGFS, 2025) and Bilal et al. (2025) – are significantly higher, primarily because they include longer persistence of impacts and account for the role of global-scale temperature rise. However, these results remain the subject of academic debate. Some studies, such as that by Mohaddes et al. (2025), find negative GDP impacts for all countries. Moreover, the exclusion of natural capital destruction from most estimations understates the impacts of this loss on economic performance. The estimates here are a synthesis of 85 models and hence represent an average, which is likely to change in the future as the representation of extreme events and other factors improve. In particular, the lack of extreme events other than temperature extremes and coastal storm surge in the models suggests that they may produce significant underestimates.

Low- and lower-middle income countries will be hit the hardest. There is a strong income gradient in these losses, with climate change reinforcing existing inequalities, as shown in Figure 2.2.

Based on temperature changes and sea-level rise, with some tipping points, this report estimates that low-income countries are already on average 7% (4–12%) poorer in terms of GDP per capita because of climate change today and will be 12% (8–21%) poorer in 2050 and 17% (11–27%) poorer in 2075. Because of the spatial inequality of these impacts, global GDP is projected to be only 4% (1–11%) lower in 2050, half the impact for the average person.

High-income countries in the Middle East and North Africa and the East Asia and Pacific regions also face large losses and are expected to be 15% and 8% poorer, respectively, in terms of GDP per capita in 2050.

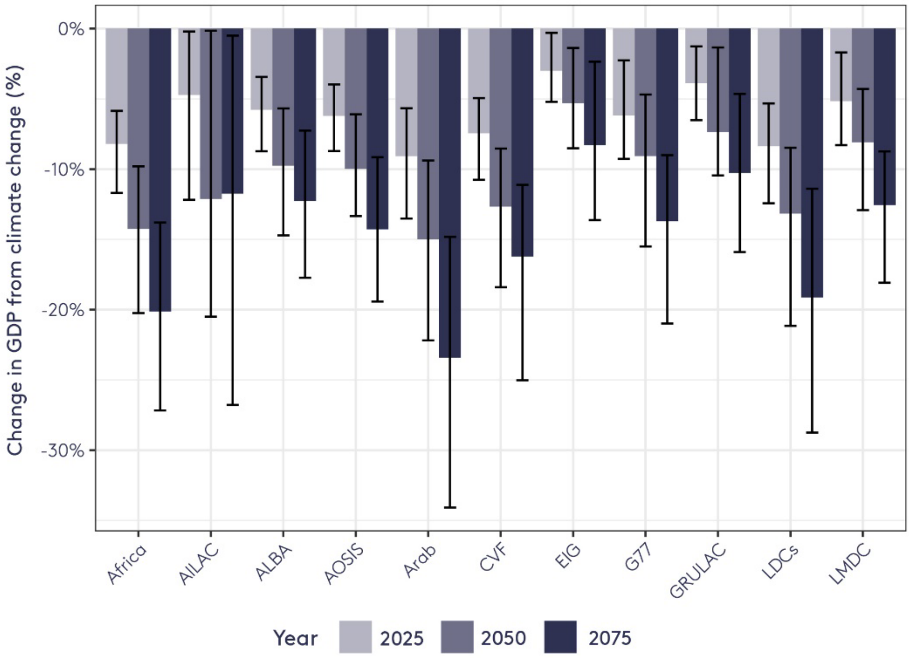
An income-based disparity in impacts of climate change on GDP is supported by many lines of evidence. The integrated assessment model (IAM) MIMOSA estimates that global GDP loss for Africa and the Middle East will be 4.2% by 2100 under the RCP 6.0 scenario, whereas this value will only be 2.4% in countries of the Organisation for Economic Co-operation and Development (OECD) (van der Wijst et al., 2023). Day-to-day temperature variability is expected to cause greater losses to lower-income countries than high-income countries (Waidelich et al., 2024).

Figure 2.3 below presents GDP impacts from the econometric evidence base according to Party groups of the United Nations Framework Convention on Climate Change (UNFCCC). The greatest losses are projected for the Arab, African and Least Developed Countries (LDCs). It is estimated that these country groups are already poorer because of climate change, and that their losses will increase rapidly over the next 50 years.

Losses can be stabilised by 2050 with reductions in many regions by following a low-emissions pathway. GDP impacts will stabilise by mid-century for almost all regions under a low-emissions scenario (SSP1-2.6) that results in a global temperature rise of 2°C compared with pre-industrial level by the end of the century (see Appendix Figure A.3.4).

All these results are based on the same top-down econometric evidence base but bottom-up studies are also an important input for policymaking. Bottom-up studies evaluate climate risks sector-by-sector and then combine these impacts to estimate macroeconomic impacts. While bottom-up studies frequently predict much lower levels of damage, perhaps because of their inherently incomplete coverage (Piontek et al., 2021), they can highlight specific channels of impact (e.g. crop losses, damage to ecosystem services), identify regions with the greatest risks and capture processes that are missing from statistical studies (e.g. flooding, wildfires). Ecosystem degradation is a specific channel that interacts closely with climate impacts and can amplify economic vulnerabilities. The loss of natural buffers such as wetlands, forests and mangroves reduces resilience to acute hazards, like floods and storms, while also undermining long-term productivity in sectors such as agriculture, fisheries and tourism. The effects relate directly to the macroeconomy, influencing GDP, employment and fiscal stability, particularly in nature-dependent economies (ECB, 2024; IMF, 2024; World Bank, 2025b).

Figure 2.3. Loss in GDP due to warming since 1960 under the high-emissions baseline scenario, by UNFCCC party group and year



The estimate is based on 85 econometric models and only accounts for temperature changes and sea-level rise, along with some tipping points. See Figure 2.1 for key excluded risks. Error bars show the interquartile range. For details of Party groupings see https://unfccc.int/process-and-meetings/parties-non-party-stakeholders/parties/party-groupings

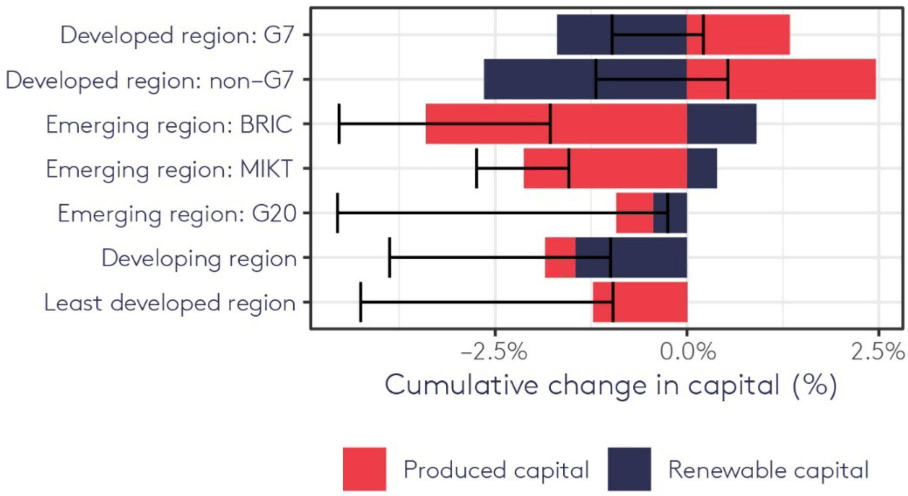
The World Bank uses a bottom-up approach, combining sectoral estimates with macromodelling, and finds GDP impacts that are similar to the values here (World Bank, 2024f). Appendix Figure A.3.5 compares the estimations calculated in this report with those countries included in the World Bank's Country Climate and Development Reports (CCDRs), showing the correlation between the results from these two methods. Notably, the World Bank approach provides important additional insight for this report by identifying adaptation benefits for GDP. Combined, the recommended adaptation actions from the CCDRs increase GDP in 2050 by up to 15 percentage points, in many cases offsetting the majority of the impacts of climate change.

Impacts on produced, natural and human capital

All economic groups have a lower capital base than they would have had without climate change, considering both produced and renewable natural capital (World Bank, 2024e).

Previous work has used the same econometric evidence base, as shown in the previous section, to study impacts on produced and natural capital. This analysis found that produced capital is already lower across much of the world today because of climate change (Rising, 2023). At the same time, under many economic systems, reduced economic activity can actually benefit ecosystems, reducing the rate at which they are exploited and increasing the quantity of renewable natural capital. This can partly offset direct climate-driven losses to these ecosystems.

Figure 2.4. Change in produced and renewable capital due to warming between 1960 and 2023, under the high-emissions baseline scenario, by economic group



Note: The estimate is based on 58 econometric models from Rising (2023) and only accounts for temperature changes and sea-level rise. Error bars show the interquartile range.

Capital loss is driven primarily by acute shocks from extreme weather events and sea-level rise. Physical capital depreciation is greater in countries exposed to tropical cyclones, particularly those with populous low-lying coastal areas (Bakkensen and Barrage, 2025). Floods, storms and tropical cyclones are expected to decrease global net asset value by an average of 4.4% by 2050 under the current policies scenario (Marcelo et al., 2023). Storm surge losses have a significant economic impact on coastal areas in China (Yin et al., 2024). In the United States, damages to coastal areas represent the highest economic losses from climate change (EPA, 2017).

Capital loss reduces current private income flows that generate welfare. Capital loss from disasters also reduces private consumption because there is greater reallocation of GDP components, such as household consumption, towards recovery. Since capital and labour are complements, the consequences of short-term capital loss are further multiplied (Hallegatte et al., 2024). In disaster-prone countries, consumption is expected to be reduced by 5.3% compared with countries not prone to disasters (Cantelmo et al., 2023). CDP Climate Change 2022's survey of firms estimated that climate change would reduce asset value by 5% (TCFD, 2023). The World Economic Forum projects that earnings could be reduced by 5–25% in a scenario exceeding 3°C of warming because of asset damage and business interruption by weather shocks, such as temperature spikes and precipitation events (WEF, 2024).

Regarding natural capital loss, under a medium-to-high-emissions scenario (SSP2-6.0), Bastien-Olvera et al. (2024) project that by 2100 the effect of climate change on ecosystems will reduce the population-weighted mean flow of benefits from non-market ecosystem services by 9.2% at a global level. Because low-income countries are more reliant on ecosystem services for their economic growth, natural capital loss-related impacts on GDP are projected to be higher in Africa and the Middle East than in OECD countries and Europe.

Human capital is also impacted by climate change. The infant mortality rate increases with rising temperatures and extreme weather events. Access to primary and secondary education is also reduced when flooding, tropical cyclones or high temperatures cause school closures (Caruso et al., 2024). Displacement and economic insecurity caused by climatic shocks (unexpected shifts in weather) can also prevent children from attending school. The mental health of students can be compromised with increasing extreme weather shocks (Sabarwal et al., 2024). Cognitive performance can also deteriorate with rising temperatures in the short term (Graff Zivin et al., 2018).

Capital loss reduces private income flows at the international as well as the national level. Dellink et al. (2017) estimate that climate change will reduce international trade at the global level, with particularly severe impacts on Sub-Saharan Africa, the Middle East and North Africa, and India. Damage to transport routes leads to higher transport costs, which may have a negative impact on international trade (Dellink et al., 2017). Moreover, the loss of natural capital and agricultural productivity also impacts global supply chains, as this leads to bottlenecks and an increase in stock-outs (Er Kara et al., 2021). However, empirical evidence concerning the effects of climate change on international trade remains limited.

Conversely, the melting of ice sheets might lead to the creation of new transport routes for international trade, as new infrastructure can be developed in previously inaccessible areas. An econometric analysis of 67 countries found that rising temperatures increased international trade relative to domestic trade. This was attributed to the differential effects that temperature changes might have on capital and labour productivity across countries. However, weather shocks appear to have a negative effect on international trade, although this relationship is statistically insignificant when China and Japan are excluded (Martínez-Martínez et al., 2023).

Total welfare losses

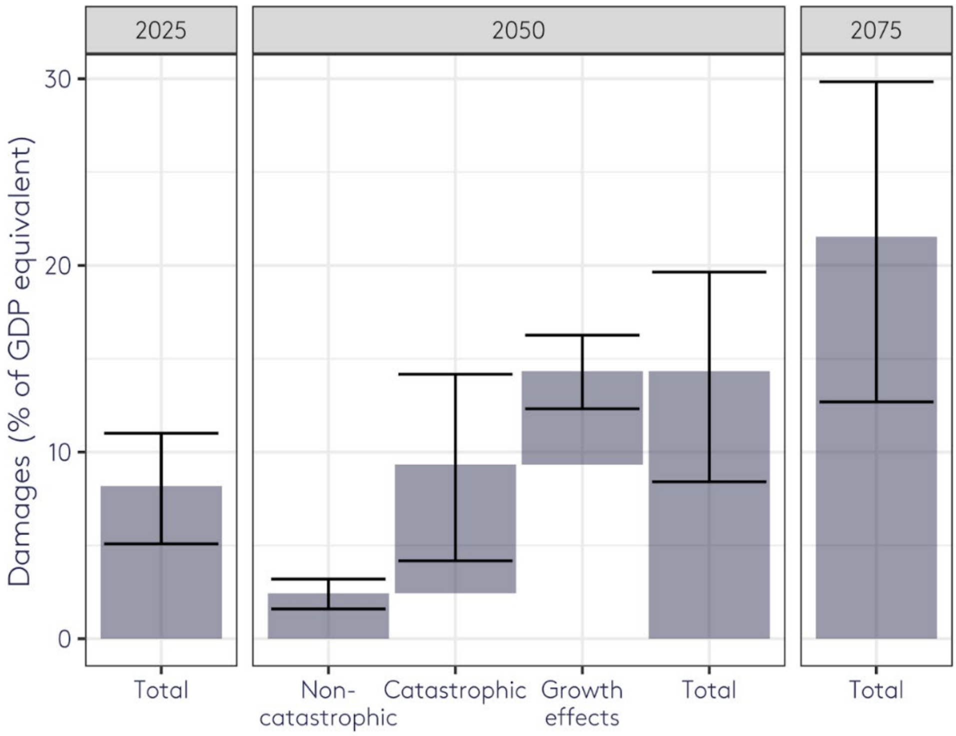
Total welfare losses are expected to be higher than GDP per capita losses. Recent estimates of climate change-induced welfare loss and damage vary significantly, reflecting a range of assumptions and methodologies. Markandya et al. (2019) use an integrated assessment modelling approach to estimate that non-Annex I Parties to the UNFCCC (i.e. developing countries) experienced losses ranging from US$179 to US$671 billion per year by 2020. In contrast, Songwe et al. (2022) anticipate losses to reach US$150 to US$300 billion annually by 2030 based on engineering estimates. Examining extreme weather events, Newman and Noy (2023) attribute US$53 billion per year to market damages and an additional US$90 billion per year to losses estimated through the value of statistical life (VSL) methodology. Accounting for GDP and capital losses, Rising (2023) estimates US$4 trillion per year in damages by 2023 using econometric studies.

Our study applies a meta-analysis of 105 damage estimates from 38 studies by Howard and Sterner (2025) to evaluate global welfare impacts along the baseline high-emissions scenario and for the year 2050 (see Appendix A.4). These damages are reported as GDP-equivalent losses (or, equivalently, GDP-per-capita-equivalent losses): that is, the amount of consumption loss that produces the same welfare loss as produced by the full range of welfare impacts.

According to this synthesis, in 2050 total damages will reach a level equivalent to 14% (8–19%) of global GDP per capita (see Figure 2.5 and Appendix Figure A.4.1). These results apply the same warming and global tipping points as the GDP per capita results above, but include the full impacts of climate change from both market and non-market channels. Almost 50% of damages are attributable to catastrophic impacts. The definition of catastrophic damages varies across the underlying studies in the meta-analysis but generally, tipping points or other uncertain thresholds of economic risk are indicated. One-third of damages are attributable to the effects of climate change on economic growth rates, rather than just considering the immediate impacts in a given year.

Welfare damages are much lower under a low-emissions scenario that reaches 2°C by the end of the century. Damages in 2050 under low emissions are equivalent to 11% of GDP. While climate damages continue to climb under the high-emissions baseline – up to 22% of GDP-equivalent in 2075 – they stabilise below 12% of GDP under the low-emissions scenario (see Appendix Figure A.4.1).

Figure 2.5. Welfare damages in GDP-equivalent terms projected for 2050, with total damages comparisons for 2025 and 2075

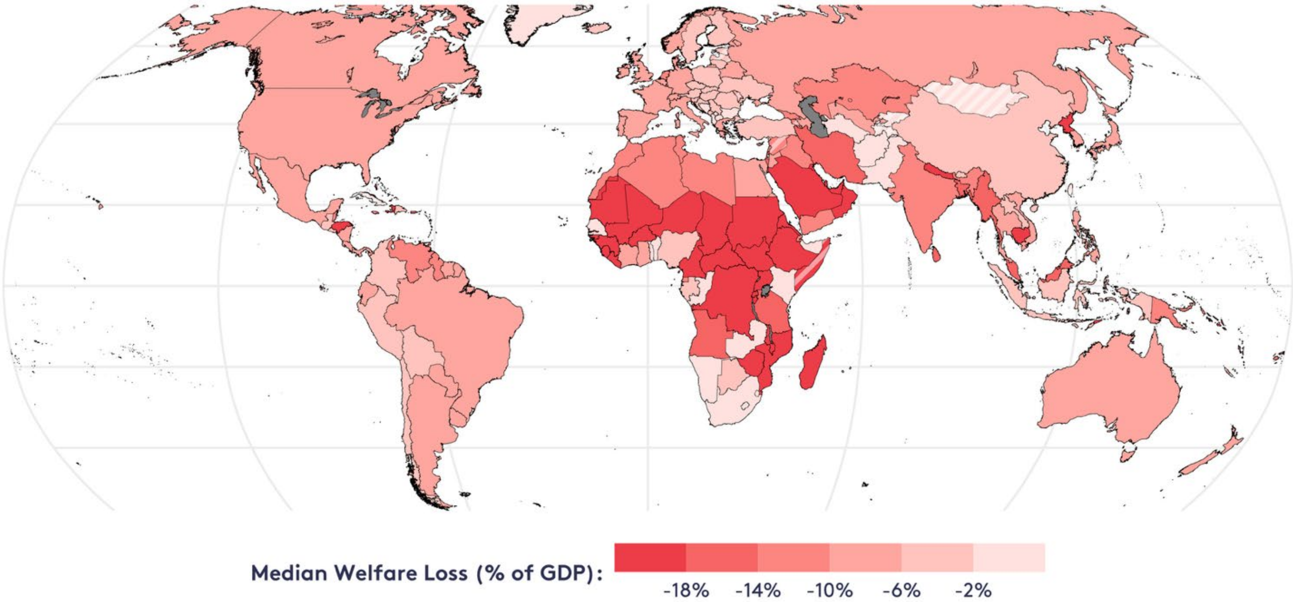


Note: Each column shows a component of the total, stacked vertically and offset to show its corresponding uncertainty (shown as the interquartile range). Projection based on a meta-analysis by Howard and Sterner (2025).

Three advanced spatial integrated assessment models have also been employed to understand country-level welfare losses as part of this study: GIVE (Rennert et al., 2022), META (Stoerk et al., 2025) and PAGE (Rising, 2026). The US Environmental Protection Agency used the GIVE model – which includes bottom-up estimates of damages for agriculture, mortality, energy and sea-level rise – in its 2023 updated estimate of the social cost of carbon. Across countries and levels of uncertainty, it produces mean damages of 1.4% (0.5–2.0%) in 2050. The META model includes top-down estimates of market, non-market and sea-level damages, plus seven climate tipping points. META produces 2050 damages of 5.8% (2.1–8.0%). The PAGE-2025 model includes four categories of top-down damages (META's three plus economic discontinuity risk), adaptation costs and benefits, trade spillovers and subnational vulnerability. PAGE produces 2050 damages of 2.4% (0.0–3.2%). These three models were not run under a consistent scenario, and instead use model-specific baselines in the absence of strong climate action. They apply different assumptions about economic growth and adaptation.

These values, averaging 3.2% losses in 2050, are significantly lower than both the global macroeconometric results (8%), which capture only market damages, and the Howard and Sterner (2025) meta-analysis (14%). While these three models address many of the concerns raised in previous critiques (e.g. Stern et al., 2022), they remain inconsistent with the GDP and welfare lines of evidence presented above. For illustrative purposes, this report uses a synthesis of these three integrated assessment models to provide national-level scaling factors for the Howard and Sterner results. Median estimated damages under this scaling, across the three models and their internal uncertainty, are shown in Figure 2.6. In line with the results above, this shows a strong income gradient, with lower-income countries impacted the most, with median welfare losses in 2050 for lower-middle-income countries at 16% (8–23%). However, unlike the macroeconometric GDP results, which showed some cooler countries with insignificant impacts, this IAM-based spatial analysis suggests that total welfare may be significantly reduced for nearly every country.

Figure 2.6. Median welfare damages for each country from integrated assessment models in GDP-equivalent terms in 2050



Note: Estimates for 2050 are extracted from GIVE (Rennert et al., 2022), META (Stoerk et al., 2025) and PAGE (Rising, 2026). Values from these three models are pooled and then scaled by the stochastic results from Howard and Sterner (2025) for 2050 under this report's high-emissions baseline scenario which produces 2.5 °C warming in 2050. Countries for which the 50% uncertainty range crosses 0 are shown with a diagonal pattern.

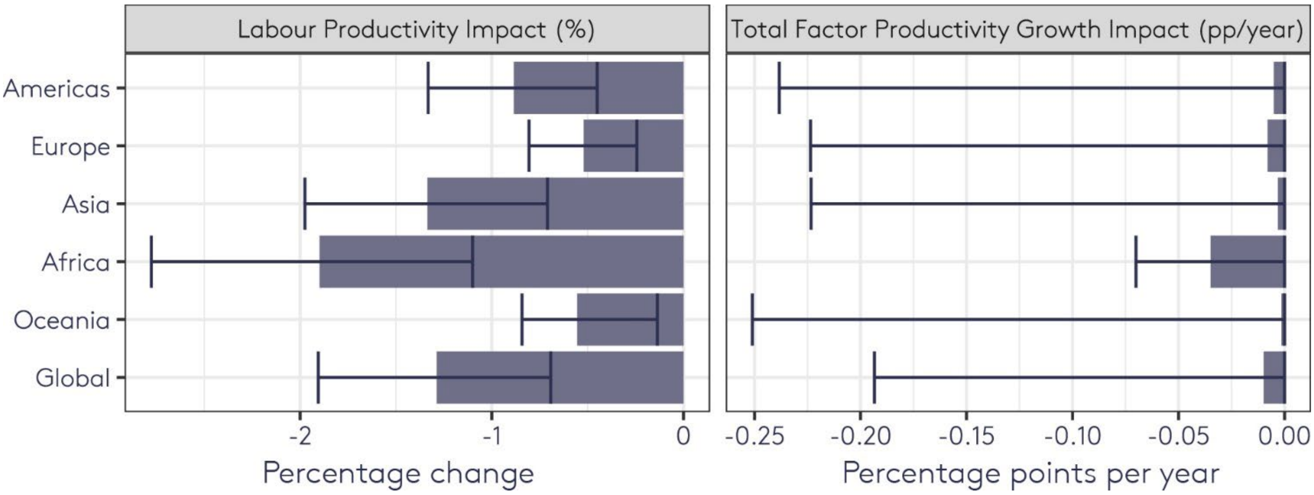
This provides additional evidence that poorer regions face greater losses to welfare, because of a combination of greater hazards and greater vulnerability.

Impacts on labour productivity

Here, labour productivity loss in the future is estimated by synthesising eight studies that report national, regional or global labour productivity loss in percentage terms, under a current policies scenario. Estimates from these studies are pooled and the distribution reported, as described in Appendix A.5.

Labour productivity is expected to be reduced in much of the world by 2050 (see Figure 2.7). This result is based on eight labour productivity studies, under study-specific baseline climate scenarios and economic assumptions. Some parts of Africa and Asia are projected to experience reductions in labour productivity of more than 5%. There is considerable uncertainty in the estimates, with a Swiss analysis suggesting that there is a one-in-20 chance that labour productivity losses will be four times their expected value (Stalhandske et al., 2021). Simultaneously, growth rates in labour productivity are expected to be impacted by climate change. In low- and lower-middle-income countries, the rate of warming between now and 2050 is expected to decrease labour productivity growth by 0.05 percentage points per year, which will result in an additional 1% loss in labour productivity beyond the immediate impact of temperatures on labour productivity (Letta and Tol, 2019).

Figure 2.7. Projected impact of climate change on labour productivity and total factor productivity growth in 2050, calculated from a synthesis of eight labour productivity studies and three total factor productivity studies



Note: Studies used different scenarios and different regional coverage, but only scenarios that can be considered middle-of-the-road, current policies, or high-emissions scenarios are included. Interquartile ranges (error bars) cover both within-study and across-study uncertainty.

The projected loss in productivity varies by the type of economy, worker occupation and even the study methodology.

The economic impacts of heat-stress-induced labour productivity decline are greater when economies rely heavily on weather-exposed activities. In many of the countries reviewed in the World Bank's Country Climate and Development Reports, the most significant impact of climate change is projected to stem from the impact of heat stress on labour productivity (World Bank, 2024f). This is found, for example, across the Sahel region (World Bank, 2022b), Democratic Republic of Congo (World Bank, 2023b), Malawi (World Bank, 2024b), Republic of Congo (World Bank, 2023c), Dominican Republic (World Bank, 2023d) and Moldova (World Bank, 2024c). According to Rode et al. (2022), the costs of increased worker disutility – the loss of the personal value of their time due to heat – are projected to be equivalent to 12% of GDP in those regions most impacted by warming.

Rising temperatures may also generate significant economic losses in high-income economies, driven by the impact of heat stress on labour productivity, although their proportional impact on GDP is lower (Rode et al., 2022). A study indicates that in the US, productivity losses from heat stress represent the most substantial temperature-related economic impact (EPA, 2017). In Australia, labour productivity loss due to increasing temperatures is projected to have a significant impact on the economy, especially outdoor productive activities. According to the available modelling, the sectors most affected by heat stress on labour productivity in Australia are agriculture, construction and manufacturing, and economic output could fall by AU$135–423 billion over the next 40 years (Australian Government, 2023).

Outdoor workers will generally also experience greater impacts than indoor workers, noting the latter are also strongly influenced by whether there are cooling measures available (including air conditioning). Under a 3°C scenario, Dasgupta et al. (2021) estimate that at the global level labour productivity will be reduced by 11.5 percentage points in low-exposed activities (indoor), whereas in high-exposed activities (outdoor) it will decrease by 13.6 points. Costa et al. (2024) find in an econometric study that heat stress in advanced European and Asian economies does not have a significant impact on indoor activities carried out in small buildings where air conditioning is used, whereas firms dedicated to construction and manufacturing do suffer from labour productivity losses during periods of heat stress.

Finally, the underlying studies show different levels of impact, driven partly by their different accounting for adaptation. Some macromodelling studies presented here (e.g. World Bank, 2022b) include autonomous adaptation – actions taken by the agents individually – but exclude adaptation policies in the results; adaptation costs and benefits are studied in the adaptation section of this report. Others rely on experimental studies that include no adaptation effects. Econometric studies include autonomous adaptation, but in some cases also represent reductions in vulnerability as regions become richer or experience more heat (e.g. Rode et al., 2022).

Other macroeconomic outcomes

Total factor productivity (TFP) growth accounts for the drivers of economic growth not explained by labour or capital productivity improvements, which are usually associated with technological progress (Letta and Tol, 2019). TFP growth is expected to be reduced by climate change, based on the combined results of three econometric studies, reporting the pooled synthesis as described in Appendix A.5. These studies all include autonomous adaptation, but otherwise represent different study-specific baseline scenarios and economic assumptions. The largest expected reductions in growth are in Africa, at 0.05 percentage points lower per year. There is considerable uncertainty around these numbers, however, with a one-in-four chance that TFP is at least 0.3 percentage points lower per year across much of the world, which would result in a 7% loss in TFP by 2050.

These indicators of productivity have consequences for capital investment. Greater economic activity drives greater investment in produced capital, and climate impacts can undermine this. Reduced investment also results in a lower productive capital base, driving a feedback loop that can result in an even greater gap in economic potential.

The effects of droughts and higher temperatures are more significant for a country's economy when the agricultural sector constitutes a significant share of its economic activities (Akyapi et al., 2025). The World Bank's Country and Climate Development Reports highlight that countries that rely on agriculture for employment and income in dry/hot scenarios are more vulnerable than others that do not (World Bank, 2024d).

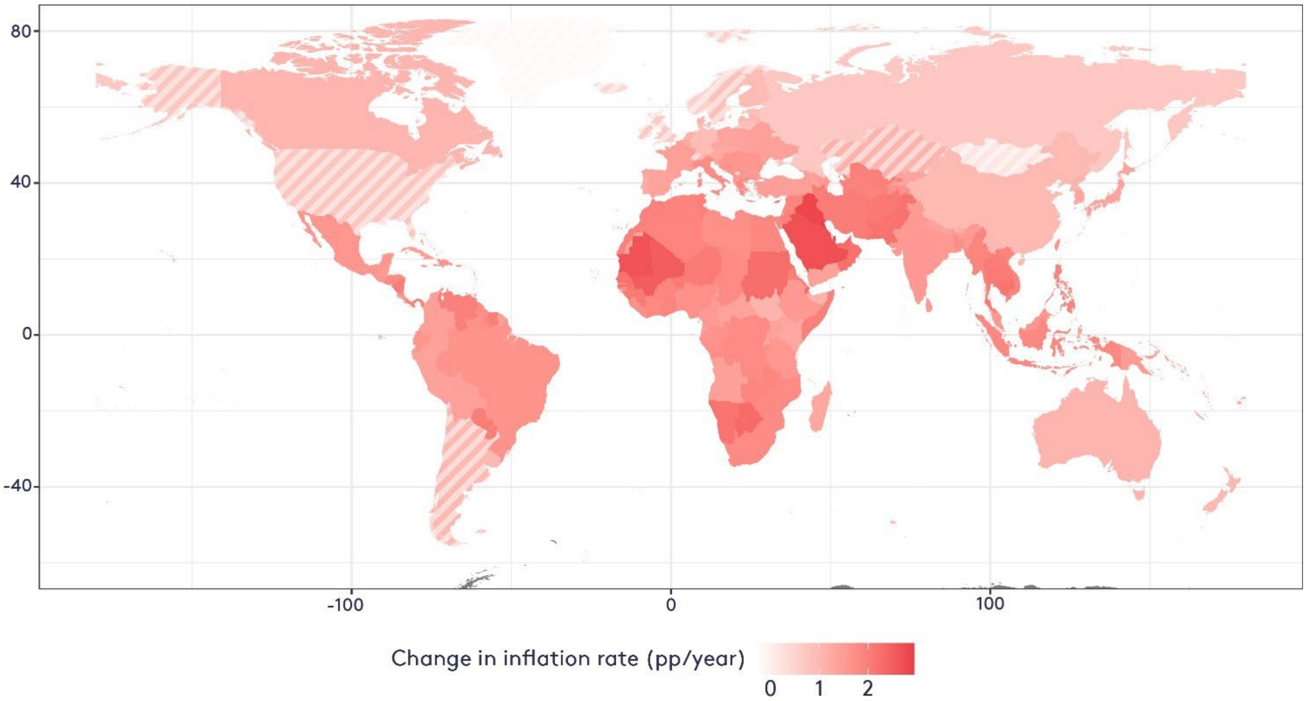
In Kenya, the main driver of GDP loss in a dry/hot scenario is crop output reduction and soil erosion caused by higher temperatures (World Bank, 2023e). In Morocco, declines in water yields will reduce agricultural productivity, lowering GDP by 3.2–15.9% by 2100 under the RCP 8.5 scenario (Pérez-Cutillas, 2024). In Greece, direct economic losses related to agricultural output decline are predicted to be between €643 million per year between 2021 and 2040 and up to €1 billion euros per year between 2041 and 2060 under the RCP 8.5 scenario (Georgopoulou et al., 2024).

Acute shocks caused by sudden spikes in temperature have a short-term effect on inflation. Econometric analysis based on historical data from 121 countries found that higher temperatures may increase inflation for up to 12 months in both high- and low-income countries. However, the effects of an increase of 1°C in the average temperature for one month do not persist for more than a year (Kotz et al., 2024). A review of several studies on inflation indicates that physical natural disasters frequently generate short-term impacts on consumer prices (Barmes et al., 2024), while Kabundi et al. (2022) estimate that inflation rises by 0.2 percentage points in the second quarter after a temperature shock in emerging economies, with the effect declining afterwards. These authors also conclude that the impact of climate shocks will depend on the type of shock, the country's income and the monetary regime. A study by the NGFS (2025) suggests that in the long term there can even be deflation due to a recovery in production.

Nevertheless, repeated increases in average monthly temperature could cause upward pressures on inflation every year. Under the high-emissions RCP 8.5 scenario, which would be more extreme than the baseline high-emissions scenario used in this study, the annual average global inflation (based on a 30-year period of persistent increases in inflation per year centred on 2035) is expected to be 1.79 percentage points higher for food and 0.9 percentage points higher for headline inflation by 2035 compared with a scenario without climate change (Kotz et al., 2024). Barmes et al. (2024) suggest that with severe and frequent climatic shocks, inflation could enter a high-inflation regime, with a self-sustaining cycle where domestic wages and prices constantly push each other upwards.

Synthesising the results of two studies that include spatial differentiation, inflation rates in 2050 are projected to increase most significantly across Africa, the Middle East and South Asia (see Figure 2.8). However, this result includes the combined effects of physical and transition risks, and the specific results of physical risks cannot be identified separately.

Figure 2.8. Physical and transition risk-driven increases in inflation rates: projected increases in inflation rates in 2050



Note: Estimates combine Kotz et al. (2024) and Boirard et al. (2022), as described in Appendix A.5. Countries for which the 50% uncertainty range includes 0 are shown with diagonal white lines.

The evidence presented by these studies suggests that multiple mechanisms drive this price increase, with food prices being the primary factor. Agricultural prices increased in 121 countries when there was an increase in temperature (Yusifzada, 2024). In fact, food inflation has been found to be higher than headline inflation when there are climatic shocks (Qi et al., 2025). Nevertheless, the impact of changes in food prices on inflation has been found to be greater in low-income developing countries when a natural disaster hits them, because food represents a larger share of the consumption basket in these countries in comparison to high and middle-income countries (Kabundi et al., 2022).

Another mechanism is related to interest rates. With extreme weather events, there is economic contraction and therefore central banks reduce interest rates, which in turn increases inflation (Qi et al., 2025). A shortage in energy supply due to climatic shocks could also raise prices (Li et al., 2023; Odongo et al., 2022).

The impact of weather shocks on supply chains and therefore inflation has been found to be relevant in some – though not all – countries (Cevik et al., 2024). In Eastern and Southern Africa, international trade is a key driver of inflation through rising import prices (Odongo et al., 2022).

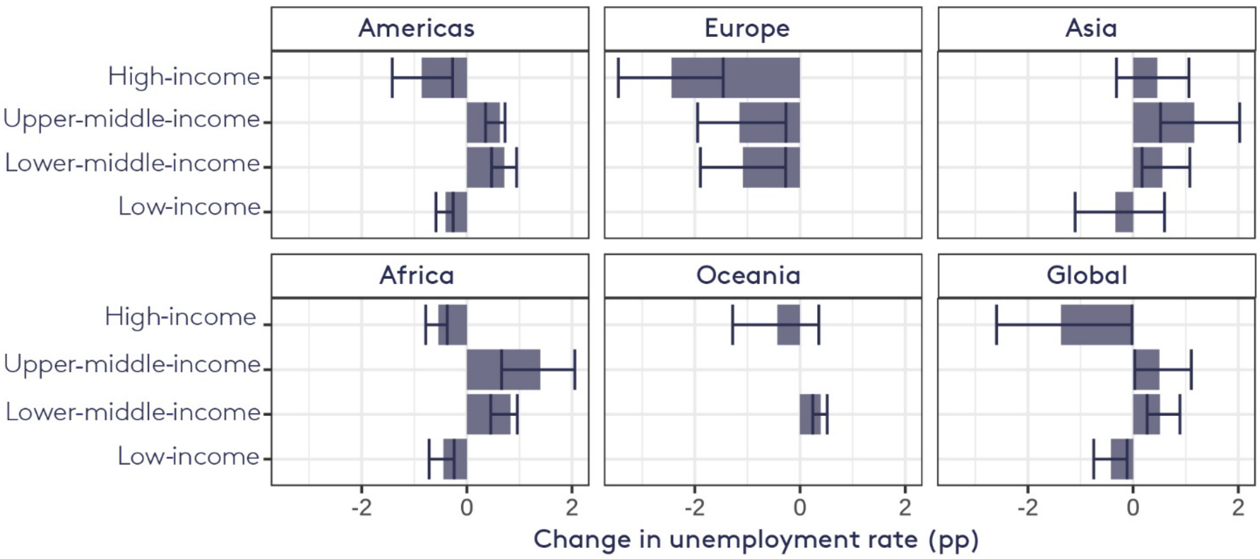
Barmes et al. (2024) identify supply-side mechanisms as the most relevant factors in determining short-term price changes, which are caused by reductions in labour productivity and capital loss.

Global warming has a significant impact on unemployment rates (see Figure 2.9). As temperatures rise, disruptions in economic activity and agricultural output can lead to declining asset values and business activities, which can increase unemployment. Using econometric methods, Liu et al. (2023) find that countries located between 20 and 40 degrees North and South experience higher unemployment linked to global warming, while regions above 40 degrees may see a reduction in unemployment. Furthermore, the effects of climate change vary across economic contexts, with middle-income countries bearing a greater burden and male employment being more affected than female employment. Long-term implications such as decreased labour productivity and increased labour costs in certain sectors further complicate this dynamic.

These results align with other econometric studies on the impact of climate change on unemployment. Adekunle (2024) finds that a 1°C increase in annual temperature raises unemployment by 8.4% in South Africa. The author estimates that only 24.9% of the labour market disequilibrium is corrected in the year following a temperature shock. Olaniran et al. (2025) show that climate shocks, including hurricanes, raise unemployment insurance claims in the US, with stronger effects in regions that are not chronically exposed to such shocks. Using a different methodology, a CGE model that calculates the impact of extreme weather events on output, capital and labour productivity loss, the NGFS (2025) estimates that in 2030 Europe's unemployment rate will be 0.03 percentage points higher than in a scenario without physical climate change risk, while for Asia the effect is greater at 0.29 percentage points, assuming the occurrence of heatwaves, drought and wildfires in 2026 and storm-flood compound events in 2027 at the magnitude of a 50-year return period.

It is essential for policymakers to develop adaptive economic policies that address these climate-induced changes in unemployment dynamics to ensure resilient financial and labour systems.

Figure 2.9. Changes in unemployment rate in 2050 driven by warming under the high-emissions baseline scenario with tipping points



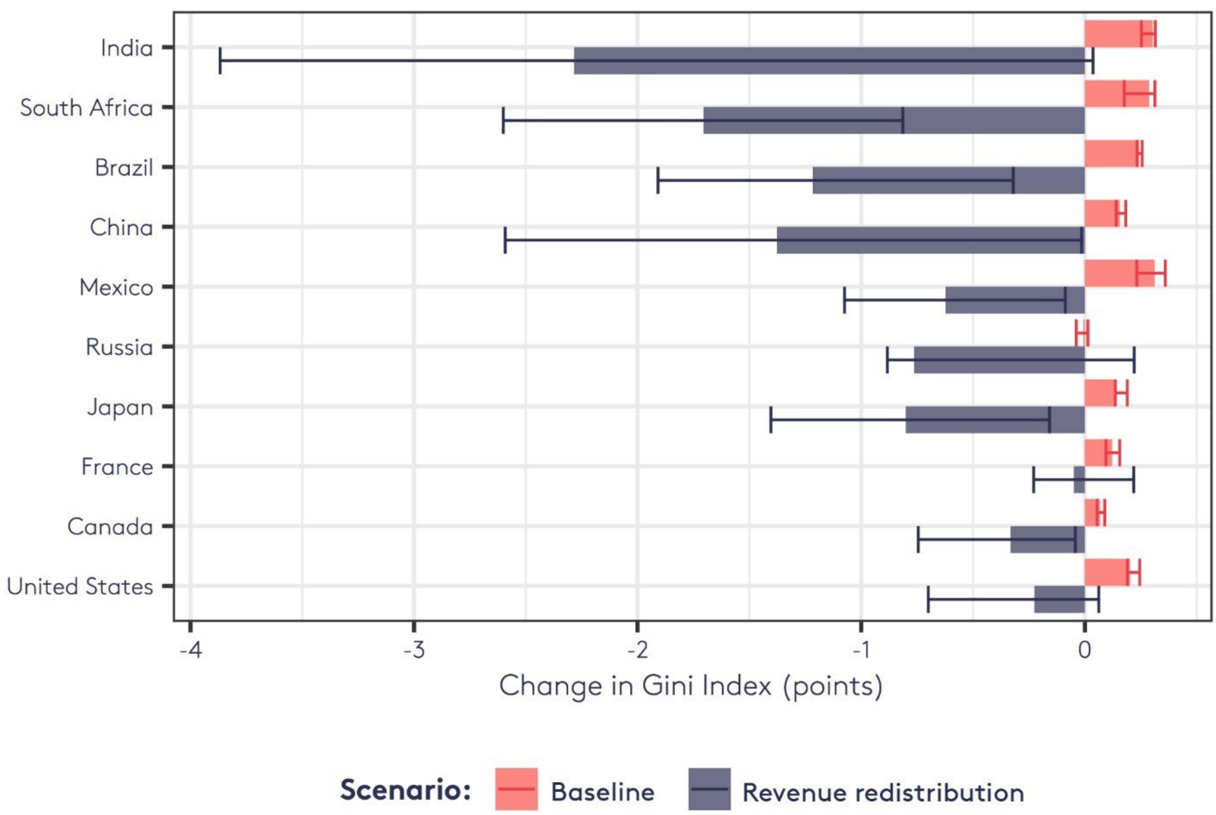
Note: projected with a high-emissions scenario using estimates from Liu and Lin (2023)

Climate change can drive increases in within-country inequality because of the disproportionately greater impact on vulnerable populations that disrupt livelihoods. Emmerling et al. (2024) employ eight integrated assessment models with distinct income groups to study this effect. Under a scenario without additional climate mitigation action, the Gini coefficient, an index of inequality, is projected to rise by 2050. Aligned with this, an econometric study based on global historical data finds that a single percentage point increase in climate change vulnerability, measured by the ND-GAIN index, increases the Gini index by 1.5 percentage points (Cevik and Jalles, 2023). Petrakos and Petrou (2025) argue that within-country inequality increases following climatic shocks because wealthier households can draw on savings while poorer households cannot, leaving them more vulnerable.

A theoretical modelling study suggests that changes in global inequality depend on whether climate change has a greater impact on labour productivity or capital shocks. If labour productivity loss predominates, then the capital-to-net-income ratio increases, meaning that there is more wealth concentration. The opposite scenario happens if capital loss is higher (Tsigaris et al., 2019).

As climate damages amplify existing disparities, they can contribute to greater economic instability and social unrest. Conversely, implementing policies aligned with the Paris Agreement targets, and redistributing the carbon revenues from those policies on an equal per-capita basis, can more than counteract these inequality increases. This approach transforms potential risks into benefits by using consumer subsidies as an adaptation mechanism.

Figure 2.10. Projected changes in the Gini index for 2050 in selected high- and middle-income countries, without climate policy (baseline) and with Paris-aligned policies and an equal per-capita redistribution scheme



Note: Projected from a model intercomparison by Emmerling et al. (2024). The majority of impacts on Gini coefficients under the Paris Agreement-aligned policy scenario are due to revenue redistribution, rather than from the direct reductions in climate impacts.

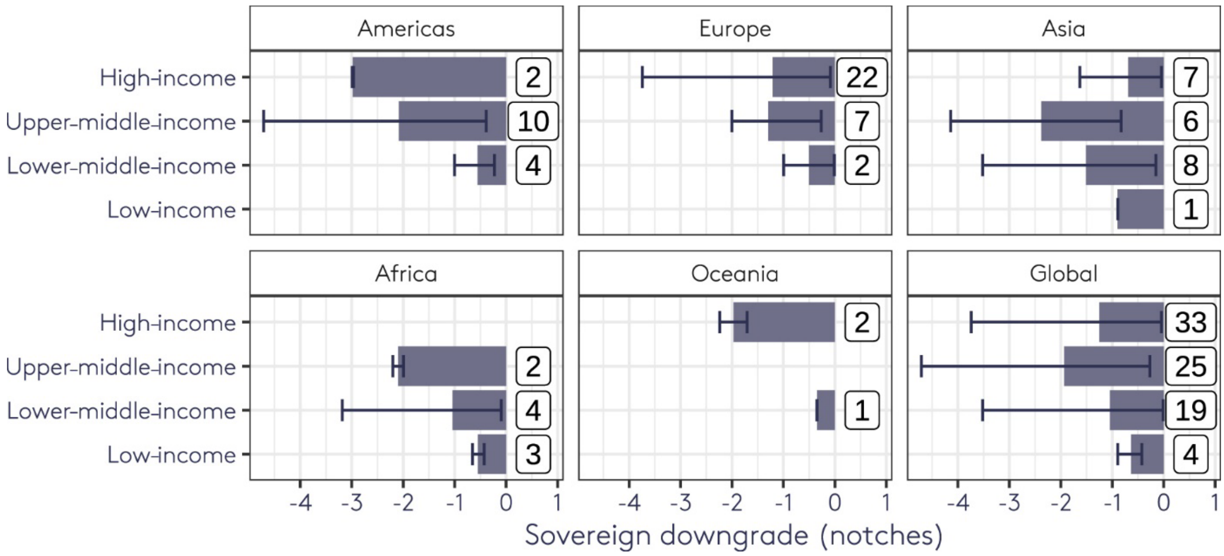
Impacts on sovereign credit ratings

Sovereign creditworthiness is expected to be increasingly shaped by the impacts of climate change. A sovereign's credit rating influences its cost of borrowing, with direct implications for both public and private financing. Some evidence shows that physical climate risks may already translate into sovereign downgrades and higher borrowing costs, particularly for emerging and developing economies, while the benefits of adaptation remain under-recognised (Volz et al., 2020; Zenios, 2022). However, lines of evidence on sovereign credit need more validation with market participants.

Empirical research demonstrates that countries exposed to climate shocks face higher risk premiums and increased default probabilities than those that are not. For example, the 2022 floods in Pakistan affected 33 million people, caused US$30 billion-worth of damage and led the agency Fitch to downgrade the country's credit rating, citing liquidity pressures exacerbated by the disaster (Fitch Ratings, 2022). An econometric analysis based on global historical data finds that countries with higher vulnerability to climate change experience higher sovereign credit default swaps spreads, which means that they are perceived to be at a higher risk of default (Naifar, 2023). Forward-looking models suggest that by 2030 almost 60 countries could face sovereign downgrades due to climate change under the RCP 8.5 scenario (Klusak et al., 2023).

Figure 2.11 illustrates results derived from Klusak et al. (2023). We apply this analysis to the year 2050, under the RCP 8.5 scenario and 30-year timeline for climate adaptation used in that study, and find that countries in all regions of the world are at risk of their credit ratings being downgraded. In contrast to the macroeconomic results, the analysis also finds that the greatest impacts fall on upper-middle-income and high-income countries, across all regions. Klusak et al. explain that high-rated sovereigns have further to fall in terms of credit rating notches, because small increases in perceived default probability can lead to significant downgrades, unlike for lower-rated countries that are already viewed as high risk. Moreover, credit ratings may be less relevant for low-income countries that rely heavily on concessional finance. In 2024, multilateral creditors alone provided 73% of net financing flows to countries that are eligible for resources from the International Development Association (IDA) (World Bank, 2025c). Given that concessional financing is allocated based on debt sustainability assessments rather than market credit ratings (IMF and World Bank, 2025), improvements in ratings offer limited benefits for accessing affordable financing in these countries.

Figure 2.11. Impact of climate change on the downgrading of sovereign credit ratings across regions and income groups in 2050



Note: evaluated under a high-emissions scenario by Klusak et al. (2023) and adjusted to represent 2050. This result relies on a 20-point scale for credit ratings, translated from the standard alphabetical ratings. Number labels report the number of countries available in each region–income group from Klusak et al.

Even though poorer countries are more vulnerable to climate impacts, their credit ratings may not reflect this vulnerability as drastically because they already face considerable political and economic challenges, which are factored into their lower ratings. The risk to credit worthiness for poorer countries is already present, with climate-vulnerable countries facing a measurable risk premium in their debt markets, which reflects both their heightened exposure to extreme events and their limited fiscal capacity to respond (Kling et al., 2018; Cevik and Jalles, 2022).

Despite these risks, adaptation efforts are rarely reflected in credit assessments. Large-scale investments in resilient infrastructure, early warning systems and disaster risk finance can materially reduce fiscal vulnerability. However, credit rating agencies typically only acknowledge such measures when they yield immediate fiscal benefits (Andersen, 2025). This results in systematic undervaluation of adaptation, even though empirical work shows that adaptive capacity is a significant determinant of sovereign credit outcomes (De Moor et al., 2018; Cevik and Jalles, 2022).

The mispricing of climate risk and adaptation creates a vicious cycle. Vulnerable economies are penalised with higher borrowing costs, which constrain their ability to finance adaptation, leaving them more exposed to the next shock. Breaking this cycle requires policy and market reforms that recognise adaptation as a credit-enhancing factor. Since adaptation investments compete with other priorities for limited resources in the short term, reference scenarios for public policy decision-making must explicitly account for the long-term benefits of climate adaptation (Aligishiev et al., 2022). Priority measures include improved disclosure and integration of climate risks into Debt Sustainability Analyses, the development of innovative financial instruments such as resilience bonds and contingent credit lines, and stronger support from multilateral development banks (ADB, 2019).

Other fiscal impacts

It is anticipated that government expenditure will increase as revenue decreases under climate change. Nevertheless, changes in public debt are uncertain as climate change may downgrade countries' credit ratings.

The effect of climate change on public expenditure shows a wide variation. This study has reviewed the literature to compile potential impacts.

In Australia, the increased frequency and severity of natural disasters are expected to increase federal disaster recovery expenditure over the next 40 years from 2023 by 3 to 3.6 times, for the RCP 2.6 and RCP 4.5 scenarios respectively, in the absence of adaptation measures (Australian Government, 2023). In the US, government expenditure increased by US$245 billion between 2015 and 2025 due to impacts of climate change. Each percentage point increase in public expenditure per degree of warming raised the social cost of carbon by 20% in the period 2015 to 2025 (Barrage, 2024). Conversely, a study by Leppänen et al. (2017) estimates a decrease of 1.5–2.6% per degree of warming for Russia using an econometric approach based on historical data. This decrease is expected to be smaller in warmer areas, as colder areas benefit more from an increase in temperature.

At a global level, Akyapı et al. (2025) find that harsh droughts (measured above 4 on the Palmer Drought Severity Index) lead to a significant increase of 0.11 percentage points in the government expenditure-to-GDP ratio, and an increase in the occurrence of extreme hot days (on which the maximum daily temperature exceeds 35°C) reduces the government revenue-to-GDP ratio by 0.14 percentage points.

In Africa, a 1°C increase in annual temperature is estimated to worsen the fiscal balance as a percentage of GDP by 1.1 percentage points on average (Kunawotor et al., 2022). In the Middle East and North Africa, it is estimated that under the RCP 4.5 scenario (a scenario in which radiative forcing stabilises in the 2080s but the rise in global mean surface temperature reaches about 2.9°C in the period 2081 to 2100 and continues to increase) there will be an average reduction in fiscal balance ranging between 1.8% in the period 2020 to 2039, to up to 3.9% in the period 2080 to 2099. The authors estimate that the reduction in non-climate expenditures is significantly lower than the increase in climate-related expenses. As a result, under the same RCP 4.5 scenario, the annual debt-to-GDP ratio is projected to increase between 5.3% in the period 2020 to 2039 to up to 12% in the period 2080 to 2099 due to climate change (Giovanis and Ozdamar, 2022). Salmon-Genel (2025) notes that a constant increase in inflation could increase debt servicing costs.

Nevertheless, evidence of the effect of climatic shocks on public debt is not conclusive. Three econometric studies based on historical data find that debt does not increase significantly after climatic shocks. According to a study by Akyapı et al. (2025), extreme temperatures and droughts do not have a significant impact on public debt at a global level. However, precipitation reduced by one standard deviation in the driest month is associated with an increase in debt-to-GDP ratio of 0.3 percentage points.

A study in the US found that public debt was lower in the 10 years following a hurricane strike. This was mostly because rating agencies raised municipal default risk by 0.1 percentage points following hurricane exposure, which in turn increased interest rates by 1%. As a result, public debt did not increase, but government expenditure was reduced (Jerch et al., 2023).

These findings suggest that governments might consider complementary strategies to addressing fiscal deficits from climate shocks, such as looking at reducing expenditure as well as increasing borrowing. For example, Noy et al. (2011) found that expenditure is reduced in the aftermath of a natural disaster in developing countries. In this sense, countries are not only penalised with higher borrowing costs when a climate shock happens, but will also have a slower economic recovery due to a lack of investment. Nevertheless, contingent liabilities that are not included in the government's balance sheet could have a meaningful impact on the public deficit (Salmon-Genel, 2025).

Other studies use modelling approaches to understand debt impacts. Gagliardi et al. (2022) perform a stylised analysis of the fiscal impact of natural disasters, finding increases between 0 and 4.5 percentage points across EU countries under a 1.5°C scenario and from 0 to 5.2 percentage points under a 2°C scenario after a one-off extreme event in the medium term. Lamperti et al. (2019) use an agent-based model to evaluate the effects of capital and labour damages and find that the debt-to-GDP ratio increases by up to 94 percentage points on average when climate change-driven impacts on both are considered under the SSP5 scenario ('fossil fuelled development'). Using a DSGE model calibrated with data from Dominica, Fernandez-Corugedo et al. (2023) find that public debt increases significantly after a natural disaster and takes approximately five years to recover to pre-disaster levels.

Interest rates are expected to increase annual payments on sovereign debt by US$45–67 billion under the RCP 2.6 scenario (in which very stringent policies are applied and the rise in global mean surface temperature is limited to about 2°C by 2100) and US$135–203 billion under the RCP 8.5 scenario (i.e. the worst-case scenario, in which global mean surface temperature reaches about 4.8°C above the pre-industrial level in 2100 and continues to increase).

Debt burdens that are denominated in foreign currencies can add additional risk for governments. When local currencies depreciate, servicing the same dollar-denominated debt requires more local currency, making repayment more expensive. This forces countries to divert resources from development priorities or borrow additional funds, which further weakens their currency and triggers more depreciation. As a result, a vicious cycle emerges where currency depreciation and debt burdens compound each other continuously (Abalo et al., 2025; Bharadwaj et al., 2025).

In 2022, debt servicing losses from exchange rate fluctuations averaged US$682 million annually per small island developing state and US$1,984 million per least developed country. An econometric study in China found that climate change shocks increase local government debt more in regions with higher economic openness, with exchange rate volatility playing a significant mediating role, particularly in the economically-developed eastern region (Wang and Hu, 2025).

Research gaps

The projections of impacts on GDP discussed in previous sections miss or under-estimate several important risks, such as those arising from regional tipping points, and they have incomplete representation of many other important risks, including storms, floods, droughts, spatial spillovers and ecosystem shifts. Addressing these gaps is a high priority, particularly to close the gap between this work and the inputs needed by risk managers.

The results described in previous sections generally present expected impacts, such as the median of estimates of loss in GDP in 2050. On their own, some of these can appear minor, but these numbers hide important changes in extreme shocks. An average loss of 5% of GDP in a region by a particular year can come from consistent 5% losses in each preceding year, or from years of status quo followed by a devastating loss in that year. The changing likelihood of extreme shocks can present a much greater challenge to countries. This study does not specifically explore extreme risks, even though they underlie the outcomes that are reported. More work on stress testing against potential extreme events and multi-event scenarios is needed.

The studies reviewed here differ widely in the hazards and dynamics they include. For example, only 3% of reviewed sources take climate tipping points into account. Mid- and late-century impacts are likely to be underestimated as a result. Generally, effects that emerge from future thresholds in the environment are not well represented in these results. Both statistical and macromodelling approaches assume that the basic structure of the economy, the stability of the climate and the relationship between the economy and the climate are relatively unchanged in the future. The 'Reasons for Concern' discussions in recent IPCC reports have highlighted the near-term risks that some of these unknown thresholds pose.

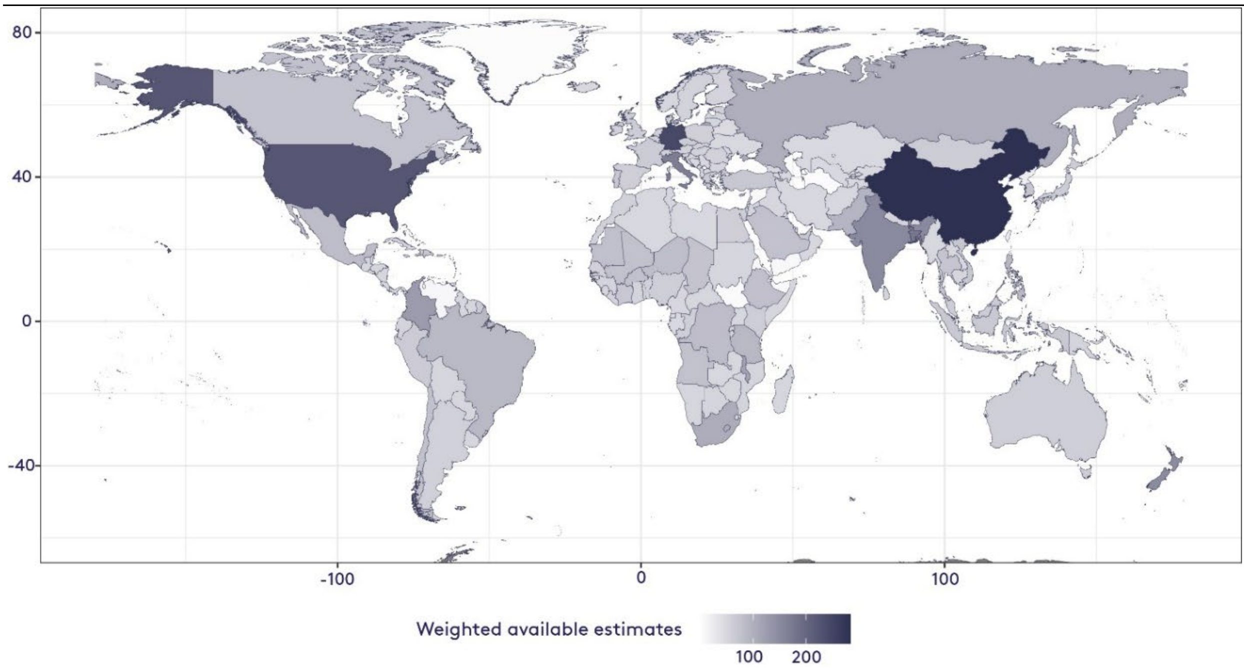
Moreover, current assessments tend to emphasise marginal losses, which can be significant yet possibly manageable within existing economic frameworks. These assessments often overlook systemic risks, such as the potential collapse of major ecosystems (e.g. the Amazon Rainforest) or the deterioration of social cohesion, which could have profound and cascading effects on global stability. Recently, the Climate Financial Risk Forum identified how nature loss could cause systemic financial risks by triggering losses in other services, and propagating negative effects via global supply chains and other market participants (Climate Financial Risk Forum, 2025). Addressing this gap and developing methodologies to incorporate these broader risks into economic models is critical for a more comprehensive understanding of climate change impacts. Lloyds of London's systemic risk scenarios and 'No time to lose scenarios' from the Universities Superannuation Scheme (USS) and Exeter University in the UK provide examples of how to incorporate cascading effects and systemic risks into climate and nature scenarios in the financial system (ibid.).

The role of extreme events and precipitation in general is understudied. Key acute hazards, including sudden events such as floods, droughts and storms, are missing from many of the results above. These will also ripple through the economy, likely affecting not only GDP but also broader macroeconomic stability (NGFS, 2024; OECD, 2025). For instance, the World Bank's Country and Climate Development Reports do not fully capture short-term impacts of extreme events since the analyses focus on annualised damage (Abalo et al., 2025). While there has been some work to incorporate hazards other than temperature into econometric analysis of GDP, the contributions of those hazards are found to be smaller than the temperature effects, although they do increase tail risks (Waidelich et al., 2024). The minor role of these other factors likely reflects limitations in how non-temperature extreme events are represented, and more work is needed to improve this.

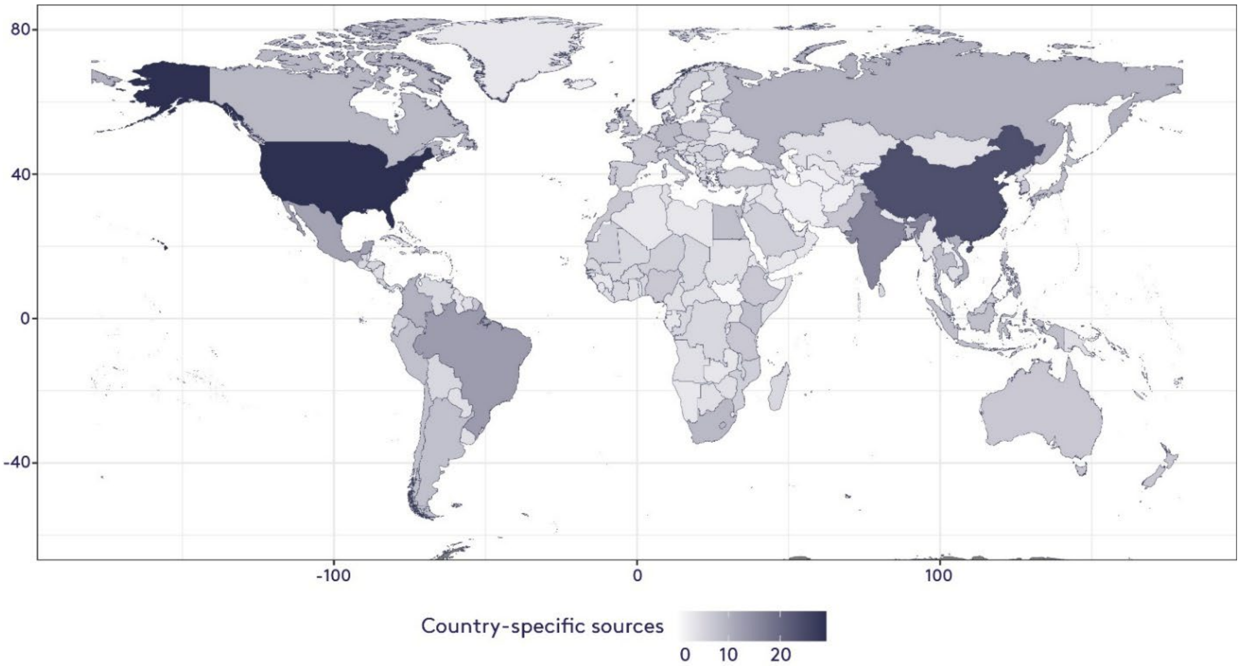
As shown in Figure 2.12, there is a strong bias in the evidence base of this report towards large countries, including the US and China. Macroeconomic and fiscal risks across much of the lower-income parts of the world remain poorly studied.

Figure 2.12. Global distribution of available macroeconomic estimates across the full reviewed dataset

a) Number of estimates related to macroeconomic and fiscal risks, by country



b) Number of sources providing country-specific values, by country



Note: For estimates applied uniformly to many countries, the estimate count is evenly divided across countries. See Appendix A.7 for dataset.

The effects of physical climate risks on several macroeconomic outcomes are also understudied. Studies on unemployment that focus on physical risks rather than transition risks are limited. Therefore, it is important to examine how high temperatures, weather shocks and sea-level rise impact unemployment at the national level. This review only identified three studies that analysed the impacts of climate change on TFP. This variable is crucial for understanding long-term economic growth.

Studies related to capital loss are typically static in nature and show accumulation over time. Given that capital loss represents a reduction in a country's wealth, it usually has ongoing implications for consumption, productivity and welfare. Consequently, there are opportunities for new research to focus on the long-term welfare impacts of capital loss. There are also limited studies quantifying natural and human capital loss due to climate change.

There is a need to expand analyses that include cascade effects between sectors and macroeconomic variables to make more accurate forecasts of macroeconomic risks for the economy (Abalo et al., 2025). For instance, the interaction between the downgrading of sovereign credit ratings, increased public expenditure and decreased public revenue caused by climate change remains unclear. There is insufficient evidence of how countries are most likely to address fiscal deficits from climate shocks, such as which budget categories could be affected by reduced government revenues.

The metric of fiscal (primary) balance seems ripe for analysis: climate change is likely both to reduce revenues and increase expenditures for governments, and the effect of the combination of these may be more tractable than the impact on either process in isolation. However, evidence on the impact of climate change on fiscal balance is very sparse. Within this review, two papers provided such evidence: a stylised analysis of the impact of natural disasters on the fiscal balance of EU countries (Gagliardi et al., 2022.) and an analysis of optimal fiscal rules for Pacific Islands (Nakatani, 2021).

Our evidence database records many important features of the analyses behind these results, including aspects of the methodology (for example, the use of econometric and macroeconomic modelling methods), the types of hazards included, the level of spatial disaggregation, and the potential for interactions between impacts (see Appendix A.1). Future work could use this information to better assess why some results show a larger impact or more variable, and this information could be central to an improved conceptual framework for understanding the scientific uncertainty around macroeconomic risk estimates.

In addition, there is significant potential to use the full collection of estimates in this study's database for more comprehensive and integrated assessments. Because macroeconomic and fiscal outcomes are related, it may be possible to fill the data gaps across the various indicators using existing data and data from similar countries. The changes in values might also be integrated into a kind of 'disruption index' (see the example in Appendix A.5.1), which may have benefits for understanding risks before they are specifically identified.

3. The case for adaptation investment

The imperative for strategic investments in adaptation and resilience is becoming even more urgent for economic decision-makers – particularly within Ministries of Finance – as the impacts of climate change continue to escalate. The rationale for adaptation investments extends even beyond direct climate resilience: it contributes to a broader economic and social landscape that offers a multitude of potential dividends, as this section explains.

The core adaptation dividend is damage reduction. Investing in adaptation provides an opportunity to tackle the adverse impacts of climate change before they manifest into more severe economic disruption. Effective adaptation measures can reduce losses in crucial sectors such as agriculture, infrastructure and public health, reducing the risk to national and local economies from slow-onset and extreme weather events related to climate change.

By investing in adaptation today, decision-makers can reduce the future economic costs and fiscal risks described above. The concept of reduced risk – an analytical framework that assesses the potential damages averted through reactive and proactive measures – lies at the heart of adaptation investment (Carleton et al., 2024):

- **Reactive adaptation** addresses risks that are already being experienced, and can help contain the extent of loss and damage.
- **Proactive adaptation** measures involve anticipating potential climate risks and implementing strategies. These actions aim to protect against current and future disruption and reduce damages.

Existing macroeconomic and fiscal frameworks, including those used by the IMF, World Bank and credit rating agencies, typically treat climate shocks as downside risks to growth and stability (IMF, 2025; Fitch Ratings, 2023). They do not incorporate the full upside potential of resilience investments, even if some channels of positive effects are acknowledged (see World Bank, 2025a). The evidence presented in this section can help to correct that asymmetry by demonstrating that adaptation can yield measurable economic returns and contribute to macroeconomic resilience.

Box 3.1 showcases integrated water resources management (IWRM) – here in the Nigerian context – as a key adaptation practice, because it provides substantial fiscal benefits by significantly reducing flood-related economic losses, safeguarding public infrastructure and revenues, and attracting private investment.

Box 3.1. Nigeria case study

Benefits of investing in integrated water resources management (IWRM) to reduce flood risk

Floods are Nigeria's costliest and most frequent natural hazard. Flooding in 2022 alone caused both direct damages and up to US$9.1 billion in broader economic losses, straining federal and state budgets through emergency relief, rehabilitation of transport and energy assets, and expanded social protection needs (World Bank, 2022a).

Nigeria's exposure to flood risk is rising due to rapid urbanisation, watershed degradation, silted channels and climate-intensified extreme rainfall. In 2018, coastal degradation, dominated by flooding and erosion, in just three states – Lagos, Delta and Cross River – cost an estimated US$9.7 billion, equivalent to approximately 2.4% of national GDP, underscoring large, recurring welfare and fiscal impacts from flood-related service disruptions and health burdens (ibid.). The 2022 floods affected 64% of households nationally, with especially severe impacts on non-farm enterprises, 91% of which reported adverse effects (UNDP, 2023). These damages drove tax base erosion and higher emergency outlays. Federal estimates put economy-wide losses at near US$9.1 billion, while rapid assessments reported US$6.68 billion in direct damages to housing, transport, agriculture and public assets – costs that risk ultimately cascading to public budgets.

IWRM offers an economically efficient and fiscally sustainable path to reduce these losses. It promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment.

Global and regional evidence indicates economic benefit–cost ratios of around 4:1 for components of IWRM such as resilient infrastructure and early warning-enabled preparedness – with early warning systems typically reflecting higher benefit-cost ratios than the average – all offering strong co-benefits for jobs, health and productivity (Hallegatte et al., 2019; UNDRR, 2019). Applying IWRM in Nigeria's priority river basins, particularly the Niger–Benue, can meaningfully lower disaster spending, protect government revenues and crowd in private investment.

IWRM is grounded in the Dublin–Rio principles[4] and embedded in Nigeria's water governance through the Nigeria Integrated Water Resources Management Commission (NIWRMC) and River Basin Development Authorities, though implementation remains uneven (NIWRMC, n.d.). In practice, a Nigerian IWRM package for flood risk reduction typically combines upstream and peri-urban nature-based solutions (NbS) such as watershed reforestation and floodplain restoration, targeted grey works like dredging and urban drainage upgrades, real-time hydro-meteorological networks and flood early warning systems, as well as policy reforms including zoning, building control and risk-layered financing (WRI, 2022).

The fiscal rationale for IWRM rests on several pillars. First, avoided damages to public infrastructure and services are significant. IWRM lowers emergency and social protection outlays. Second, by keeping firms operating and supply chains intact, IWRM protects Nigeria's tax base and economic output. Furthermore, IWRM interventions such as wetland restoration improve water quality and reduce the burden of water-borne diseases, reducing public health expenditure (World Bank, 2020a).

In practice, Nigeria's experience with IWRM illustrates both successes and persistent challenges. The **Ibadan Urban Flood Management Project (IUFMP)**, launched after the devastating August 2011 floods, represents a hybrid model that combines basin-scale planning, infrastructure investments and an early warning system. At the appraisal stage, the World Bank estimated a total project cost of US$220 million – a US$200 million International Development Association (IDA) credit plus US$20 million in counterpart funds – and set out a mixture of short-term priority works and longer-term risk-mitigation investments. The appraisal quantified economic viability via cost–benefit analysis with present values (10% discount rate) of benefits = US$409.6m and costs = US$197.5m, implying expected net present value (ENPV) ≈ US$212 million and benefit–cost ratio ≈ 2.07; an economic internal rate of return (EIRR) of ~ 40% is also reported in the Implementation, Completion and Results (ICR) report's comparison table (noting that the Project Appraisal Document itself presented cost–benefit analysis metrics rather than an explicit EIRR) (World Bank, 2014c).

By 2024, implementation had rehabilitated 37 hydraulic structures, completed dam safety works, dredged ≈ 431 km of rivers and drains and installed early-warning capabilities – benefiting a large share of Ibadan's residents. Total actual disbursements from IDA reached US$164.3 million (counterpart funds were lower than planned), after extensions that took the actual closing to 28 June 2024 (World Bank, 2025a).

4 These are four principles that were adopted at the 1992 Dublin Conference on Water and endorsed at the Rio de Janeiro Summit on Sustainable Development in the same year.

At completion, the bank re-ran the economic analysis using achieved works, incurred costs and projected operations and maintenance (O&M)/benefits. The ICR's efficiency annex reports: EIRR = 25%, ENPV = US$123.86 million and benefit–cost ≈ 1.92 (all at a 10% discount rate). The ICR report also provides sensitivity/cost–benefit analysis tables showing present benefits and costs under different horizons, and explains the gap with appraisal – notably implementation delays, cost overruns in priority works and only ~ 87% physical progress in long-term drainage/channelisation at closing. Even so, the completion-stage EIRR remained well above the 10% social discount rate, confirming continued economic viability (World Bank, 2025a).

Independent evaluation materials further note mixed institutional results – for example, adoption of an asset-management plan without full legal codification and early-warning constraints due to data/staffing – underscoring that sustainability hinges on formal adoption of master plans and adequate O&M financing to preserve the benefits of the large civil works (World Bank, 2025a).

In northern Nigeria, the **Komadugu–Yobe Basin Trust Fund** was established by six riparian states and the federal government with support from the African Development Bank (AfDB) to coordinate dam operations at Tiga and Challawa Gorge. The goal was to restore downstream flows to the Hadejia–Nguru wetlands while reducing destructive floods. Benefits included improved fisheries, farming opportunities, and reduced conflict between irrigation and downstream users. However, institutional complexity and the lack of enforceable operating rules have limited its full effectiveness (AfDB, 2023).

The **Nigeria Erosion and Watershed Management Project (NEWMAP)**, implemented across more than 20 states, rehabilitated degraded watersheds using bioengineering and drainage improvements. At project completion, the World Bank conducted an ICR economic analysis drawing on data from between 84 and 91 completed sites. Benefits included avoided infrastructure damage and displacement, reduced traffic disruption, afforestation, greenhouse gas reduction and increased land values. Using these observed outcomes and projecting benefits forward (phased in at 10% in 2023, 40% in 2024 and fully from 2025), the analysis estimated a net present value of US$317 million, with a benefit–cost ratio of 1.4 and an EIRR of 15%. These ex-post results confirm that upstream rehabilitation reduces sedimentation, prevents infrastructure damage and is fiscally cheaper than repeated dredging or road repairs (World Bank, 2022a).

By contrast, the **Oyan Dam along the Ogun River** illustrates the risks of incomplete integration. Seasonal water releases regularly inundate downstream communities in Lagos and Ogun States. While authorities issue early warnings and relocate households, limited transparency about reservoir operations, weak enforcement of zoning laws and solid waste clogging drains mean that flood losses persist year after year.

Nigeria's practical experiences demonstrate that IWRM has potentially high economic benefits, and can also have high fiscal benefits if paired with robust implementation and enforcement mechanisms, transparent management and complementary urban planning (NEMA, 2024).

Evidence of adaptation's effectiveness and economic benefits

Introduction and methodology

There is an emerging evidence base for the economic returns from climate change adaptation. In practice, these economic returns vary because adaptation is a response to site- and context-specific climate risks, reflecting local hazard, exposure and vulnerability, and these risks change dynamically over time. There are also some particular challenges with adaptation that make it very different from climate change mitigation, including very high uncertainty over its efficacy and benefits. Nonetheless, many short-term adaptation actions to reduce current and emerging climate risks can be implemented now.

This section collates some of the evidence on the effectiveness and economic benefits of adaptation, focusing on these early opportunities for taking action – action that can provide returns that are both quickly realised and likely to increase under future climate change.

We review the adaptation costs, benefits and economic returns from 75 studies and combine the results from 22 studies into three consistent metrics for the benefits of adaptation: adaptation effectiveness ratios (e.g. World Bank, 2024a), economic benefit–cost ratios (e.g. WEF, 2024) and economic internal rates of return (e.g. Brandon et al., 2025). The studies include ex-ante estimates of project-specific engineering costs and avoided impacts, statistical analyses of observed adaptation returns, and model-based projections of adaptation investment. They generally do not include financing strategies or opportunity costs. The methodology is described more fully in Appendix A.6.

We synthesise the results from multiple studies and calculate metrics where the component outcomes are reported. Where studies provide project-specific results, these are combined to sectoral-level averages within each country. Some studies perform macroeconomic modelling analysis of adaptation benefits directly, and some of these explore the full range of adaptation needs, although their handling of market and non-market losses is inconsistent. Most of the studies under consideration, however, concentrate on physical adaptation measures, such as infrastructure, with more limited coverage of non-technical, nature-based or social protection approaches. These results are shown later in this section as histograms over sectors.

Adaptation effectiveness ratio (AER)

Adaptation can be measured in different but complementary ways, each offering a distinct lens on its relative benefits. One straightforward measure is the adaptation effectiveness ratio, which captures the portion of losses that are reduced thanks to adaptation. This is important because adaptation is rarely completely effective in reducing risks, and costs may increase disproportionately with higher levels of risk reduction. The costs of further risk reduction rise sharply as we approach zero residual damage – even across wealthier economies – thus, some residual risk is accepted as economically efficient. This in turn leads to a trade-off between costs, benefits and residual damage, and the objectives set for adaptation: for example, the aim might be to attain the optimal economic level, to maintain current risk levels, or to reduce damage to as little as possible. Further, combinations of adaptation are often needed – or are more effective together – to reduce risks at scale, as these can address different elements of risks, for example exposure and vulnerability. For a specific project, the AER is the *share of baseline losses that are avoided because the measure is in place*.

Conceptually:

AER = (baseline expected losses – expected losses with adaptation) / baseline expected losses

Practitioners estimate this by:

1. Defining the hazard set (e.g. temperature rise, flood extent and depths, storm surge, heatwave days)
2. Computing baseline average expected annual damages (EAD) to assets/people *without* the project; these damages describe market losses and in some cases include non-market losses
3. Re-computing EAD *with* the project (e.g. with levées, mangroves, early warning systems, or cool roofs in place)
4. Taking the ratio of avoided to baseline losses.

The AER has to be defined for the specific site and context being assessed, because of the particular hazards, but also the specific exposure and levels of vulnerability, which are determined by the number of people or assets at risk, and existing measures, such as protection infrastructure and early warning systems, and the socioeconomic importance of the assets at risk. In turn, this means that effectiveness is site- and context-specific and there can be large ranges even for the same measure.

For example, especially strong results are obtained from projects that provide public goods, technological innovations or direct financial transfers. This illustrates the practical value of AER as a measure: it tells us how much damage would be avoided in reality and helps convey adaptation's tangible role in protecting households, farms and communities from shocks and stresses, as well as slower-onset processes such as sea-level rise, drought or long-term temperature increases.

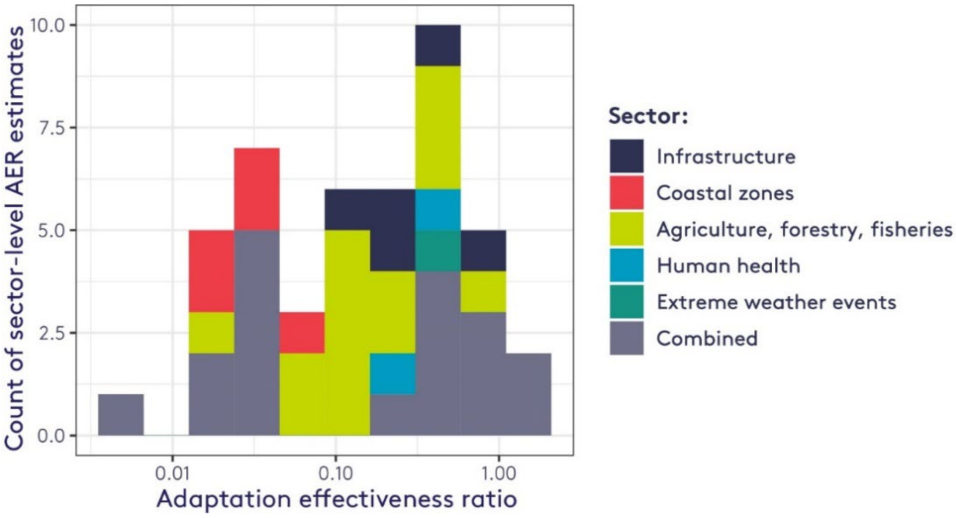
For this analysis, we use three examples to illustrate the economic case:

- For **coastal risks**, hydrodynamic models of mangrove/salt marsh restoration routinely show sizeable avoided damages, although they do not remove risks completely. While they substantially reduce the damage from moderate flooding, they are less effective during extreme events and are therefore often combined with engineered protection in urban or high-risk areas.
- For **early warning systems**, meta-analyses support a conservative AER of around 0.20 (Hallegatte et al., 2019; World Bank 2024a), reflecting typical loss reductions from timely alerts (WMO, 2024; World Bank, 2019). An AER of 0.2 is relatively modest but consistent with expectations, given that early warning systems may reduce the impacts of hazards but not the hazards themselves.
- **Urban heat action plans** can deliver particularly high risk-reduction benefits, with AERs often between 0.4 and 0.8 based on avoided excess mortality (Azhar et al., 2014; Knowlton et al., 2014). Across these cases, AER communicates the tangible risk reduction on the ground.

The evidence

Figure 3.1 presents a histogram of AER values from the reviewed literature.

Figure 3.1. Reported adaptation effectiveness estimates, representing the portion of impacts avoided, grouped by sector and study



Note: Estimates draw from 26 studies. X-axis shown on a log-scale.

Figure 3.1 reveals a bimodal distribution, with one portion of the literature reporting estimates showing minor reductions in damages (AER < 0.05), while another reports estimates showing large benefits (AER > 0.10). Some of the low-AER portion of this distribution derives from ex-post studies that show that broadly defined interventions have a small effect on a large population. The larger estimates are typified by project-specific ex-ante estimates (aggregated to the sectoral level here). As a comparison, World Bank (2024a) finds that approaches supporting locally targeted adaptation can reduce climate risks by 38–72%, an AER of 0.38–0.72. It is not clear whether one of these sources of evidence is preferable, since well-chosen context-specific initiatives are expected to have greater returns than broad policy changes.

Economic benefit–cost ratio

Costs, in the form of capital expenditure (CapEx) and operating expenditure (OpEx), are used *alongside* the AER (e.g. to calculate the benefit–cost ratio, or net present value) but are *not* part of the AER calculation. Policymakers will also want to know whether investing in adaptation 'pays off'. This is where the economic benefit–cost ratio is central: it compares the discounted stream of benefits with the discounted stream of costs over a project's lifetime. The broad literature frequently finds economic benefit–cost ratios for adaptation that are well above one, with medians around 4:1 in some syntheses, as shown below. This is because adaptation contributes to avoided disaster losses, preserves service continuity and protects against chronic and gradual climate stresses. In this context, service continuity is considered an avoided loss, referring to the ability of essential services, infrastructure and transport systems to remain open and functional for continued market access and uninterrupted supply chains – thereby avoiding output and welfare losses. Several examples are discussed below.

Consider **multi-hazard early warning and hydrometeorological (hydromet) systems**. In practice, the costs of these systems (the denominator in benefit–cost ratios) comprise the capital expenditure (e.g. on observing networks, radar, information and communications technology) and recurrent operating expenditure (staffing, maintenance, public communication). The benefits (the numerator) aggregate *avoided* asset losses and, where appropriate, avoided health and mortality impacts (which are also monetised). National and regional assessments consistently report high returns: studies by UNISDR (2015) and GCA/WMO (2024) document that the economic benefit–cost ratios are typically between about 4:1 and 36:1, reflecting relatively small system costs against large, recurring avoided losses when warnings lead to action and reduced damages. [5]

A similar logic underpins **flood protection infrastructure**. These investments lead to large economic benefits from reduced damages, especially when avoided fatalities and injuries or indirect benefits are included. The reported economic benefit–cost ratios are typically 3:1 or 4:1, though these are site- and context-specific. Synthesis studies report median flood protection benefit–cost ratios of around 3:1 (and averaging around 6:1), which are consistent with high returns where exposure is large (EconAdapt, 2015; Mechler, 2016).

For Bangladesh's Coastal Embankment Improvement Project (CEIP-I), the cost side includes raising and strengthening embankments, replacing gates, and ongoing operation and maintenance, while the benefits side values avoided flood damages to homes and crops, as well as avoided indirect economic damage behind the polders. The World Bank's economic analysis also included a valuation of avoided fatalities using the value of a statistical life (VSL), which contributes materially to the total estimated benefits. Using catastrophe and depth–damage

[5] The computation of costs and benefits for such systems is theoretically simple but quite complex in practice. It requires site-specific data and analysis of the effectiveness of the early warning system from the generation of the warning, through communication, to uptake and use, including the effectiveness of end users in using the data – and the efficiency losses from each step of this value chain. Nonetheless, it is possible to estimate expected annual damages (EAD) without the system, apply empirically grounded loss reduction factors to derive EAD with the system, monetise any damage or health reductions – the latter potentially using economic appraisal techniques such as value of statistical life (VSL) to assess changes in risk, discount both benefits and costs, and take the ratio of present values (Hallegatte, 2012; Rogers and Tsirkunov, 2013). However, most benefit–cost ratios exclude end-user response costs (e.g. preventative actions, time, income foregone), so reported ratios may reflect early warning system costs versus avoided losses.

modelling to generate baseline expected annual damages (EAD) and 'with-project' EAD across return periods, the World Bank's implementation completion report estimates economic benefit–cost ratios ranging from 2.9 to 5.1 at a 6% discount rate, with large positive NPVs – illustrating how robust physical protection can yield durable fiscal and welfare gains when exposure is high (World Bank, 2023c).

Related **cyclone shelter programmes** in Bangladesh combine structural works with evacuation protocols. Their economic benefit–cost ratios range between 1.1 and 1.6, for an annual probability of a cyclone of 1%, and are built by summing avoided fatalities (valued via VSL), avoided damages among sheltered populations and continuity of essential services, and then dividing this by the capital and recurrent costs of building, staffing and upkeep. Ex-ante and ex-post analyses commonly find benefit–cost ratios above one for multipurpose shelters, though the results are sensitive to assumptions about responses to warning and shelter utilisation rates (World Bank, 2014a).

In **mangrove and salt marsh restoration**, capital costs cover site preparation, planting and hydrological reconnection, with recurrent monitoring, maintenance and enforcement; benefits are quantified by re-running storm surge and wave models with restored habitats and then converting reduced flood depths and extents into avoided losses. Global analyses show that mangroves avert tens of billions of dollars of expected flood damages each year; at project scale, cost–benefit studies frequently return benefit–cost ratios above one, and higher when co-benefits (e.g. fisheries, carbon sequestration) are included (Tiggeloven et al., 2022). The results are still positive – though typically smaller – when analysts restrict benefits solely to coastal protection. However, these solutions are most suitable for low risk levels and certain locations and cannot address all major coastal risks on their own, hence they are often combined with hard coastal defences.

The method requires care in scoping: reporting benefit–cost ratios both with and without co-benefits, and testing discount rates and habitat performance assumptions, makes results interpretable and policy-useful (Narayan 2016; Menéndez, 2020). As with other areas, analysis is highly site- and context-specific.

In sum, for early adaptation actions, the economic benefit–cost ratio is a disciplined way to express whether adaptation 'pays off', as it:

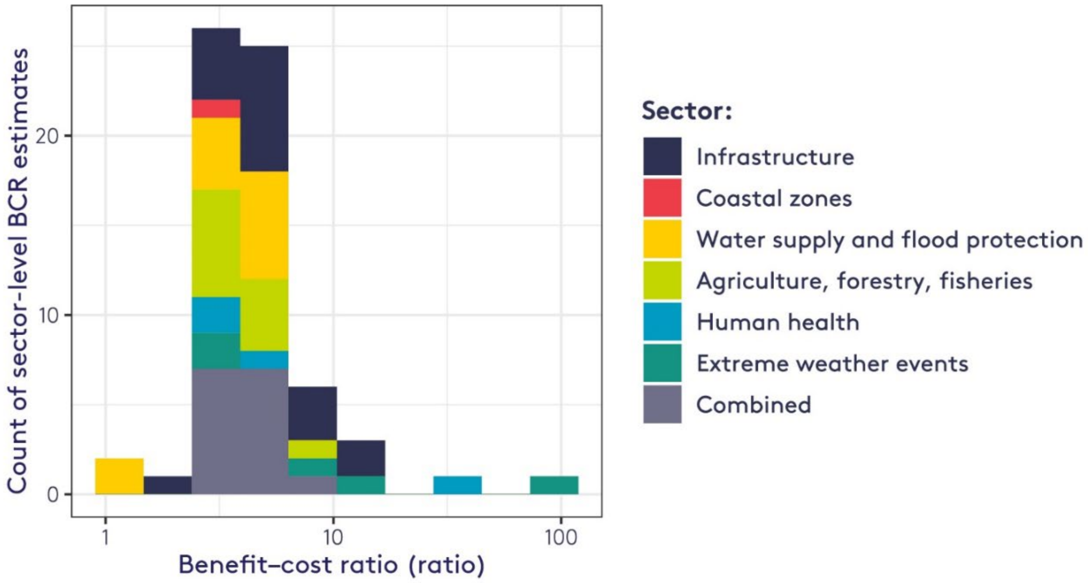
- Sets up a consistent with/without analysis on the same hazard set
- Monetises the resulting avoided losses – and any health or ecosystem benefits, where in scope; these are typically microeconomic, rather than macroeconomic, in scope
- Discounts benefits and costs over the asset's life, which can be up to 50 years
- Reports the ratio transparently with sensitivity tests.

However, there is increasing recognition of the persistent limitations under simple cost–benefit analysis (CBA) methods, especially when moving beyond early no-regret actions, which can lead to misinformed results, and has resulted in a greater focus on the use of *extended* CBA (Chambwera et al., 2014). The project examples above – early-warning systems, embankments and shelters, and coastal, nature-based measures – show how practitioners can move from itemised CapEx/OpEx to defensible benefit streams, and why results vary by exposure, valuation scope and assumptions. Readers should interpret any single benefit–cost ratio alongside these underlying choices rather than in isolation.

Note that for more proactive adaptation responses, where benefit streams arise in the future, there are additional methodological challenges, notably with uncertainty – namely uncertainty associated with different climate scenarios and models, impact models and uncertainty over adaptation's costs and benefits. To address these challenges, extended cost–benefit frameworks have been developed that allow decision-making under uncertainty; for example, through robust decision-making, real options or dynamic adaptation pathways (discussed later in this section).

Figure 3.2 presents a histogram of outcomes from this study's literature review, aggregated to the sectoral level. The vast majority of reported economic benefit–cost ratios are between 3:1 and 8:1, although some benefit–cost ratios for extreme weather events (e.g. from early warning systems) and human health (e.g. reducing costly VSL-valued deaths) are estimated to have benefit–cost ratios over 20.

Figure 3.2. Reported benefit–cost ratios (BCR), including market and non-market benefits, grouped by sector and study



Note: Estimates draw from 15 studies, using study-specific discount rates where reported as benefit–cost ratios, or 5% where benefit–cost ratios are computed here.

Economic internal rate of return (EIRR)

A related but distinct measure is the economic internal rate of return. Rather than embedding a fixed discount rate, as with a benefit–cost ratio, the EIRR is the discount rate that sets the project's economic net present value to zero: that is, the rate at which discounted benefits – primarily avoided losses and service continuity, plus health and other non-market gains where in scope – equal discounted costs, i.e. capital outlays and operations and maintenance (O&M).

Analysts construct two comparable streams – with and without the intervention – under the same hazard, vulnerability and exposure assumptions, monetise the differential (the time series of benefits associated with the estimated avoided losses), add any valued co-benefits and then solve for the discount rate that equates those benefits to the capital and O&M profile. However, in practice, deriving EIRR requires credible with/without trajectories, performance assumptions and sensitivity tests (for hazards, exposure and uptake).

The evidence base suggests that adaptation can also perform strongly on this metric. In this study, all EIRR estimates are drawn from work by the World Resources Institute (WRI) (see Brandon et al., 2025). Across these estimates, the median EIRR is around 25%, comfortably above typical public investment thresholds. Some disaster risk reduction investments return approximately double this median. However, these averages are from ex-ante project estimates, and ex-post evaluations are still needed.

Bangladesh's Coastal Embankment Improvement Project (CEIP-I) provides a concrete illustration, where hydrodynamic and depth–damage modelling produced annual streams of avoided flood losses behind strengthened polders. When these benefits are compared with staged rehabilitation costs and expected O&M, the independent completion review reports an EIRR of 26% (with benefit–cost ratios of 2.9–5.1, depending on polder scope), underscoring robust performance even after accounting for delivery risks and scope changes (World Bank, 2023c).

Early warning and hydrometeorological systems provide a second, methodologically transparent example of how EIRRs are derived. As mentioned earlier, the cost includes the upfront capital for observing networks, radar and communication infrastructure, plus recurrent spending on staffing, maintenance and periodic system upgrades (though as noted for benefit–cost ratios, there are often additional user costs associated with action that are additional to these system costs). The benefit side aggregates avoided asset losses and business disruption (often parameterised using conservative loss reduction factors in the 15–25% range), and, where appropriate, monetised mortality and morbidity benefits.

In the Pacific Resilience Program, the appraisal estimated an EIRR of 19% for the programme's early warning investments based on a 20% reduction in expected annual losses and casualties. At completion, reflecting only the subset of directly quantifiable early-warning benefits, the EIRR was re-estimated at 14.9%. The accompanying documentation sets out each step: baseline EAD without modernised warning; with-project damages after impact-based forecasting and coverage improvements; valuation of avoided fatalities; then discounting and solving for the rate at which present-value benefits equal present-value costs. Sensitivity tests (±5 percentage points on loss reduction) move the completion EIRR to between about 10% and 20%, remaining above social discount rate benchmarks (World Bank, 2014b; 2024).

Nature-based protection projects also report EIRRs, and they make clear how choices about scope affect results (e.g. whether or not to include carbon sequestration or ecosystem services). Vietnam's Forest Sector Modernization and Coastal Resilience Enhancement Project evaluated mangrove and coastal forest restoration with a standard with/without flood risk model and an explicit accounting of carbon sequestration and other co-benefits. The EIRR was 57.4% in the base case, including carbon. Crucially, a sensitivity run excluding carbon still yielded an EIRR of 27.9%, showing that the adaptation (i.e. risk reduction) benefits alone sustain high returns, while also illustrating why transparency about what is – and is not – counted is essential for interpretation.

A recent sustainable asset valuation (SAVi) assessment of mangroves protecting the DEEP C Industrial Zone in Vietnam similarly walks through CapEx (for site preparation, planting and soil works) and OpEx (for monitoring and maintenance), and then values avoided flood damages, infrastructure O&M savings and property value effects. Across scenarios, the internal rate of return ranges from around 19% to 32% when growth and protection efficiency are high, but falls to low single digits when efficiency is assumed to be poor. This demonstrates again how EIRRs hinge on credible hazard, exposure and performance assumptions, and why analysts present ranges rather than point estimates (IISD, 2025).

Taken together, these cases show how EIRRs are obtained in adaptation appraisal:

1. Define comparable 'with/without' trajectories on the same hazard set
2. Monetise avoided losses, typically from a microeconomic perspective, and any scoped co-benefits, such as benefits to health and the environment
3. Map the timing of capital outlays, reinvestments and O&M
4. Compute the discount rate at which present value benefits equal costs over the lifetime of the asset
5. Report transparently with sensitivity tests.

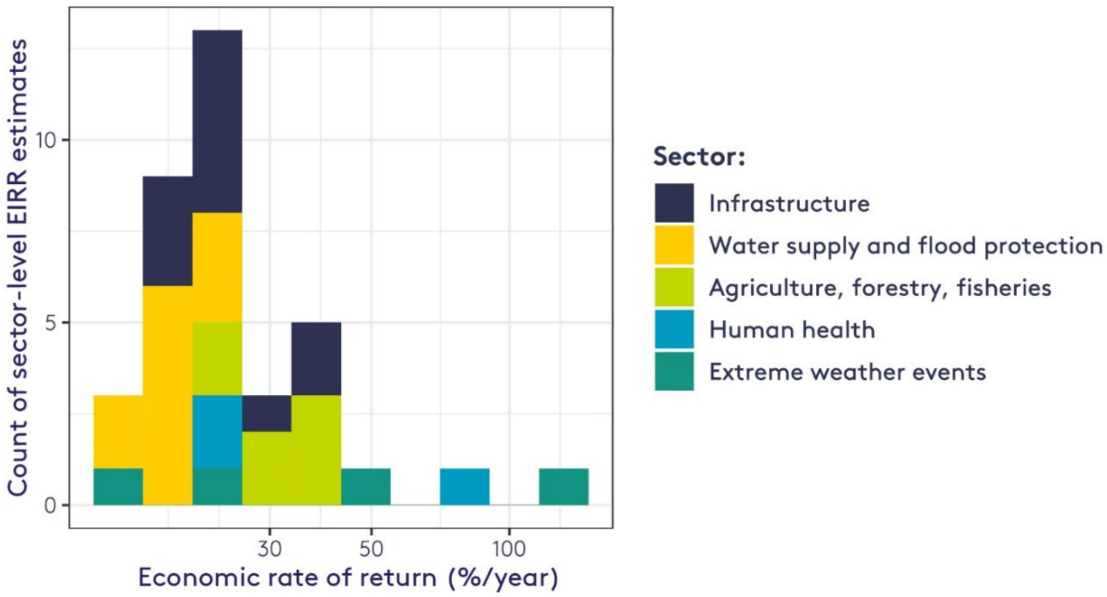
The median EIRR of around 25% in this study's database – focused on early interventions that produce early benefits – aligns with the project evidence described here, while higher returns in selected disaster-related interventions reflect concentrated exposure and substantial avoided damages.

It remains critical, however, to recognise that EIRRs include both market and non-market benefits when appropriate, and that differences in valuation scope (e.g. inclusion of carbon, ecosystem services or mortality risk) can materially shift results.

The Financial Internal Rate of Return, which only includes market benefits, is lower, and significantly so in many cases. For that reason, reported EIRRs should be read alongside their assumption sets, benefit scopes and sensitivity analyses, not as decontextualised point estimates (World Bank, 2024a). Further, as earlier, it should be noted that analyses are site- and context-specific, and more advanced methods are needed for more proactive adaptation.

EIRR estimates are only available in our database from WRI (Brandon et al., 2025), and these are shown as a histogram in Figure 3.3. Projects are aggregated to the sectoral level within each country studied. EIRR values show a long tail, with most estimates below 30% per year, but larger EIRR values are reported across agriculture, infrastructure, human health and extreme weather. Under these high levels of returns, benefits can exceed costs rapidly. If we assume that benefits begin to accrue in the year after costs are paid – as for a rapidly implemented reactive adaptation project – accumulated benefits are expected to exceed costs after about three years for the median project.

Figure 3.3. Reported ex-ante economic internal rate of return (EIRR), including market and non-market benefits, grouped by sector



Note: Data are from WRI (Brandon et al., 2025).

Differing metrics but a consistent picture

The three adaptation metrics described here differ in scope and emphasis. AER focuses solely on avoided losses, while economic benefit–cost ratio and EIRR explicitly incorporate costs. Economic benefit–cost ratio is tied to a chosen discount rate, whereas EIRR makes the discount rate itself the central outcome. Yet they are also connected: projects with a high AER often also yield strong benefit–cost ratios and EIRRs, and, in most cases, high benefit–cost ratios go hand in hand with high EIRRs. What emerges from the data is a consistent picture: adaptation not only reduces damages to society, but is also a sound economic investment, generating strong returns.

This study does not find evidence that current adaptation options present an unrealistically optimistic view of the returns. To evaluate whether there is a bias in the current evidence base, we compare ‘leading projects’ implemented today, and presumably chosen for their high returns, with estimates of the returns for the total adaptation needs of a country. Statistically significant differences between these two groups are not found for any of these three metrics. This may, however, reflect the use of leading project data to calibrate the returns for total adaptation needs.

Broken down by sectors, high benefit–cost ratios are found for extreme event adaptation and infrastructure adaptation. This aligns with evidence that early warning alerts for extreme events are highly beneficial while being low-cost. Infrastructure improvements provide broad co-benefits to the economy, while also providing high levels of adaptation effectiveness (23% on average).

Table 3.1. Range of estimates from this review for sector-wide adaptation effectiveness ratio, economic benefit–cost ratio and economic internal rate of return

Sector	Adaptation effectiveness ratio		Economic benefit–cost ratio		Economic internal rate of return (%/year)	
Agriculture, forestry, fisheries	0.10 (0.05–0.18)	(*n*=17)	3.2 (2–6)	(*n*=13)	32.2 (28–42)	(*n*=7)
Coastal zones	0.03 (0.02–0.04)	(*n*=5)	3.9 (3–5)	(*n*=2)	N/A	
Extreme weather events	N/A		6.4 (3–13)	(*n*=5)	35 (23–66)	(*n*=4)
Human health	0.14 (0.0–0.33)	(*n*=4)	4.6 (3–15)	(*n*=4)	26 (25–58)	(*n*=3)
Infrastructure	0.23 (0.12–0.38)	(*n*=6)	5 (3–8)	(*n*=18)	23.2 (20–28)	(*n*=11)
Water supply and flood protection	N/A		3.8 (3–5)	(*n*=12)	17.4 (16–21)	(*n*=11)
Miscellaneous	0.17 (0.02–0.61)	(*n*=19)	3.9 (4–5)	(*n*=15	N/A	

Note: Entries are labelled N/A if none of the included syntheses report results for that sector. For each included sector, the median and interquartile range of estimates are shown, across countries and studies. Only entries with multiple estimates are shown. 'n' is the number of estimates, aggregated to the sector–country–study level.

One important fiscal benefit of adaptation identified in the literature review is the reduction in future increases in borrowing costs due to climatic shocks. The connection to fiscal debt risk can start with climate change-induced capital loss and reduced labour productivity. This leads to economic disruption, which reduces tax revenue and increases demand for government expenditure to support recovery (Bernhofen et al., 2024).

The impact of poor macroeconomic performance on the fiscal balance of a country depends on which sectors of the economy are impacted, how much additional public expenditure is needed to address the impacts, how much tax revenue is lost and the government budgeting rules (Bachner et al., 2019). This dual pressure threatens a country's fiscal sustainability and, consequently, its ability to service debt. In turn, the creditworthiness of a country may be undermined, leading to an increase in borrowing costs (Bernhofen et al., 2024). Effective adaptation reduces capital losses and labour productivity declines, helping to break this chain of adverse economic consequences that makes the mobilisation of finance more expensive (Cevik et al., 2022).

In Austria, evidence indicates that publicly funded adaptation can increase tax revenue because the benefits from sustained economic activity outweigh the additional public expenditure for the investment in adaptation (Bachner et al., 2019). The extent to which non-climate-related government expenditure is affected depends on the extent to which tax revenue loss is reduced by adaptation, and whether adaptation investment actually mitigates losses.

Using metrics developed by the Notre Dame Global Adaptation Institute (ND-GAIN), Cevik et al. (2022) find in an econometric study that a 1% increase in climate change vulnerability leads to a 3.1% increase in long-term government bond spreads in emerging market economies, while a 1% increase in climate change resilience reduces bond spreads by 0.75%. Because this value is an econometric calculation, it does not account for the accumulation of climate shocks on sovereign credit ratings over time, so it could be underestimated. For example, if a country with an annual deficit of US$1 billion makes adaptation investments that lead to a 50-basis-point reduction in borrowing costs, this translates to savings of approximately US$5 million annually, or US$150 million over a 30-year period.

Early adoption of adaptation strategies can have a beneficial impact on debt-to-GDP ratios because they enable countries to restore their capital stock more quickly after climate shocks (Catalano et al., 2020). Moreover, they can reduce credit rating downgrades, which also has positive fiscal impacts (Klusak et al., 2023).

Nevertheless, it is important to note that these benefits are often realised in the long term, given that the debt-to-GDP ratio will rise in both the early and late adaptation scenarios because of the higher public expenditure allocated to adaptation (Catalano et al., 2020). In fact, Chamon et al. (2022) estimate that only 21 of 64 low-income countries have fiscal space of more than 20% of their GDP to invest in adaptation without being at high risk of debt distress, according to the IMF–World Bank's debt sustainability framework for low-income countries. Hence, even if adaptation is beneficial, current fiscal deficits can prevent countries from investing in adaptation without coming dangerously close to debt distress.

The financial returns of adaptation strategies are generally lower than the economic returns, which disincentivises investment in adaptation: this represents a further significant challenge beyond fiscal constraints.

One of the main barriers to the private sector investing in adaptation strategies is that the expected financial returns are lower than market benchmarks, largely because adaptation measures produce positive externalities and public goods that cannot be fully captured by private investors. Moreover, returns from anticipatory adaptation are not necessarily observed in the short term (OECD, 2025).

These issues might be more serious in developing countries. Finance may be more difficult and expensive to access for emerging market economies because of their higher capital costs, less developed financial markets, less structured bankable adaptation strategies and higher risk profiles (OECD, 2025; Larsen et al., 2025). These differences in access to capital are not considered in the adaptation analyses, which often assume costless financing.

Wider co-benefits and dividends of adaptation

Beyond avoided losses, some adaptation investments can yield a 'triple dividend' (Surminski et al., 2016). The triple dividend approach evaluates multiple economic outcomes from investing in adaptation:

1. Adaptation prevents loss and damage by protecting economic assets and communities.
2. Increased investment may stimulate economic activity and innovation, often leading to job creation and increased productivity. These kinds of investments provide both an immediate economic return and future resilience.
3. Adaptation projects can sometimes deliver social and environmental co-benefits, such as improved public health and enhanced biodiversity, which further enhance communities' quality of life.

Adaptation does not automatically deliver a triple dividend: this depends on the intervention, and adaptation can also involve trade-offs: for example, increased cooling or flood-prevention infrastructure may lead to increased greenhouse gas emissions or other environmental impacts. In addition, when firms or governments take on debt to finance adaptation solutions, it reduces the net benefits they receive. This highlights that the choice of adaptation intervention is important.

Increasing adaptation investments can also foster a more sustainable and robust socioeconomic fabric. If locally led, it can empower communities through capacity building, enhance adaptive governance and build societal cohesion by promoting shared responses to climate risks. This is particularly true if adaptation strategies are implemented alongside community-empowerment programmes that ensure affected people participate in designing and implementing such measures (Dushkova and Ivlieva, 2024). Popular resistance against adaptation strategies has demonstrated the importance of community engagement in understanding the vulnerabilities that underlie the need for climate adaptation (Vargas-Falla et al., 2024).

The perspective taken here, focusing on the triple dividend, arises from a broad definition of adaptation that overlaps significantly with development, blurring the lines between the dividends of development and those of adaptation. In one sense, development can be defined as the reduction of vulnerability to both climatic and non-climatic risks (Sherman et al., 2016). However, reducing non-climatic risks without considering a changing physical environment is problematic, as strategies may be less effective under changing climatic conditions than they would be in a stable climate (Systemiq, 2025). As a result, adaptation strategies are necessarily entangled with the management of other vulnerabilities and thus with development investment.

There is also increasing recognition that specific targeted adaptation investments may be needed in addition to climate-resilient development. These protect existing development gains, but also run the risk that they reallocate resources away from economic development. This will lead to potential trade-offs, and the appropriate balance of investment will vary with country, risk and time period.

Importantly, too, the distribution of benefits and costs of adaptation can either contribute to or hinder development, depending on how adaptation strategies are implemented, and there is growing evidence of maladaptation presenting risks. When defining adaptation narrowly as only investments addressing future climate change (strict additionality), the 'adaptation deficit', i.e. underinvestment in addressing current climate risks, may exceed the costs of preparing for future climate change (Aligishiev et al., 2022). Since failing to address this deficit undermines future adaptation effectiveness, development needs should be integrated into adaptation strategies through a broader definition of adaptation.

Some analyses, like the World Bank's Country Climate and Development Reports, incorporate scenarios that differ in terms of economic development and compare the outcomes of implementing adaptation strategies or not. In the business-as-usual scenarios, economic growth, adaptation and mitigation policies remain without change. In the aspirational development trajectories, economic growth is fostered, along with infrastructure improvement and social services (Abalo et al., 2025). The comparison of different economic scenarios used in adaptation assessments enables development strategies to be linked to adaptation measures.

Adaptation investments yield returns, particularly when considering the social and environmental co-benefits and opportunities created, although these can be difficult to measure. According to the recent WRI study (Brandon et al., 2025), when considering the triple dividend, co-benefits (i.e. the second and third dividends) exceed avoided losses (i.e. the first dividend) in all sectors of the economy.

The WRI database is based on ex-ante economic cost–benefit analyses of 320 adaptation projects in agriculture, health, infrastructure and water implemented by multilateral development banks and international climate finance institutions, and thus it does not account for benefits or costs that could have been captured in an ex-post evaluation. Additionally, it does not include benefits or costs that were not monetised (though note that the economic framework explicitly captures non-market benefits).

Adaptation strategies generate diverse co-benefits across multiple dimensions. Health benefits arise primarily from infrastructure development related to health service delivery and from nature-based solutions. For instance, in Dhaka, Bangladesh, stormwater management and flood control reduced exposure to water-borne diseases, while green space creation in São Paulo, Brazil, mitigated air pollution (Sharifi, 2021). Environmental co-benefits are also evident: in Lima, Peru, a wastewater recycling project designed to address climate-induced water scarcity simultaneously improved the water quality of rivers previously contaminated by untreated wastewater. Economic co-benefits likewise emerge from adaptation investments. In rural Nigeria and Burkina Faso, soil and water conservation practices reduced poverty levels (Spencer et al., 2017).

These examples show how adaptation can yield high returns from co-benefits. However, some care is needed: adaptation is needed to reduce climate-related impacts, and measures that have a high amount of co-benefits but small avoided losses may not add much to the reduction in risk, leaving high residual impacts and damages. It is also notable that co-benefits would often be obtained even in the absence of climate change, as capital investment would boost economic growth regardless, and nature-based adaptation solutions inherently provide environmental and social co-benefits.

It is also worth noting that many types of benefits accrue directly to individuals. This is the case, for example, for health benefits from reduced indoor temperatures. This raises the challenge of fiscal capture, where investments by governments and firms do not result in higher revenue streams. Where governments can raise taxes or fees for public services to recoup costs, populations will still experience net benefits, as represented by the strong BCR and EIRR metrics above, but the political economy of these higher household costs can be a significant barrier.

The effectiveness of transferring workers to less weather-exposed economic activities as an adaptation strategy, compared with physical adaptation, is uncertain. An example of a development strategy that might not be aligned with adaptation effectiveness is labour reallocation from less productive to more productive sectors. Productivity losses from climate shocks may be offset if capital and labour are reallocated to less weather-exposed activities (World Bank, 2024a). Nevertheless, the evidence is contradictory. Rode et al. (2022) find that under a high-emissions RCP8.5 scenario, climate-driven labour reallocation causes an increase of 0.3 percentage points in labour disutility costs, compared with a scenario with climate change but without climate-driven reallocation.

However, evidence from the Sahel region of Africa suggests that the difference in avoided GDP losses between low-, medium- and high-growth scenarios, which consider a shift in economic activities from agriculture to the industry and services sectors, is not as significant with adaptation. For example, by 2030 in a dry scenario (defined as the 10th percentile of mean precipitation change across SSP3-7.0 and SSP5-8.5), avoided losses in Burkina Faso are expected to be 2.7% of GDP in a low-growth pathway, while in a high-growth pathway they are 2.2% of GDP (World Bank, 2022b).

In Brazil, labour market frictions have reduced the rate of reallocation of workers from agriculture to manufacturing. Instead, two-thirds of displaced workers have either migrated to agricultural and service jobs in other regions or remained locally unemployed or in informal employment (Albert et al., 2024). A quantitative literature review by the World Bank (2024a), based on studies in Ethiopia and China, found that labour reallocation, mostly through migration and off-farm work, only reduces climate losses by 14% on average. Studies on the constraints of spatial and sectoral reallocation are also very limited.

Evidence on air conditioning as an adaptation strategy presents a mixed picture. At the national level, evidence is scarce and inconclusive across different macroeconomic variables, with particularly insufficient data on effectiveness in low-income countries. At the firm level, cooling systems show a medium reduction in asset damage (EDHEC Climate Institute, 2025). The evidence is nuanced when analysing labour market impacts.

In India, air conditioning helped to maintain the same level of output in the manufacturing sector during hot days. However, this was primarily because worker productivity was maintained in a climate-controlled environment (Somanathan et al., 2021). Costa et al. (2024) find that firms in advanced economies in warmer areas tend to experience smaller labour productivity losses arising from extreme temperatures, than similar countries in cooler areas. This is because these warmer countries have adapted to working in higher temperatures. Nevertheless, there are limits to adaptation, as higher temperatures relative to a warmer baseline in the same location still cause significant labour productivity declines. This productivity finding is consistent with evidence from the Democratic Republic of the Congo showing similar gains from cooling systems (World Bank, 2023b).

Adaptation strategies are more effective at reducing climate change damages when greenhouse gas emissions are reduced worldwide. Climate damages are highest when neither adaptation nor mitigation strategies are implemented globally. Damages decrease substantially when either adaptation or mitigation strategies are adopted independently, with both approaches yielding reductions. However, climate damages as a percentage of global GDP are lowest when adaptation and mitigation strategies are combined and implemented simultaneously (Watkiss et al., 2015).

There are abundant opportunities for adaptation, decarbonisation and development to effectively work together by overcoming challenges related to coordination and market dynamics, and thereby crowd in private finance. For example, Brazil is showing that investing in nature-based solutions offers a sustainable and fiscally beneficial approach for countries to enhance climate resilience and economic growth by integrating ecosystem management with development strategies (see Box 3.2).

Box 3.2. Brazil case study

Nature-based solutions and the potential to achieve economic development alongside climate change mitigation and adaptation

Brazil faces significant climate risks to agricultural production. Agriculture, forestry and fishing account for about 6% of Brazil's GDP. As a major exporter of agricultural products, these impacts are felt globally. For example, Brazil grows 40% of the world's coffee and droughts in 2014–2016 that reduced yields by 10–15% increased global prices for coffee by 50% (Nestlé, 2019).

As temperatures climb, the risk of extreme events impacting people and ecosystems increases. By 2050, 93% of Brazil's population will be at risk from heatwaves (Quiggin et al., 2021). If higher temperatures instigate the die-back of the Amazon Rainforest, it could cost Brazil 10% of its GDP by 2050 and unleash hundreds of gigatons of CO_2 into the atmosphere, with serious global implications (World Bank, 2023d).

Conversely, better ecosystem management has the potential to support strategic goals. By maintaining natural capital and ecosystem services, healthier environments can further economic development. By reducing land use change and reversing the loss of carbon stocks, protected ecosystems can reduce greenhouse emissions. Under the rubric of 'nature-based solutions' (NbS), ecosystem management can also provide adaptation benefits. Brazil provides a good case study for the potential of investing in NbS, with a history of success across its agricultural sector and broader economy.

For example, reduced deforestation can drive a virtuous cycle of agricultural productivity. Since 2023, Brazil has been investing over R$1 billion in the **restoration of the Amazon Rainforest on private land**, as exemplified by the National Plan for the Recovery of Native Vegetation

(Planaveg) and Restoration Arc, managed by the Brazilian Development Bank, BNDES. While deforestation reduces rainfall over large areas and leads to erosion, maintaining forest stands also provides benefits outside these areas (Leite-Filho et al., 2021). Higher rainfall results in higher yields for farmers and less risk (Dos Santos et al., 2024). In the southern Amazon, reducing deforestation rates has increased agricultural productivity by up to US$1 billion per year (Leite-Filho et al., 2021).

Financial incentives can lead to necessary behaviour changes. **Making rural credit conditional on land use practices that preserve forests** produces significant reductions in deforestation rates (Assunção et al., 2020). Brazil invests 0.5% of GDP in this kind of financial support, one of the highest percentages in South America. As a likely result, it has the lowest level of crop vulnerability to droughts on the continent (Caucheteux et al., 2024). Brazil also has a long history of providing market support to coffee farmers in periods of volatility and investing in capital for coffee farmers. This has contributed to it having one of the highest coffee productivity levels in the world (Sachs et al., 2019).

The **Brazilian Agricultural Policy for Climate Adaptation and Low Carbon Emission (ABC+)** serves as a transformative framework that underscores the nation's commitment to sustainable agriculture through NbS. By promoting practices such as agroforestry, crop–livestock integration and enhanced soil management, ABC+ seeks to mitigate greenhouse gas emissions while increasing carbon sequestration in agricultural landscapes. This initiative not only addresses climate resilience and adaptation for farmers but also fosters biodiversity and restores ecosystem integrity across Brazil's diverse biomes. ABC+ represents a strategic investment in the future of agriculture that harmonises economic growth with environmental stewardship, ultimately leading to long-term benefits for both rural communities and the wider economy.

NbS are also relevant for **energy infrastructure, cities and industry**. The Itaipú dam, the third largest hydropower dam in the world, uses NbS to protect its critical infrastructure and enhance environmental resilience. After the planting of more than 44 million trees and the restoration of 421 watersheds in the vicinity, the region has seen improvements in water quality and reduced sedimentation, as well as improved operational efficiency for the dam in the face of extreme weather (Rycerz et al., 2020).

In Campinas, the Municipal Green Plan (PMV) guides the integration of NbS into urban planning, addressing urban challenges exacerbated by climate change, such as frequent flooding and a reduction in green space. Notably, the establishment of ecological corridors and linear parks aims to mitigate these issues by enhancing biodiversity, improving air quality and providing socioeconomic benefits such as recreation and tourism. A key component of Campinas's strategy is the regional Connectivity Area, fostering biodiversity conservation and ecosystem service provision across the Metropolitan Region of Campinas. The strategies employed not only align with sustainability goals but serve as scalable models for effective urban governance in other Brazilian cities, illustrating potential pathways for investment that align with economic and environmental priorities (Seleguim et al., 2024).

NbS also present a significant opportunity to **bolster economic resilience and sustainability**, particularly amid the increasing hydrological volatility driven by climate change. In Brazil, strategic investments in NbS can counteract substantial economic losses associated with drought conditions.

For example, NbS applied to the São Paulo Cantareira water supply system are projected to have benefits totalling R$443.9 million in avoided losses for the severe 2014–2015 drought. This represents a 28% reduction in the total economic cost of drought for the industrial and water sectors. Accounting for both increased water supply and reduced social costs associated with carbon sequestration, the net present value of this intervention would be R$632 million (Ciasca et al., 2023).

Since 2023, Brazil has invested over R$23 million in green urban infrastructure projects based on NbS through national programmes such as the Resilient Green Cities Program (PCVR) and Resilient Green Peripheries, with more than 20 cities participating. Currently, over R$3 billion is being raised for the implementation of local projects in NbS through the Brazilian Climate Fund, with the start date scheduled for 2026.

In the regulatory field, the Brazilian Ministry of the Environment created an advisory working group to develop the national NbS strategy (GT-ENSBN, 2025) with the aim of developing a proposed legal framework to support local governments to implement NbS, by facilitating financing and capacity-building; the objective is to transform environmental challenges into socioeconomic opportunities.

For Ministries of Finance, these examples underscore a viable pathway not only to avert future economic disruptions, but also facilitate sustainable long-term growth that harmonises environmental restoration with economic development strategies. The integration of NbS could thus be a crucial component of national planning, promoting fiscal stability through enhanced natural capital and reduced reliance on costly engineering-based solutions.

The IPCC frames 'climate-resilient development' as the joint pursuit of adaptation and decreasing risk to advance sustainable development for all, highlighting that resilience policies enhance human well-being, equity and long-run growth when embedded in core development planning. In other words, building resilience is not a parallel agenda: it is a pathway to achieve development outcomes more reliably under a changing climate (IPCC, 2022; Schipper et al., 2022). Kenya's experience, described in Box 3.3, highlights that climate resilience can be enhanced by investing strategically in tailored support for vulnerable agricultural and pastoral communities, strengthening local capacities for emergency preparedness and institutionalising climate-related spending to balance fiscal sustainability with effective responses to climate impacts.

Box 3.3. Kenya case study

The development–adaptation link: identifying private household resilience to guide 'easy win' entry points for public investment in climate resilience

This case study is based on an analysis performed for this report of World Bank household surveys carried out in Kenya during the period 2019 to 2022 to assess climate hazard impacts driven by the Indian Ocean Dipole (IOD), a climate pattern affecting the Indian Ocean, and household coping mechanisms. However, the goal of this summary box is to guide investment priorities for greater resilience to climate shocks in general. Global evidence shows that climate shocks push households into poverty and keep them there by destroying assets, disrupting services and markets, and eroding human capital; hence, disaster risk management is inseparable from poverty reduction (Hallegatte et al., 2017; IPCC, 2022).

Investment requirements to boost resilience

The 2019 'positive IOD' (pIOD)[6] exposed Kenya's agricultural sector to multiple climate hazards, causing flood-damaged infrastructure, disrupted markets and reduced yields, at the same time as an outbreak of locusts harmed crops and grazing lands, worsened by pesticide shortages and unsafe control practices.

The preliminary results from the analysis of the World Bank household surveys indicates that exposure to these hazards is shaped by livelihood, crop choice and infrastructure. Vulnerability is in part driven by local government budgets, preparedness, wealth and income diversity.

[6] NASA describes the India Ocean Dipole as follows: "During a positive phase, warm waters are pushed to the Western part of the Indian Ocean, while cold deep waters are brought up to the surface in the Eastern Indian Ocean. This pattern is reversed during the negative phase of the IOD." See https://sealevel.jpl.nasa.gov/data/vital-signs/indian-ocean-dipole/.

Wealth enables post-shock recovery and diversification of income sources to smooth out shocks, while weak government budgets limit safety net capacity. Social safety nets can help but are often underfunded. Pre-existing poverty forces otherwise self-sufficient households to buy food when harvests fail.

The analysis of the household surveys demonstrates that farm size is the strongest predictor of earnings, followed by household size and housing quality. Access to fertiliser and credit boosts incomes, while reliance on informal loans often signals distress.

The analysis also highlights the synergistic nature of development and resilience. Farmers appear to benefit most from access to land, fertiliser and formal finance, while pastoralist incomes depend on credit and government assistance. Building resilience requires crop- and livelihood-specific interventions, better credit and input access, stronger safety nets and sustainable budget frameworks. Because shocks induce poverty traps through asset loss and costly coping mechanisms, investments that protect assets and services, alongside targeted social protection, accelerate income diversification and structural transformation – objectives at the core of both development and resilience goals (Hallegatte et al., 2017; IPCC, 2022).

To reduce the fiscal burden and strengthen resilience, investments must address the hazard, vulnerability and response determinants of climate shocks. Resilient infrastructure – such as irrigation, flood-safe rural roads and reliable electricity infrastructure – raises farm and non-farm productivity by improving market access and reducing downtime. In addition to assets, reliable services are critically important for development because service interruptions impose large output and welfare losses on firms and households. Hence, resilience upgrades crowd in private investment by lowering risk and transaction costs (Hallegatte et al., 2019).

The Kenyan Treasury highlights that the Financing Locally-Led Climate Action (FLLoCA) programme, implemented across 78% of Kenya's wards, has created more than 85,000 jobs (with youths accounting for 44% of these), and supported more than 2,245 sub-projects, more than 1,570 of which are already implemented. The sectoral distribution of FLLoCA investments – to water (47%), the environment (25%), agriculture (22%) and other sectors (6%) – shows a strong emphasis on adaptation and a balanced approach to climate resilience programming. FLLoCA demonstrates how local ownership and vertical coordination between national and county governments can enhance adaptation outcomes and accountability.

Burdens on the public budget resulting from complex climate risk

Climate shocks generate macro-fiscal risks, diverting budgets from growth-enhancing investments in health, education and road systems to emergency responses, slowing down development. The World Bank's *Lifelines* report finds that resilient infrastructure and services protect firms' and households' productivity, with estimated net benefits of US$4.2 trillion in low- and middle-income countries over the lifetime of new infrastructure (around US$4 return per $1 invested), by avoiding service disruptions that depress output and welfare (Hallegatte et al., 2019).

Scaling up Kenya's public programmes has been vital to mitigating the impacts of climate shocks, given that vulnerable groups already facing undernutrition, disease and food price volatility are often hit the hardest (Serdeczny et al., 2017). However, this also creates fiscal pressure. The analysis performed for this report showed that domestic expenditure in the form of public government aid programmes rose more than 40-fold after the 2019 pIOD-driven climate shocks. The spending increases were driven by expanded coverage of social protection schemes rather than larger transfers. From 2019 to 2022, average benefits per household stayed between 2,100 and 3,400 Ksh, while coverage rose from less than 1% to 11% before dipping to 9%. Government financial support per 100 households peaked at nearly 28,000 Ksh before contracting, reflecting both welfare gains and fiscal risks; the risks include less finance available for health, education and infrastructure and increased public debt.

Kenyan Treasury officials note that while coverage of climate-related aid spending has expanded significantly, the government is working towards institutionalising this spending through budget tagging and tracking systems to improve efficiency, transparency and accountability.

Evaluations of Kenya's Hunger Safety Net Programme (HSNP) show that predictable cash transfers and emergency scale-ups during climate shocks stabilise consumption, enhance people's ability to cope and protect minimal assets – effects that preserve human capital and productive potential. While most resources from this programme are designed to meet immediate need (though it also directs long-term investment to the very poorest people), the development payoff comes from avoiding irreversible losses, such as from distress sales and school dropouts (Merttens et al., 2017).

Additional benefits from investments

Investing in climate resilience for Kenyan agricultural households provides benefits beyond fiscal savings, including avoided losses and co-benefits in the form of food security and welfare, while embedding gender equality and social inclusion through flagship programmes like FLLoCA. Expanding adaptive credit and safety nets reduces reliance on loans and child labour while stabilising welfare. The Kenyan Treasury stresses that fiscal decision-making is increasingly considering cost-effectiveness and long-term savings from disaster risk reduction.

Investing in adaptation: costs

Some adaptation metrics, such as economic benefit–cost ratios, combine costs and benefits to consider the net effect. In this section we offer some insights from the literature considering the costs in particular.

Analysis in UNEP's 2025 *Adaptation Gap Report* estimated the potential costs of adaptation in developing countries using two approaches: on the one hand, based on incremental modelled costs, and secondly, comparing these to the estimates presented in nationally determined contributions (NDCs) and national adaptation plan (NAPs). The resulting cost estimates were then extrapolated to all developing countries. These two approaches led to an indicative central range of adaptation cost estimates of US$310 to 365 billion/year by 2035 (UNEP, 2025), though there is a very large range around these central estimates. Mechanisms for financing adaptation are a core issue, as non-concessional loans have increased as a share of international adaptation finance, raising these costs further.

These adaptation costs are projected to increase significantly by 2050 (UNEP, 2023; Chapagain et al., 2020). While low-income and lower-middle-income countries have lower absolute adaptation costs (in US$) than upper-middle and high-income countries, their adaptation finance needs constitute a higher share of GDP (Brandon et al., 2025). Agrawala et al. (2010) found the same results when comparing Sub-Saharan Africa and India/Indian subcontinent with China and the US.

While the benefits of adaptation are clear, securing the fiscal space needed to finance adaptation can be a challenge. The World Bank (2024h) provides a case study of benefits and financing options for Caribbean states, highlighting trade-offs between immediate and long-term gains, the management of debt-to-GDP ratios, and the role of the private sector.

Adaptation also requires public planning. Since many of the most effective adaptation strategies are public goods (or quasi-public goods), their associated costs cannot be met by individual firms or households. The adaptation effectiveness ratio of public goods such as transport infrastructure, health system interventions and large-scale irrigation projects is 0.64, which is the highest out of all the strategies considered (World Bank, 2024a). Furthermore, some studies project that adaptation costs will rise as a percentage of GDP over time, especially for capital-intensive investments, making early investments with long-term benefits a crucial component of effective adaptation strategies (Agrawala et al., 2010).

Adaptation costs are lower when there is more mitigation at a worldwide level. Several studies provide the evidence for this. By 2050, adaptation costs for developing countries are estimated to comprise 0.27–0.89% of GDP in a high-emissions scenario, while in a low-emissions scenario they comprise 0.11–0.35% of GDP (Chapagain et al., 2020). Similarly, by 2100, adaptation costs in a below 2°C scenario were estimated to represent less than 1% of global GDP, whereas in a 3°C scenario they were estimated to reach 4% (WEF, 2024). Including both investment and residual damage costs, Dietz et al. (2022) estimate that under the high-emissions RCP8.5 scenario total global costs in 2050 will amount to US$24 billion, whereas under the stringent-policies RCP2.6 scenario total global costs will reach US$9.8 billion. These latter estimates are based on the damages caused by Arctic ice melt and on the implementation of adaptation measures such as coastal protection and household relocation.

Economy-wide adaptation: benefits

This section combines the evidence for sectoral adaptation to produce an economy-wide adaptation picture. As in previous sections, we consider a broad range of economic benefits from adaptation, rather than only direct financial benefits. As a result, at the economy-wide level, the full benefit of adaptation investments does not equate to increases in GDP. Non-market benefits, such as longer, healthier lives, contribute to economy-wide welfare, but may not have clear macroeconomic or fiscal effects. At the same time, we include indirect benefits of adaptation where possible, and some indirect benefits may contribute significantly to GDP growth (such as increased public investment).

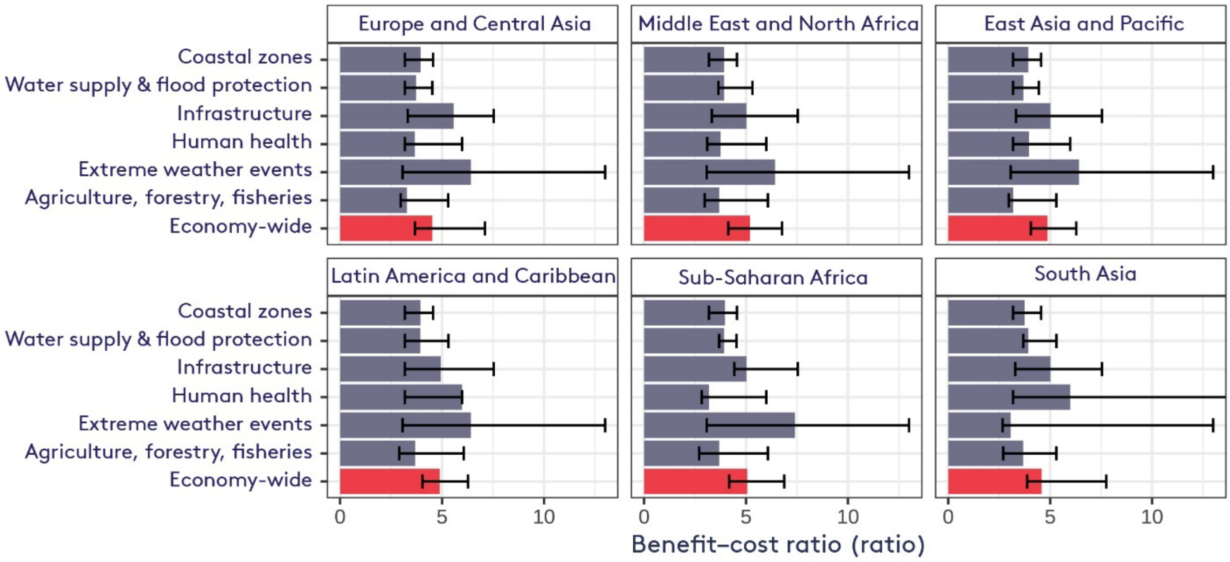
We construct economy-wide economic benefit–cost ratios for developing countries by aggregating across the sectoral benefit–cost ratios described in previous sections. This is possible because total adaptation investment needs – annual adaptation investment costs – are available from UNEP (2025), broken down by sector and region. Economy-wide economic benefit–cost ratios can be estimated by weighting these sectoral benefit–cost ratios by the needed investment levels. We use benefit-cost ratios specific to each region, where available (see Figure 3.4).

This figure illustrates that most benefit–cost ratios are relatively consistent, although there are notable outliers. For example, adaptation strategies focused on extreme weather events in Sub-Saharan Africa showcase exceptionally high benefit–cost ratios, indicating the pressing need for targeted action in this region. Conversely, the infrastructure adaptation benefit–cost ratios in developing countries in the wider Europe and Central Asia region exhibit a higher uncertainty range, underscoring the necessity for careful evaluation and planning.

Economy-wide estimates of benefit–cost ratios, indicative of the aggregate benefits across all required adaptation costs, hover around 4:1. This is an indicator that adaptation investments, when scaled-up appropriately, can yield substantial economic returns. It is important to note that these estimates are predicated on the assumption that future projects will maintain similar benefit–cost ratios to those observed historically.

This study attempts to test this hypothesis by identifying whether each benefit–cost ratio estimate is based on ex-ante modelling or ex-post analysis. It does not find statistically significant differences in the adaptation metrics for these two sets of assessments, although there is a shortage of ex-post data and more evidence is needed to test how robust this finding is across sectors and geographical regions.

Figure 3.4. Sectoral and economy-wide benefit–cost ratios in developing countries, by region



Notes: Estimates are based on studies within each region, where available. Economy-wide estimates (shown in red bars) combine benefit–cost ratios according to the sector-specific cost needs of each country. The adaptation costs, used to weight the benefit–cost ratios, are from UNEP (2025), but only for non-Annex I countries. The human health 75th percentile for South Asia is 40, based on available studies, but clipped for clarity of the other estimates. Note that countries only include developing countries, as defined non-Annex I countries under the UNFCCC.

Based on data from the UNEP Adaptation Gap Report (UNEP, 2025).

Adaptation investments must be tailored to specific contexts but also offer significant benefits on a national scale, supporting a country's economic objectives and enhancing fiscal health. The diverse nature of climate impacts and socioeconomic conditions across different regions necessitates customised adaptation strategies that consider local needs and priorities.

The process of assessing and addressing physical risks and adaptation strategies must be iterative. This means that physical risks must be assessed before and after adaptation strategies are implemented to calculate their impact. Adaptation strategies are also selected based on how physical impacts vary. In this sense, adaptation management is iterative, interconnected and dynamic (Surminski et al., 2025).

Alternatives to GDP should be considered in the context of quantifying and considering adaptation financing and investment. GDP is an inherently limited metric, and several avenues are being pursued to offer additional high-quality measures. For example, comprehensive wealth includes human-made capital, human capital (e.g. health, education), and natural capital (renewable and non-renewable). Such capital-based measures are a better basis for long-term sustainability and welfare (World Bank, 2024e). Similarly, Gross Ecosystem/Environmental Product (GEP) captures the value of ecosystem services, which are crucial to economic productivity but poorly captured by GDP. Updates to international standards of national accounts are mainstreaming some of this monitoring.

Research gaps

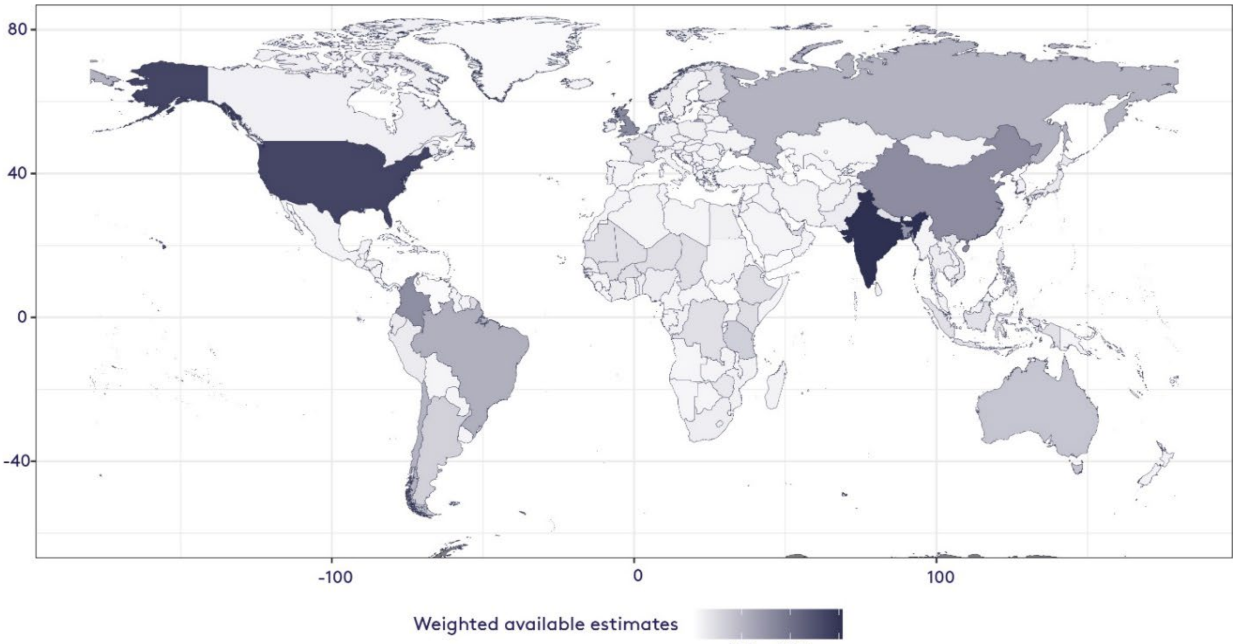
There is a need for much greater evidence on the effectiveness, applicability and benefits of adaptation. In addition, much greater coverage of sectors is needed for risks and adaptation. Further, more ex-post analysis is needed, to record observed outcomes and costs, and this also needs to take account of projects' locations and site specificity. In fact, three-quarters of the available evidence in our database is from ex-ante studies. These likely miss both important costs and benefits. As a result, comprehensive evaluations after projects have been fully implemented should be prioritised for further study. With this evidence in hand, it will be possible to better understand how the value of adaptation varies across contexts.

There is also a need for more evidence on anticipatory adaptation. This includes specific analysis from extended cost–benefit analysis studies and the literature on decision-making under uncertainty.

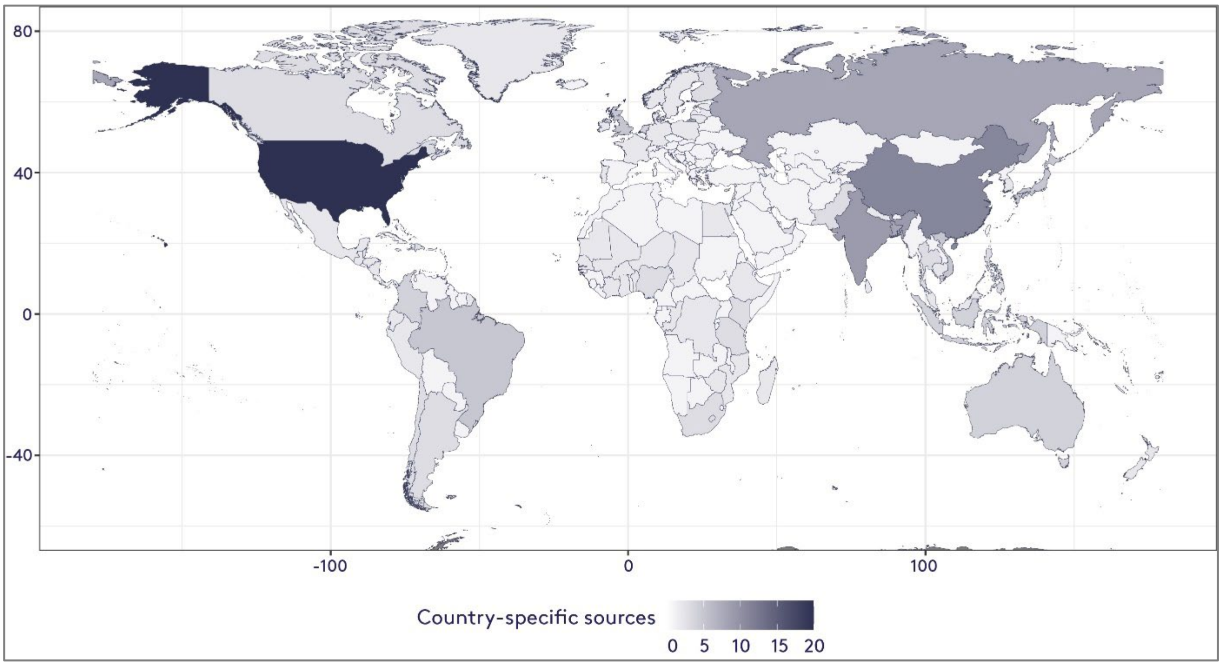
While the evidence on adaptation collected here is global, large countries – in particular the US, China, India and Brazil – have generated vastly more estimates, as shown in Figure 3.5.

Figure 3.5. Global distribution of available adaptation estimates, across all adaptation measures

a) Number of estimates related to adaptation benefits, by country



b) Number of sources providing country-specific values, by country



Note: For estimates applied uniformly to many countries, the estimate count is evenly divided across countries. Analysed from the full reviewed dataset (see Appendix A.7).

Clear gaps are present in the component adaptation costs and benefits used to calculate the measures used above. Many adaptation cost estimates are based on 'engineering' estimates that solely consider building costs. However, the full economic cost of adaptation includes other impacts on welfare. For example, if an adaptation practice requires labour reallocation costs, which is a common adaptation strategy adopted by households, this imposes additional costs on them. Frictions in the labour market have not been properly quantified in the context of adaptation and this could also add costs to this strategy commonly adopted by households. Costs for households also have direct implications for the full implementation costs for governments, since these can require coordination, incentives and financial support.

Non-monetary costs, such as social and cultural impacts, must be acknowledged and integrated to present a holistic evaluation of adaptation strategies. On the other hand, residual damage costs should also be incorporated in the benefit–cost ratios of adaptation strategies being evaluated. Of the 22 studies quantitatively synthesised, only four included residual economic damages after implementing adaptation strategies in addition to the financial costs of adaptation investments.

Adaptation benefits are also incompletely measured. For example, the methodology used to measure adaptation benefits on firms' net asset value in the literature reviewed (EDHEC Climate Institute, 2025) is mostly descriptive, and the climate change scenarios are not clearly defined. The financial benefits of adaptation for firms should be calculated using more rigorous methods.

Moreover, the quantification of labour reallocation, both as an adaptation strategy and as a consequence of adaptation, is limited. This gap is significant given that labour reallocation represents a common reactive household adaptation strategy (World Bank, 2024a).

Most studies that perform a selection of adaptation strategies do so based on maximising the discounted sum of net benefits, rather than accounting for planning processes, budget constraints and future uncertainty. Given that Ministries of Finance have limited resources, the impact of different levels of adaptation strategies on macroeconomic variables could be studied in greater depth, as this has only been addressed in a few of the studies reviewed. Moreover, only one study (Agrawala et al., 2010) examined the difference between early stock capital adaptation and reactive flow capital adaptation. Adaptation strategies related to fiscal adjustments, changes in household savings and firm investments need to be studied in greater detail. Bakkensen and Barrage (2025) provide a useful example of how to incorporate these macroeconomic adaptation strategies into climate change adaptation analysis. Moreover, other behavioural adaptation strategies, such as changes in working hours to avoid productivity losses, could also be incorporated into the analyses. Costa et al. (2016) measure the effectiveness of changing working hours in three different cities and find that this action can reduce productivity losses in some scenarios when there is heat stress. Day et al. (2019) also highlight that behavioural changes can have a higher systemic impact than cooling systems.

4. A call for action on adaptation investment

Adaptation is a vital component of the response to the challenges of climate change. While mitigation efforts aim to reduce greenhouse gas emissions, adaptation focuses on minimising the vulnerabilities and risks associated with climate impacts. Both of these are needed and adaptation investments are more effective, and less costly, when they are made alongside global mitigation action. Adaptation and mitigation can often work together, allowing us to confront the immediate and evolving challenges posed by a warming world.

There are many complementary motivations for investing in adaptation. It is not only critical for safeguarding human health, infrastructure and economic stability, but also for protecting natural capital, which serves as a necessary input for economic growth.

Adaptation projects are necessarily context-specific because of the diverse array of local environmental, social and economic conditions they are embedded within, and the variation in hazard, exposure and vulnerability. The design and implementation of adaptation measures must be tailored to the unique needs and capacities of each case. By focusing on both the national level and individual project interventions, this report emphasises the importance of national publicly-funded action, but this goes hand in hand with privately-funded and local action.

Importantly, not all adaptation measures require significant financial investment. Much can be gained by embedding adaptation strategies into existing decision-making processes. By integrating climate considerations into urban planning and infrastructure development at the design stage, it is possible to improve resilience at a fraction of the cost of retrofitting adaptation later (Hallegatte et al., 2019). For instance, Surminski et al. (2025) highlight the significance of incorporating adaptive planning in policymaking, which can yield substantial dividends by pre-emptively addressing risks.

Part of the policy challenge is to ensure that short-term decisions include long-term thinking aimed at recognising path dependences and avoiding 'locking-in' increasing exposure and vulnerability.[7] In this sense, there is a need to recognise the importance not just of post-disaster recovery but also proactive risk management (Surminski et al., 2025). Decisions made today have implications for decades to come in terms of both future risk levels and future adaptation opportunities. Where and how we choose to build infrastructure will shape vulnerability and resilience patterns for much of this century. Hence, proactive and strategic planning is essential to avoid costly missteps and enhance adaptive capacity.

From an economic standpoint, investing in adaptation is not merely a defensive strategy but is supported by a robust rationale. The costs resulting from inaction or delayed response are likely to be greater than proactive adaptation investments. This economic perspective is rooted in a compelling body of evidence and is underpinned by the quantitative insights identified throughout this report. By acting decisively now, we not only reduce future risks but also catalyse economic benefits, enhance societal well-being and promote sustainable development.

The economic case for adaptation

Investing in targeted climate adaptation is a strategic economic decision with far-reaching implications. A robust economic case for adaptation can be built on multiple lines of argument, including immediate and future benefits and co-benefits, as well as opportunities for investment.

Reducing the size of the gap between current adaptation needs and actions makes economic sense, even given uncertainty over global climate change mitigation efforts. This is explored with a stylised but informative analysis in Appendix A.6.3 to assess potential adaptation strategies. The

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[7] Watkiss and Betts (2021) define lock-in as, "Early actions or decisions that involve long lifetimes or path dependency, which will potentially increase future risk or vulnerability and that are difficult or costly to reverse later (quasi-irreversibility). This can be from an action or decision that is 'business-as-usual', from a lack of an action or decision, or from a mal-adaptative action or decision."

analysis compares a proactive adaptation strategy against a 'wait-and-see' strategy under uncertainty about how bad the impacts of climate change might turn out to be. Embedding adaptation into economic decision-making now is likely to yield the greatest benefits, compared with delay. The significant co-benefits associated with adaptation investments make proactive adaptation the most cost-effective strategy. Even excluding co-benefits, principles of decision-making under uncertainty support the proactive adaptation strategy, as it allows benefits to be realised earlier.

The economic returns on adaptation investments can be realised in both the short and long term. Some of the immediate benefits might be avoided damages from climate-related disasters, such as flooding or heatwaves, which can have direct economic implications. For example, proactive investments in protective infrastructure can significantly reduce the economic burden associated with disaster response and recovery.

This report shows that the long-term benefits of adaptation are likely to outweigh the upfront costs. By fostering resilience today, we can reduce future vulnerabilities and the associated economic risk. As empirical evidence shows, strategic investments in adaptation yield positive net present values, protecting economies from the escalating costs of climate change impacts and promoting sustainable development and growth.

Despite the clear economic rationale for adaptation, several challenges and barriers continue to impede private and public investment in it. These include coordination challenges across sectors, a lack of understanding regarding the quantification of risks and insufficient metrics to measure the impacts of adaptation efforts. Moreover, many adaptation interventions may not generate immediate financial returns, leading to hesitancy from decision-makers who are focused on short-term economic indicators.

To overcome these barriers, it is essential to enhance collaboration between economic actors, improve risk assessment methodologies and develop clear frameworks for measuring the economic benefits of adaptation. Ministries of Finance have an important role in driving this work forward – and through the actions they take, improving advocacy for, and allocation of resources towards, adaptation initiatives.

There are, however, some easy wins – or low-regret adaptation strategies – that offer clear, immediate economic benefits while minimising risks. These include measures such as disaster preparedness, urban greening initiatives and resilient agricultural practices. Many of these strategies require modest upfront investment while producing tangible benefits such as increased agricultural productivity, improved air and water quality, and strengthened community resilience.

Focusing on these low-regret options not only boosts immediate resilience but also lays the groundwork for more comprehensive and ambitious adaptation efforts in the future. By prioritising these strategies, Ministries of Finance and other economic actors can catalyse momentum towards a more resilient and sustainable economy, showcasing the transformative potential of strategic adaptation investments.

Finally, adaptation strategies should not only focus on new investments but also critically evaluate current spending patterns. Reallocating existing funds from subsidies that inadvertently promote unsustainable practices – such as construction in flood zones, excessive use of fertilisers and unfettered energy consumption – can enhance resilience. These subsidies often encourage risk-taking and environmental degradation, undermining long-term adaptation goals. By redirecting financial resources towards sustainable and adaptive measures, we not only address current vulnerabilities but set the foundation for resilient and environmentally sound economic growth. An example of this kind of action from the UK is described in Box 4.1.

While this report has focused on the benefits of domestic adaptation, the evidence also clearly points to the returns on investments in adaptation and resilience overseas, particularly in lower-income countries. In addition to the benefits to the country receiving the investments, there are returns for investors as well. For instance, it is more cost-effective to invest in adaptation measures that reduce loss and damage in lower-income countries than to provide emergency aid after weather-related disasters made more frequent and intense by climate change. Investments in resilience also counter the potential for rising political instability and conflict in vulnerable countries, and can thus contribute to reducing flows of refugees and migrants escaping climate change impacts. They can also help to protect global supply chains, enhancing the security of food and other essential goods and services. For these reasons, investments in adaptation and resilience overseas can be viewed as based on 'enlightened self-interest'.

Box 4.1. UK case study

Government has a critical role in resolving market failures and implementing enabling factors to manage macroeconomic and fiscal risks through adaptation

The UK government is playing a role in addressing the complex barriers that hinder effective climate adaptation. These barriers include a range of market failures – such as information failures, asymmetries and unpriced externalities (Pauw et al., 2021) – as well as policy and coordination failures (Frontier Economics, 2022).

Adaptation is also constrained by the site- and context-specific nature of climate impacts, the inherent complexity of socio-ecological systems, and high levels of uncertainty surrounding future risks. While much of the attention to date has focused on project- and programme-level barriers, many of these challenges are equally relevant to macroeconomic and fiscal policy, where climate risks can have systemic implications.

Recognising these challenges, the UK government is addressing market and policy failures proactively and providing the enabling conditions – through policy, planning and regulation – necessary for effective adaptation. Several examples of good practice illustrate how the UK has sought to integrate adaptation considerations into its broader economic and fiscal governance.

A major focus of government intervention has been tackling information failures. Over the past two decades, the UK has developed and improved its national climate projections – with important stages in 2001, 2008 and 2018 – providing a suite of advanced information tools such as downscaled projections and weather generators (e.g. see UK Climate Projections 2018 [UKCP18]). These tools enhance analytical consistency and support evidence-based decision-making across sectors.

The legally mandated Climate Change Risk Assessment (CCRA) for the UK, undertaken every five years, complements these projections. This provides a detailed analysis of current and future risks and directly informs the National Adaptation Programme (NAP) for England and equivalent programmes by the devolved administrations. Importantly, the assessment forthcoming at the time of writing (the CCRA4 technical report, to be published in 2026) has expanded its scope to include analysis of macroeconomic and fiscal risks, marking a significant step towards integrating climate adaptation into national economic planning.

In parallel, the UK has introduced mandatory climate-related financial disclosures for publicly listed and large private companies (BEIS, 2023), along with supervisory expectations for banks and insurers (PRA, 2024). These measures are designed to improve transparency and ensure that financial markets price climate risks more accurately.

The government has also acted to address market failures associated with public goods and externalities. Many adaptation measures generate societal benefits – such as enhanced flood protection or ecosystem resilience – that are not reflected in market prices. These can be addressed with policy reform. For example, to correct these imbalances, the UK has begun shifting from traditional agricultural production subsidies to payments for public goods, thereby incentivising adaptation actions that produce positive externalities; the use of on-farm natural flood management measures, which reduce downstream flooding, is now supported through such schemes (Defra, 2023a).

Efforts have also been made to **reduce policy and coordination failures**. Each of the more than 50 priority climate risks identified in the CCRA has been assigned to a specific government department or ministry as a designated 'risk owner', to ensure clear accountability (Defra, 2023b). Cross-governmental coordination mechanisms further support multi-sectoral adaptation solutions. Climate risk is now increasingly mainstreamed across economic, fiscal and financial planning processes. This is not only seen within government departments – where, for example, there is supplementary guidance on including climate change in government economic appraisals (Defra, 2025) – but also within the UK's independent fiscal institutions. For example, the Office for Budget Responsibility has incorporated climate risks and adaptation considerations into its fiscal risk statements since 2024 (OBR, 2025).

The government has introduced **policy and regulatory reforms to strengthen enabling conditions for adaptation**. Recent updates to building codes for new residential developments, for example, require features such as passive ventilation to improve resilience to future heat risks. Similarly, economic regulators have been instrumental in ensuring that climate change is systematically addressed within regulated sectors. The water regulator, Ofwat, authorised climate resilience investments by private water companies as part of its latest five-year price review (Ofwat, 2024), ensuring a balance between water supply and demand under changing climatic conditions. It introduced resilience standards that companies are required to meet (Ofwat, 2025). Furthermore, innovative regulatory mechanisms – such as payment for ecosystem services and public–private partnerships – are being piloted to support adaptation initiatives, including flood protection.

However, while progress on delivering adaptation – as set out above – has been made, **gaps exist, and greater ambition is needed to tackle coming risks**. This has been identified by the independent Climate Change Committee (2025), which has a formal role in scrutinising progress on climate change. Other gaps include the need for strategic analysis at the sectoral and regional level, including the case for adaptation investment, as well as developing the rationale for intervention on a distributional basis, to avoid exacerbating inequality.

Finally, there is growing recognition within the UK that **further government intervention may be needed to address residual market imperfections** that distort private adaptation decisions. At the same time, there is an emerging opportunity for the government to foster new markets for adaptation goods and services, not only to strengthen domestic resilience but also to position the UK as an exporter of adaptation expertise and technology on the international stage.

In sum, the UK's experience demonstrates that government action is essential to overcome systemic barriers to climate adaptation. Through a combination of regulatory frameworks, fiscal planning, market-based instruments and information provision, the UK is embedding adaptation within its macroeconomic and fiscal policy landscape, and starting to see progress on implementation, though action needs to be scaled up to address increasing risks.

Narrowing the gap in adaptation provision

To narrow existing adaptation gaps requires a multi-faceted approach informed by good governance, policy-first frameworks, effective collaboration between the public and private sectors, and a commitment to decision-making under uncertainty with forward-looking approaches.

Effective governance is crucial for driving successful adaptation initiatives. A policy-first approach ensures that adaptation measures are systematically integrated into national strategies and local practices (Surminski et al., 2025). This entails the creation of an enabling environment for sustainable investment, the establishment of clear leadership structures and the fostering of stakeholder engagement to ensure that adaptation efforts are responsive to local needs and priorities.

Balancing the roles of the public and private sectors is essential in addressing adaptation gaps effectively (Watkiss et al., 2025). Public institutions are responsible for creating regulatory frameworks and providing infrastructural support, in addition to delivering public goods. The private sector has multiple roles, including financing (providing the upfront finance for adaptation, for both the public and private sectors); delivering adaptation goods and services; and addressing their own needs (adapting their own assets and supply chains). They have a key role in innovation, investment and efficiency to adaptation efforts, for both publicly- and privately-funded adaptation.

Collaboration is key; by leveraging the strengths of both sectors, it is possible to maximise resources, mitigate risks and drive down adaptation costs. Blended finance can help in overcoming barriers to private investment, while public–private partnerships can amplify the impact of investments, enhance knowledge sharing and foster community engagement to build a more resilient future.

Government support is often needed to resolve market failures and achieve full adaptation benefits. Public support can catalyse investments where private sector participation is insufficient or where externalities dissuade individual actors from investing in resilience measures, as illustrated by the UK case study in Box 4.1. By mitigating systemic risks such as those posed by climate change, adaptation investments can also contribute to the achievement of broader national development plans.

Rwanda's success in delivering adaptation outcomes, described in Box 4.2, highlights the crucial role of comprehensive institutional arrangements, national strategy integration and high-level government commitment in mainstreaming climate considerations into economic and fiscal planning, enabling the effective mobilisation of adaptation finance and implementation.

Box 4.2. Rwanda case study

The role of institutions in delivering adaptation outcomes

Institutional and governance arrangements are central to delivering effective adaptation outcomes, particularly at the macroeconomic and fiscal levels. Governments play a critical role in resolving market failures, creating enabling conditions and mobilising finance to deliver adaptation at scale. Adaptation is not a one-off action but an evolving process that requires iterative decision-making in response to changing risks. Effective institutional design, clear strategies and adaptive governance mechanisms are essential. However, market failures and coordination challenges can hamper progress, underscoring the need for deliberate government intervention to establish the necessary policy, regulatory and financial frameworks for adaptation.

Institutional and enabling actions should be recognised as a key form of adaptation in their own right. They are foundational to achieving and sustaining adaptation outcomes, yet their importance for macroeconomic and fiscal policy is often underexplored. This case study focuses on Rwanda, a country that has developed one of the most advanced and coherent climate policy frameworks globally, examining how institutional arrangements and enabling conditions can enhance macroeconomic and fiscal adaptation.

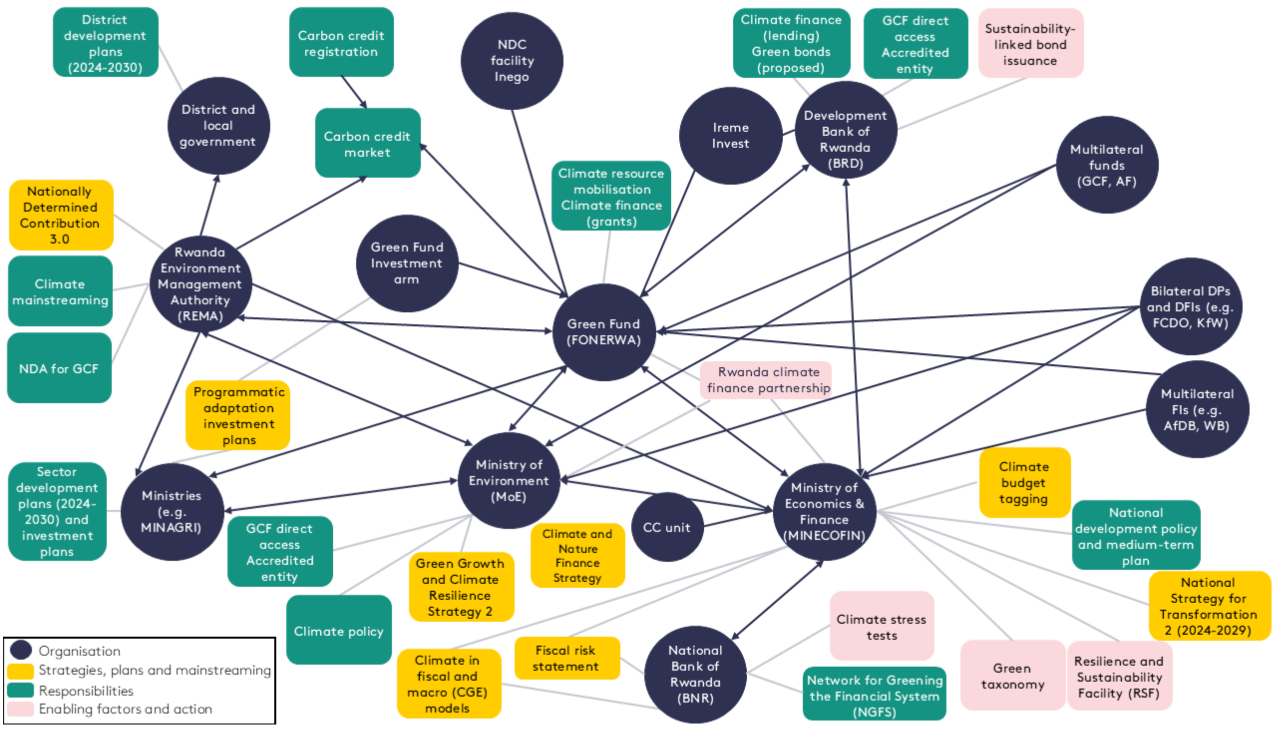
A literature review undertaken for this study identified three central themes underpinning successful macroeconomic and fiscal adaptation:

1. Institutional arrangements and coordination
2. Strategies and mainstreaming
3. Enabling factors

Together, these elements mobilise finance, strengthen the effectiveness of implementation and help scale up adaptation actions, although measuring these benefits quantitatively remains challenging.

Building on these themes, a detailed institutional review performed by Paul Watkiss Associates, supported by social network mapping and interviews with key government and institutional representatives, provided further insights into the factors driving success in Rwanda.

The social mapping exercise visualises relationships between actors, responsibilities and enabling mechanisms, resulting in the network diagram below, which illustrates the dense and interconnected institutional landscape that supports adaptation in Rwanda. It maps the roles of key organisations – such as the Ministry of Environment (MoE), the Ministry of Economic Planning and Finance (MINECOFIN), the Rwanda Environment Management Authority (REMA) and the Green Fund – alongside a range of ministries, local governments, financial institutions and international partners. The colour-coded relationships highlight how responsibilities, mainstreaming mechanisms and enabling factors are distributed and coordinated across the system.



The institutional mapping and interviews revealed that strong coordination and distributed mandates across government have been critical in driving adaptation. While MoE plays a leading role, responsibilities extend across multiple ministries, including MINECOFIN, ensuring that climate change considerations are embedded throughout the government apparatus.

A particularly influential factor has been the integration – or mainstreaming – of adaptation into national development planning. MINECOFIN has incorporated climate change into Rwanda's five-year development plans (RoR, 2017; RoR, 2024a), ensuring that adaptation priorities are not treated as standalone initiatives but as integral components of economic growth and fiscal stability.

This mainstreaming has extended into medium-term expenditure frameworks, budgeting systems, and macroeconomic and fiscal analysis, effectively institutionalising climate risk considerations across public financial management systems. Most recently, MINECOFIN developed and published a Climate and Nature Finance Strategy (CNFS) (RoR, 2024b), and it is in the process of setting up a designated climate finance department within the ministry to support climate-resilient and low-carbon development and investment at scale.

The mapping also found that **Rwanda has implemented nearly all the enabling factors identified in the academic and policy literature**. These include the establishment of a country platform for investment, a green taxonomy, programmatic adaptation investment planning and mechanisms for risk disclosure and analysis. Among these, the Rwanda Green Fund (formerly FONERWA) stands out as a particularly impactful innovation. Functioning as both a country coordination platform and a financing mechanism, it has mobilised significant volumes of adaptation finance – especially concessional resources – while also catalysing private sector participation.

Innovative instruments such as private sector climate facilities, on-lending schemes, blended finance mechanisms, equity investments and green bonds have further diversified Rwanda's adaptation finance landscape.

The Green Fund has evolved and broadened its resource mobilisation since it began as a public-sector-oriented fund targeting international public finance – work that continues through the NDC Facility (Intego) (Intego, 2025). It has added a blended facility model, the Rwanda Green Investment Facility (Ireme Invest), to develop new financial instruments to support and de-risk private sector investment (Ireme, 2025).

Because of these initiatives – and broader progress on institutional and governance – Rwanda has been extremely successful in **mobilising international public finance for adaptation**, with climate finance flows over the last five years tracked at US$840 million (UNEP, 2024).

The analysis also highlights **innovative institutional arrangements within the financial sector**. The Development Bank of Rwanda and the National Bank of Rwanda have played central roles in greening financial systems through climate-linked investment standards, climate stress testing and participation in global initiatives such as the NGFS. These efforts have deepened the integration of climate risk into financial decision-making, reinforcing the systemic resilience of Rwanda's economy.

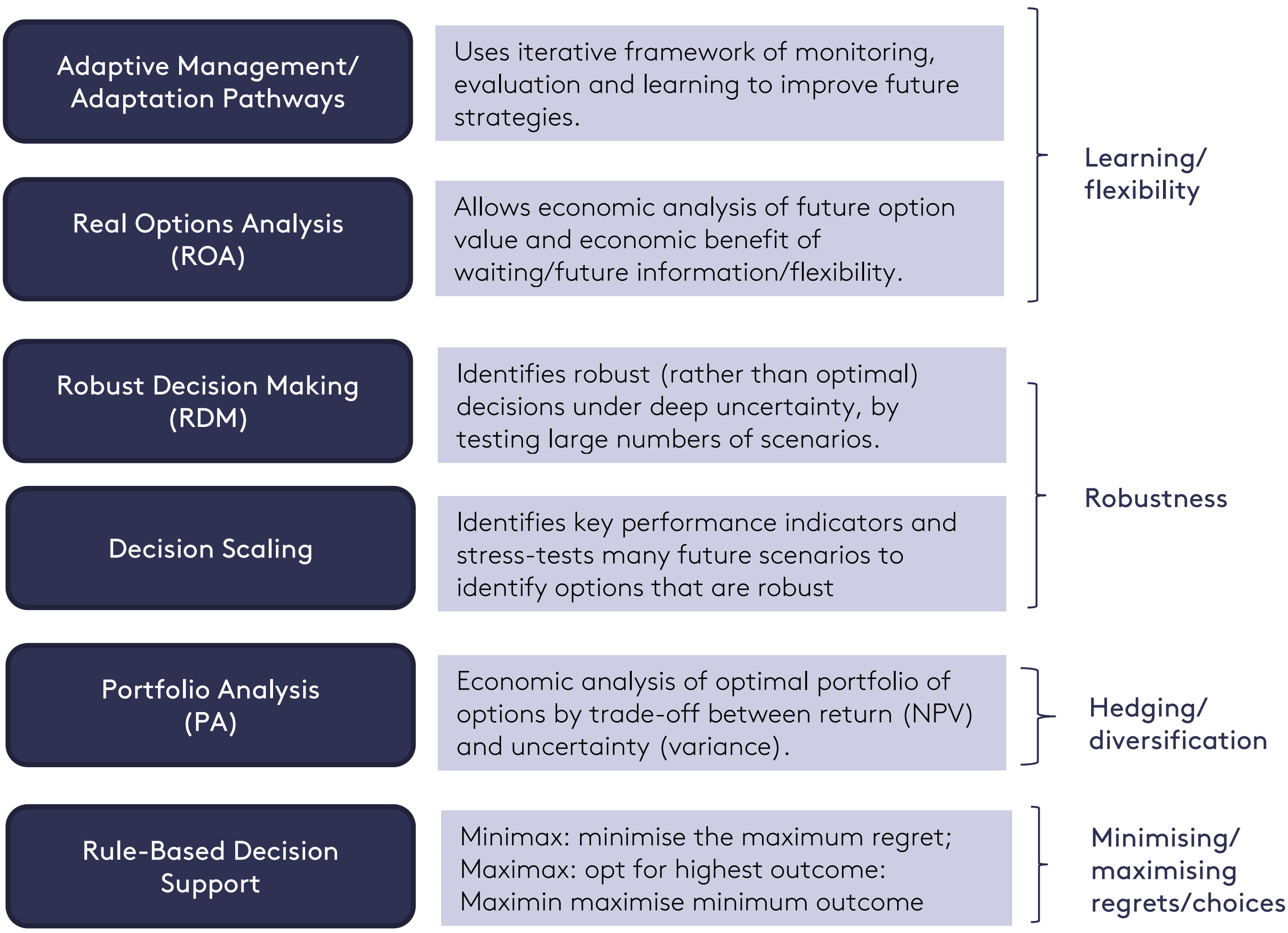
When interviewees were asked what had catalysed this high level of institutionalisation and coordination, a consistent theme emerged: **strong political commitment and national recognition of climate risk**. Climate change is acknowledged across the Rwandan government as a core development and fiscal concern, informed both by studies quantifying the costs of inaction and by recent climate shocks, notably the devastating 2023 landslides and their macroeconomic and fiscal repercussions. Capacity-building efforts have further strengthened institutional capabilities, reinforcing Rwanda's leadership in integrating climate adaptation into fiscal and macroeconomic planning.

Rwanda's experience demonstrates how robust institutional frameworks, clear strategic direction and comprehensive enabling mechanisms can transform adaptation from a policy ambition into an integrated component of national economic management.

Numerous tools and frameworks are available to assist governments and financial institutions in assessing and managing physical climate risks and adaptation strategies. A notable resource is *How Finance Ministries Can Assess and Manage Physical Climate Risks and Adaptation* (CFMCA, 2025c), which provides insights into and guidelines on integrating climate risk assessment within fiscal policy and decision-making processes, highlighting existing methodologies that can be employed to ensure sustainable adaptation investments.

Frameworks are also emerging to help the prioritisation of adaptation decisions under uncertainty (Watkiss, 2025). These include frameworks for early adaptation prioritisation and sequencing over time: broad typologies that provide help with developing adaptation policy and programmes, as well as initial scoping of options at the project level, for example as part of an initial economic review to shortlist options. Decision-support methods or tools for adaptation are also available: more formalised methods that can be used in appraisal, as shown in Figure 4.2.

Figure 4.2. Methods for decision-making under uncertainty, and their complementary benefits



Source: Watkiss (2025)

By employing these types of approaches, as well as stress testing and other forward-looking methodologies, decision-makers can make informed investments that not only enhance resilience but also foster economic growth. As Box 4.3 shows for Bangladesh, enshrining these ideas in national development plans can also help unlock new international funding, including concessionary finance, technical assistance and capacity-building.

Box 4.3. Bangladesh case study

Innovations to address adaptation finance and coordination

Bangladesh has been identified as one of the countries with the greatest risks from climate change globally. It has a vulnerable population exposed to multiple extreme hazards, including frequent, intense, persistent and erratic cyclones, floods, droughts, and slow-onset climate impacts such as sea-level rise, ocean acidification and salinity intrusion. To take one hazard, by mid-century under climate change, Bangladesh faces a quadrupling in the risk of extreme rainfall events during the monsoon, as the monsoon becomes more erratic (Fahad et al., 2024; Kamruzzaman et al., 2024).

These risks are already manifesting, with six flooding events that each affected over 5 million people in Bangladesh over the last decade (Delforge 2025). Studies have also highlighted the disproportionate impact on women and the elderly, with potential for food insecurity and health risks (Hazrana et al., 2025). These events also have very long-term impacts, with lasting health, educational and economic consequences from events like the 1970 cyclone, which were still observed in affected populations over 40 years later (Eskander and Barbier, 2021).

Like many developing countries, Bangladesh aims to integrate the multiple demands of climate adaptation, economic development and climate mitigation (Ayers et al. 2017). Bangladesh is notable in its activities to mainstream adaptation into medium-term development, including under its 8th Five-Year Plan. In support of this, the country has developed key frameworks, such as the Bangladesh Climate Change Strategy and Action Plan (BCCSAP), adopted in 2008, which remains pivotal for climate finance accounting and reporting. However, subsequent plans, such as the National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs), have often been underfunded and inadequately integrated into the fiscal policies and plans of line ministries.

The **Bangladesh Climate Development Partnership (BCDP)** was established in 2023 to improve coherence, synergy and financing in climate governance. This innovative country platform aims to address Bangladesh's persistent climate finance deficit (Islam and Nur, 2020; Dewan et al., 2021) and ensure that climate policies and plans are actionable and impactful. The BCDP also focuses on mobilising and coordinating across multiple sources of finance including external and internal finance, as well as public and private finance. It applies a whole-of-society approach uniting government, the private sector, civil society and academia under a common framework to tackle climate challenges. Guided by the 4S Principles (Synergy, Scale & Speed, and Sustainability), this approach fosters ownership, innovation and legitimacy across all sectors involved.

A significant achievement of BCDP has been the rapid approval of climate projects, exemplified by the internal financing approval for four projects following its Board's inaugural meeting. By integrating diverse actors and ensuring policy coherence, BCDP reduces fragmentation, enhancing complementarity and effectiveness.

A second innovation is the Climate Public Finance Tracking (CPFT) system. The CPFT uses climate budget tags to monitor budgets and spending related to climate change. Tracking these line items across ministries supports more informed policy decisions, better project design, and the identification of future financing needs (Bangladesh Finance Division Ministry of Finance 2025).

Financing mechanisms are also an area of development. For example, the Bangladesh Climate Change Resilience Fund was a partnership with the World Bank to implement Bangladesh's climate change strategy and action plan for 2009–2018 with high levels of economic efficiency. The current **Bangladesh Climate Change Trust Fund** plays a critical role in financing climate adaptation and mitigation activities, receiving annual allocations from the government budget to support these initiatives.

While extensive evaluations of the benefits of this process are unavailable, Brandon et al. (2025) highlight the Weather and Climate Services Regional Project, which is estimated to have avoided $93 million in losses between 2016 and 2024, and to provide $10 million in economic benefits, producing an economic rate of return of 75%.

Collectively, these initiatives lay the groundwork for systemic transformation, embedding climate considerations into governance structures, and fostering sustainable business models crucial for mobilising private finance. The success of these mechanisms to address persistent challenges, such as adaptation budget shortfalls and cross-ministry coordination, remains to be seen.

5. Conclusion

The macroeconomic case for adaptation investment is clear and compelling. As climate change continues to pose serious threats to global stability, strategic adaptation investments stand out as critical measures not only to mitigate adverse climate impacts, but also to encourage sustainable economic growth across the globe.

In many parts of the world, physical climate risks have already increased significantly and severe losses lie ahead. Based on the synthesis of 85 econometric models reviewed for this report, at current levels of vulnerability and without further adaptation, some nations in Sub-Saharan Africa and Southeast Asia could face GDP losses of more than 20% in 2050 due to temperature changes and sea-level rise alone, while total welfare losses are expected to be far higher. Alarmingly, many of the least developed countries are already experiencing the negative impacts of climate change, and could be 10% poorer today as a result of current warming.

Synthesising estimates from eight studies, labour productivity loss is projected to exceed 5% in some regions – including Africa and Asia – by 2050, while three studies on total factor productivity growth suggest that it could be reduced by up to 0.3 percentage points per year. This could drive long-term economic stagnation in some regions.

The fiscal landscape is increasingly intertwined with the challenges of climate change, which is expected to drive up government expenditures while eroding revenues. There is considerable variability in the expected impacts across regions. Global trends indicate that extreme climate events lead to higher expenditure-to-GDP ratios and diminished revenue ratios, constraining fiscal balances (Akyapı et al., 2025). The fiscal impacts are compounded by a vicious cycle whereby vulnerable economies face escalating borrowing costs, hampering their ability to finance crucial climate adaptation measures.

As climate risks evolve, they exert an influence on sovereign creditworthiness, directly affecting borrowing costs and fiscal stability. Emerging markets and developing economies are vulnerable, facing downgrades and elevated risk premiums as climate shocks increase (Volz et al., 2020; Zenios, 2022; Klusak et al., 2023). However, smart investment in adaptation offers hope.

In this report we have emphasised that **adaptation investment can yield substantial economic returns**, often at a scale that surpasses traditional metrics due to broad spillover co-benefits and enhanced market opportunities. In collecting the adaptation costs, benefits and economic returns from 76 studies and combining the results from 35 of those into consistent metrics for the benefits of adaptation, our results indicate that adaptation actions can deliver significant economic benefits, with a median economic benefit–cost ratio of 4 to 1 and a median internal rate of return of 23%. This highlights the economic potential of adaptation but – importantly – the focus of these studies is primarily on reactive or 'low-regret' adaptation measures rather than the proactive approaches needed to anticipate future challenges. Proactive adaptation strategies, incorporating elements of foresight and planning, will be crucial to reducing the projected impacts of physical climate risks on economies.

Our study has shown that adaptation offers a valuable investment, both domestically and overseas, but also that considerable challenges and uncertainties persist, particularly in implementing long-term, forward-thinking measures. Evolving our adaptation practices to better balance immediate actions with strategic, future-oriented planning is essential for maximising benefits and sustaining resilience.

The evidence we have presented underscores the necessity for proactive and coordinated efforts between Ministries of Finance and other key economic actors. Adaptation investments protect human and natural systems, but they are also a **strategic economic decision that helps stabilise fiscal environments, safeguard livelihoods and foster economic resilience**. This involves a conscious integration of adaptation into fiscal planning and national strategies, ensuring that economic policies are both climate-responsive and future-proof.

The future landscape of climate action demands bold leadership and strategic foresight. It is essential to recognise that the avoidance of loss through adaptation translates into tangible economic benefits, contributes to national development objectives and enhances fiscal health. As such, **national-level economic actors are pivotal** in championing adaptation initiatives that prioritise cost-effective, high-impact measures tailored to specific local contexts.

By learning from the rich case studies and existing literature we have discussed in this report, economic actors can integrate adaptation into fiscal policy, leverage international funding and drive significant progress in managing climate risks. The economic incentives of adaptation investment, juxtaposed with the potential costs of inaction, underline the **urgent necessity of embracing adaptive resilience as a national priority**.

Adaptation is not only necessary but is also an opportunity for transformation – a chance to rethink current trajectories and **create economies that are not only resilient to climate impacts but also thrive**. Investing in resilience through strategic, targeted and well-coordinated adaptation efforts will define the prosperity of future generations.

Methodologies for further progress

A global survey of Ministries of Finance undertaken in 2024 by the Coalition of Finance Ministers for Climate Action showed a significant gap between Ministries' awareness of climate risks and the degree to which they integrate adaptation into their fiscal and macroeconomic planning (CFMCA, 2025a). Despite growing recognition of the fiscal implications of climate change, only a small minority of Ministries had undertaken any form of analysis to estimate public expenditure or financing needs related to climate adaptation and resilience. In contrast, a far larger share had begun to assess mitigation-related costs or design tax mechanisms for decarbonisation. Fewer than one in four Ministries reported that adaptation considerations were integrated into their fiscal projections or national macroeconomic models, and many acknowledged that adaptation remains the mandate of other departments rather than a core financial concern.

These results reveal that even though climate action is increasingly viewed as a priority, adaptation remains largely absent from macro-fiscal decision-making. Given the mounting fiscal costs of climate shocks and the long-term economic benefits of resilience investments, this is a critical omission.

This gap provided the rationale for the present study. However, the survey results also reflect the deep analytical and institutional barriers that have limited such integration to date.

The analysis and quantification of adaptation in financial planning are inherently complex, requiring cross-disciplinary methods that link uncertain physical climate risks to economic systems, budgetary processes and long-term growth trajectories. Existing evidence is limited, fragmented and often based on models that simplify or exclude adaptation dynamics. As highlighted in the Coalition of Finance Ministers' recent report on tools for assessing physical climate risks and adaptation, current macroeconomic modelling tools frequently underrepresent adaptation or treat it with highly stylised assumptions (CFMCA, 2025c). These modelling limitations echo those discussed in other studies, such as the World Bank's integrated modelling approach, which suggests that an empirical approach based on historical data can complement these models (World Bank, 2024g). Data gaps, unquantified benefits and the absence of harmonised risk assessment methodologies make it difficult to assess costs and returns with confidence.

These challenges mean that few Ministries of Finance are currently equipped to capture adaptation's fiscal relevance, but they also imply that the present study – while advancing understanding – faces its own analytical limitations. Hence, this report has also considered tools and approaches beyond traditional econometric modelling that can complement quantitative fiscal analyses. For instance, while integrated assessment models (IAMs) and computable general equilibrium (CGE) models remain useful for long-term scenario assessment, they often fail to capture short-term shocks, feedback loops and non-market losses, and a broader suite of methods is required. One option is probabilistic catastrophe modelling, as employed in frameworks such as CLIMADA or the Oasis loss modelling framework, which can simulate the fiscal consequences of extreme weather events under varying adaptation scenarios.

There are also scenario-based approaches such as the IMF's Climate Macroeconomic Assessment Program (CMAP) or the Climate Resilient Fiscal Planning Framework produced by the Asian Development Bank, which allow Ministries of Finance to explore adaptation options within debt–investment–growth frameworks and assess their macroeconomic implications under uncertainty. Additionally, integrated modelling approaches like those used in the World Bank's Country Climate and Development Reports can draw upon multiple lines of evidence (World Bank, 2024f).

Further, complementary decision-support tools, including cost–benefit analysis with probabilistic extensions, decision-making under uncertainty analysis and anticipatory adaptation frameworks, can help evaluate investment trade-offs and timing when future climate outcomes are uncertain. Moreover, physical metrics such as exposure, vulnerability and resilience indices offer non-economic indicators that can be linked with fiscal analytics to enrich risk-informed budgeting.

There is no single definitive method for the integration of adaptation into macro-fiscal analysis. A plurality of approaches is required. Quantitative modelling must be combined with scenario-based reasoning, stakeholder engagement and iterative decision-making processes that recognise deep uncertainty. This study contributes to that broader effort by compiling and examining emerging evidence on the fiscal and macroeconomic dimensions of adaptation investment. However, it should be emphasised that **the results presented here are not final answers but steps towards more comprehensive understanding.** Readers are encouraged not to fixate on individual data points or figures without considering the underlying assumptions, scope of coverage and inherent uncertainties in the analyses. Instead, findings should be interpreted as indicative of trends and relationships that warrant further exploration and refinement as the evidence base continues to evolve.

Opportunities for Ministries of Finance

In this review we have shown how vital it is that economic and financial decision-makers – including in Ministries of Finance – incorporate climate risks and opportunities to invest in adaptation within their macroeconomic and budget projections and capital investment planning processes. This can build on existing Climate Public Expenditure and Financial Accountability (Climate PEFA) and Climate Public Investment Management Assessments (Climate PIMA) and tools, but moving more from climate risks towards adaptation.

A fuller incorporation of adaptation planning into fiscal decision-making will be essential to help countries plan for the rising fiscal demands from climate change and invest in adaptation measures to offset the risks. In this sense, Ministries of Finance can contribute to demonstrating the value of proactive adaptation in terms of avoided losses and costs that can incentivise investment (Surminski et al., 2025).

To do this, Ministries of Finance and other economic decision-makers need to start by investing in building their analytical capabilities to identify and assess risks and opportunities. There are several options at the disposal of Ministries of Finance, working with other departments across government, including:

- **Assessing risks and impacts.** As we have outlined throughout this report, a growing number of studies, tools and models can help Ministries of Finance understand the current and potential future macroeconomic and fiscal impacts of climate change for their economies. Many of these approaches are captured in a recent report of the Coalition of

Finance Ministers for Climate Action on *How Ministries of Finance Can Assess and Manage Physical Climate Risks and Adaptation: Available Analytical Tools and Emerging Good Practice* (CFMCA, 2025c). Approaches include using a diverse portfolio of models such as econometric modelling, IAMs, CGE models, catastrophe modelling, scenario-based approaches, and many others. Ministries of Finance should take the strengths and limitations of different approaches into account, and cast their eyes beyond traditional approaches to include factors such as tipping points and non-marginal change. Assessments can start with systematically identifying potential climate hazards and quantifying their economic impacts across multiple time horizons using a range of tools.

- **Developing a long-term vision for what a well-adapted economy might look like.** Once they better understand the risks, Ministries of Finance can work with other departments across government to set clear goals for the level of climate change an economy must be prepared to withstand and set out a vision for what a 'well-adapted' country could look like. This should start with a more in-depth analysis of the current risks and existing adaptation costs and benefits (macroeconomic, fiscal and the effects on public finances, economic), and then look to the future, taking account of uncertainty.
- **Appraising adaptation strategies and creating the enabling conditions.** In the context of delivering on this overall vision, Ministries of Finance can continue to scale up the strategic integration of adaptation into national development planning and expenditure frameworks, and assess the potential implications for the economy and public finances. They can also support the enabling conditions for adaptation, including through policy reforms or broader public financial management strategies. Many relevant assessment approaches are also captured in the recent report on adapting to physical climate risk of the Coalition of Finance Ministers for Climate Action (CFMCA, 2025c). Given that the future macroeconomic and fiscal risks of climate change involve deep uncertainty, actors can use an adaptive management approach to identify early urgent priorities for investment. One approach is laid out in Watkiss et al. (2021), which includes: first, prioritising early no-regret adaptation options that generate early economic and fiscal returns (high benefit–cost ratios); second, ensuring that adaptation is built into all near-term infrastructure decisions with long lifetimes; and third, investing in information evidence to improve future decisions.

More broadly, Ministries of Finance can use the types of analytical exercises outlined above to play a more active role with others across government in developing national adaptation plans, including by ensuring that they are well aligned with national development planning and budget processes. They may want to consider including contingent liabilities from physical risks in the fiscal planning and budget process; introducing climate and nature stress-testing requirements for financial institutions; working with central banks to better understand and manage sources of vulnerability for the financial system; and thinking about how to build natural disaster clauses into debt management strategies with creditors.

Ministries of Finance can also consider setting up national mechanisms that enable quick financial responses to disasters to be put in place. This might include contingency funds, credit lines, traditional insurance and insurance in the form of catastrophe risk bonds and regional risk pools that help to transfer risk and enable fast recovery and resilient rebuilding or relocation.

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Appendix: Methodology and extended tables

Contents

A.1. Literature review methodology

Academic papers and grey literature were tracked on a series of spreadsheets. In addition to paper and process information, information listed in Figure A.2.1 was recorded, with different fields for macroeconomic/fiscal studies and for adaptation studies.

Table A.1.1. Attributes their definitions recorded for each study included in the review

Attribute	Definition	Explanation/examples
Macroeconomic/fiscal studies		
Drivers of risk	What shocks or changes are impacting the outcomes?	Examples: Local temperature changes, global temperature change, natural disaster, SLR.
Methodology	How is the analysis performed and when are its results applicable?	Provide information on the data, modelling or statistical approach, and what is included/considered.
Calibration approach	What calibration or modelling approach was used in the analysis? [Econometric, macro-model, stylised?]	– Macro-model means an I/O model, CGE model, IAM, DSGE, or similar. – Results produced by multiplying a hazard variable by a coefficient, or a similarly simple approach, are labelled Stylised.
Hazard definition	What kind of hazards were analysed in the paper? [Acute shocks, chronic trends, stylised changes?]	– Acute: e.g., uses weather predictors. Most econometric studies (except cross-sectional or long-differences). – Chronic: e.g., uses climatic averages.
Impact persistence	To what degree is persistence in impacts considered? [None, permanent, adaptive?]	– None: if hazards are removed, immediate return to baseline outcomes. – Permanent: if hazards are removed, grows at baseline rate but never returns to baseline. – Adaptive: gradually returns to baseline after hazards removed or gradually stops being impacted by repeated hazards.
Space disaggregation	What level of disaggregation was used in the analysis? [Global, regional, local?]	– Use "global" if there is no spatial disaggregation (even if it's not actually global).

		– Use "local" if grid cell, household or firm level. – Use "regional" if regions are used.
Impact interactions	Were interactions between impacts considered in the analysis? [Sequential interactions, spatial interactions, sectoral interactions?]	– Sequential: a drought two years in a row is worse than twice one drought. – Spatial: a drought on country A produces losses in country B. – Sectoral: a drought results in health problems from food insecurity.
Economic dynamics	Was the dynamic nature of the economy considered in the analysis? [Static, transitional (accounting for changes over time), adaptive (reflecting shifts in economic behaviour in response to impacts?)]	– Static: economic assumptions are calibrated to given historical period. – Transitional: the economy continues to evolve according to a prescribed scenario. – Adaptive: the evolution of the economy depends on climate impacts or decisions.
Climate features	Were tipping points or other notable climate complexities included? [Tipping points, other?]	– Other: "Notable climate complexities" must be beyond prescribed inputs from GCM/ESM models. Examples: ENSO, ecosystem regime shifts, glacial retreat.
Adaptation considered	How and to what extent is adaptation considered?	Is adaptation already included in the results?
Adaptation studies		
Impacted sector	Is there a specific sector of the economy that is impacted?	The adaptation is in response to some experienced or expected impacts. What was impacted? Examples: households, farmers, agriculture (the sector), transportation, urban.
Benefits of adaptation	How are benefits of adaptation quantified?	Examples: avoided losses, adaptation co-benefits, economic investment benefits.
Costs of adaptation	How are costs of adaptation quantified?	Examples: CapEx, OpEx, deadweight loss, in-kind trade-offs.

Ante/post?	Does the analysis rely on ex-ante modelling or ex-post observations?	– Ex-ante: a modelling study of the expected costs/benefits of adaptation. – Ex-post: an observational study of the measured costs/benefits of adaptation.
Planning process	What is discussed about the adaptation planning/decision-making process?	Often "None". Examples: national adaptation plans, stakeholder engagement, adaptation pathways.
"Soft options"	What is the benefit of "soft options" (e.g., informational and institutional interventions)?	Often "None". Examples: nudges, awareness campaigns, information feedback loops, shifting administrative or power-of-purse responsibilities.
Sufficiency definition	How do different papers understand sufficient adaptation levels (i.e., what it means to be well-adapted)?	Often "None". Examples: maximize welfare or GDP; Eliminate "non-acceptable" risks; Marginal benefits or NPV above a given level.

Quantitative results were then recorded for each study in separate spreadsheets (one study could be associated with many outcomes). Quantitative values were extracted from the text, appendices, tables and, where necessary, figures using the PlotDigitizer. These attributes are specified in Table A.1.2.

Table A.1.2. Attributes recorded for quantitative values extracted from studies

Attribute	Protocol question
All studies (common attributes)	
Country(ies)	What specific country or group of countries was considered? Just provide the country names or group.
Scenario	Under what socioeconomic or climate scenario were the outcomes analysed? Just provide a technical scenario name.
Units	What are the units of the quantitative outcome?
Value	What is the value of the quantitative outcome? Specify this as positive if the affected outcome is greater than the comparison scenario – so, for example, losses in the outcome will be negative.
SD	What is the standard error or standard deviation of the result? Specify a number or N/A.

Low quantile	If a lower quantile value is specified, what is the percent value of that quantile, or N/A?
Low value	If a lower quantile value is specified, what is the value at that quantile, or N/A?
High quantile	If a lower quantile value is specified, what is the percent value of that quantile, or N/A?
High value	If a lower quantile value is specified, what is the value at that quantile, or N/A?
Result source	Where is this quantitative result reported in the paper? Include the page number.
More notes	Do you have any other notes?
Macroeconomic/fiscal studies	
Outcome	What is the outcome that is affected by climate change? Just provide a single term. If reductions in the outcome are described, do not include 'losses' or similar in the outcome name, since we will report these as negative.
Year	In what future or past year is the outcome evaluated? Just specify a single year.
Relative to	What comparison scenario are quantitative outcomes reported as being relative to? For example, specify a baseline year or, if it is relative to no climate change, write "No CC".
Adaptation studies	
Impacted sector	What economic sector or group is being impacted by climate change? Just provide a single term or "All" or "NA".
Solution	What type of solution is being evaluated? Just provide a single term or "Any" or "NA".
Quantification	How are the effects of adaptation being quantified? Just provide a technical term.
Expression	See A.1.1 Adaptation Expression below.
Type of value	What is being included in the costs or benefits? Specify "Monetary" (cash flows), "Fiscal" (government balances), "Economic" (monetary and nonmonetary), "Various" (not clearly distinguished) or "N/A".
Sample	Is this a description of the reporting sample, reflecting just those leaders who likely have good results (Lead), or is this an analysis across the whole range of needed adaptation (Need)? Specify "Lead", "Need" or "N/A".

A.1.1. Adaptation expressions

We use a standardised set of variables to bring together results from many different studies. Valid terms in this expression include (with common units in brackets):

AvoidedImpact [million USD / yr, % of GDP]

MonetaryBenefits [million USD / yr, % of GDP]

NonMonetaryBenefits [million USD / yr, % of GDP]

BaselineImpact [million USD / yr, % of GDP]: this is the same unit as AvoidedImpact, and is the impact from climate change without adaptation.

AdaptationCost [million USD / yr, % of GDP]

CapExCost [million USD]

OpExCost [million USD / yr]

BaselineLevel [million USD / yr, % of GDP]: This is in the same units as AvoidedImpact, and it's the level we would get without adaptation.

Note that, generally, AvoidedImpact < MonetaryBenefits + NonMonetaryBenefits and AdaptationCost > CapExCost + OpExCost.

Functions like the following are also permitted in the adaptation expressions:

DiscountedSum() [million USD]

RateOfReturn() [%]

Some common expressions are:

Adaptation Ratio (as defined by WB): *AvoidedImpact / BaselineImpact*

Benefit-Cost Ratio: *(MonetaryBenefits + NonMonetaryBenefits) / AdaptationCost*

Economic Internal Rate of Return: *RateOfReturn(MonetaryBenefits + NonMonetaryBenefits - AdaptationCosts)*

Net Present Value: DiscountedSum(*MonetaryBenefits + NonMonetaryBenefits - AdaptationCosts)*

A.1.2. Artificial intelligence methodology

We performed a broad Scopus and Web of Science search to find relevant papers. The Boolean search used on both services was ("weather" *or* "temperature*" *or* "climate" *or* "global warming") *and* ("GDP" *or* "growth" *or* "economic*") *and* ("global" *or* "world*" *or* "national") *and* ("panel" *or* "time-series" *or* "longitudinal" *or* "long-term" *or* "historical"). This retrieved 19,880 articles on Scopus and 35,782 articles on Web of Science, with 41,183 articles uniquely identified across the two services (based on their DOIs).

Next, we designed an automated process to filter out papers that did not meet our criteria, based on their abstracts, titles and keywords. The approach was to perform a query for each paper on both OpenAI's GPT-4o model and Google's Gemini 1.5 flash model. The query was:

I am performing a global review and analytical synthesis of the macroeconomic and macro-fiscal risks of climate change and the costs and benefits of adaptation at a national level.

The following is a paper identified by very general search:

{title}

Abstract: {abstract}

Keywords: {keywords}

*Based on this information, should this paper be included in the review? If *not*, please classify this with one or more of the following codes:*

XC: Not related to climate risks

XV: Not valued in economic terms

XN: Not nation-scale or multinational (not macroeconomic or related to nation-wide adaptation)

XA: No new analysis (using previously-published work)

XO: Excluded for another reason (please specify)

*If it *should* be included, classify it with one or more of the following codes:*

RE: Reports macroeconomic outcomes (GDP effects, productivity loss, interest, inflation, etc.)

RF: Reports fiscal outcomes (budget balance, borrowing costs, public expenditure or revenue, etc.)

RA: Reports both economic costs and/or benefits (or related measures like ROI, NPV) of nation-wide adaptation.

Provide a succinct explanation, and only mention codes identified for this paper.

In addition, for any paper that was not excluded by both AI tools, we asked the following question to exclude papers focused on mitigation:

*Based on this information, does this paper describe outcomes driven by climate change (that is, all the effects that come from increased greenhouse gas concentrations, such as increased temperatures and other weather changes), as opposed to the effects of climate policy? I am also interested in adaptation and resilience, but again, I do *not* want to consider reductions in losses that are coming from reduced greenhouse gas emissions.*

We only excluded articles if both the GPT-4o and Gemini models agreed on a reason for their exclusion or based on the question above. We performed an AI-automated online search for each of the remaining papers. This started by checking each PDF linked for the given DOI within the multiple versions provided in Google Scholar and, if none was available, performing Google searches and following links to try to find the PDF.

Next, for each page of the PDF, we used the following query:

I am performing a global review and analytical synthesis of the macroeconomic and macro-fiscal risks of climate change and the costs and benefits of adaptation at a national level. The following is a page from a paper that is potentially relevant to my review:

{pagetext}

Please summarize and extract any relevant information from this page relevant to the following categories:

Outcome(s) of Interest: Specific macroeconomic outcomes (GDP effects, productivity loss, interest, inflation, etc.) or fiscal outcomes (budget balance, borrowing costs, public expenditure or revenue, etc.) or measures of economic costs and/or benefits (or related measures like ROI, NPV) of nation-wide adaptation.

Drivers of Risk: What shocks or changes are impacting the outcomes?

Quantitative material: Is there quantitative information on the outcomes of interest on this page?

Methodology: How is the analysis performed and when are its results applicable?

Highlights: What are the most important outcomes of the analysis?

More Notes: Do you have any other notes?

Only include information specifically contributed by this paper, not material referenced from other studies.

Specify the results in a list with single lines of text in a YAML dictionary (each line should read "Category": "Extracted Information"), and only include those entries for this page where there is concrete relevant information. This page may have no relevant information, in which case report 'No relevant information'.

For the paper-level attributes described in Table A.1.1, we collated all information retrieved from the prompt above and summarise it. At this point, the AI system was also prompted to classify the paper as relevant due to macroeconomic/fiscal outcomes or adaptation outcomes, or as irrelevant:

Does this paper produce new quantitative results on specific macroeconomic outcomes (GDP effects, productivity loss, interest, inflation, etc.) or fiscal outcomes (budget balance, borrowing costs, public expenditure or revenue, etc.) or measures of economic costs and/or benefits (or related measures like ROI, NPV) of nation-wide adaptation?

Specify the answer as one of the following: Macroeconomic, Fiscal, Adaptation, or N/A.

The system did this using the page-specific data in the quantitative material and methodology fields. If it was identified as N/A, no quantitative information was extracted.

We passed each page identified as having quantitative information into the following prompt:

The following is the text of page {pagenum}, which may have detailed information we want to extract:

{pagetext}

Please summarize and extract any quantitative results that are either macroeconomic outcomes (GDP effects, productivity loss, interest, inflation, etc.) or fiscal outcomes (budget balance, borrowing costs, public expenditure or revenue, etc.) impacted by climate change.

Report this information under the following columns:

- Outcome: What is the outcome that is affected by climate change? Just provide a single term.

[other column definitions here]

Specify the result as a CSV, provided in triple quotes. Your response should start:

"Outcome","Country(ies)","Scenario","Year","Relative to","Units","Value","SD","Low Quantile","Low Value","High Quantile","High Value","Result Source","More Notes"

...

This page may have no relevant information, in which case report the header with no following rows.

The "[other column definitions here]" section was filled with the protocol questions from Table A.1.2. The prompt above was for macroeconomic/fiscal studies. For adaptation studies, we used the following at the top of the prompt:

The following is the text of page {pagenum}, which may have detailed information we want to extract:

{pagetext}

Please summarize and extract any quantitative results that are economic costs and/or benefits (or related measures like ROI, NPV) of national-scale adaptation to climate change.

Finally, we performed the PDF-level operations (page-level information identification, summarisation and quantitative extraction) three times and then merged the results. If a paper was identified as not relevant to the macroeconomic, fiscal or adaptation quantitative streams more often than it applied to one of those, it was excluded. The data that this process produced is provided in the Zenodo database (see Section A.7).

A.2. Climate modelling

This section describes the approach for climate change reported indicators and for the climate hazards used to compute outcomes from the GDP macroeconometrics, total welfare estimates and unemployment impacts. Other results were directly taken from self-reported baseline scenarios.

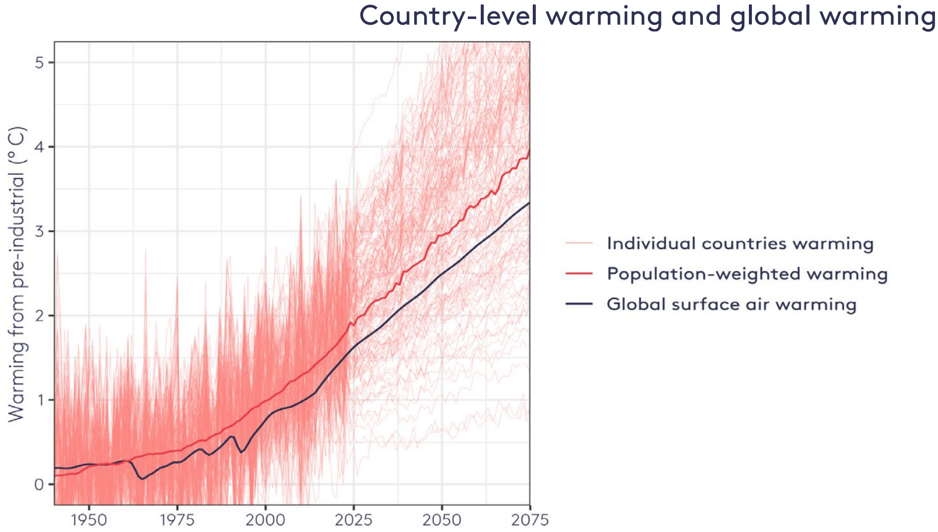
We projected these results under the high emissions scenario SSP3-7.0, and the low emissions scenario SSP1-2.6. SSP3-7.0 was considered a "baseline" scenario in the IPCC AR6, along with SSP5-8.5, but SSP3-7.0 was selected because the emissions in SSP5-8.5 are likely to be much higher than anything current policies can produce.

To estimate future global temperatures from emissions, we relied on the Finite Amplitude Impulse Response (FaIR) Model (Smith et al. 2018) v1.6.2. This is a reduced-complexity climate model, which is used to describe the full range of climate uncertainty. We used the same 2,237-member Monte Carlo ensemble of climate uncertainty that features in the IPCC AR6 WG3 report (Smith, 2021).

Our tipping point temperature corrections, from Dietz et al. (2021), capture permafrost melting, ocean methane hydrates, Arctic sea-ice/surface albedo and Amazon dieback, as well as interactions between these tipping points.

We downscaled global data using temperature data from ERA5 (daily average, minimum and maximum t2m was aggregated by population using Gridded Population of the World v3 data for 1990 for each country and ADM1 region according to Natural Earth boundaries). Daily temperatures were further aggregated according to the model specifications. Each Monte Carlo draw from FaIR was matched to a GCM, probabilistically based on the temperature of each in 2100.

Figure A.2.1. Recorded (before 2024) and downscaled (after 2024) temperatures for individual countries and as a population-weighted average of countries



Note: Warming is measured relative to pre-industrial (1850–1900), and all countries are assumed to have warmed by 0.2°C in 1940–1960. Global surface air temperature is shown from FaIR, bias-corrected to a warming of 0.85°C for 1985–2005.

A.2.1. Interpreting climate econometric studies

Some of the studies reviewed relied on methods from panel econometrics. This includes the studies used to quantify GDP impacts and unemployment rates, and some labour productivity and total factor productivity studies.

Often, these use variation in weather to across regions and time periods to evaluate the effects of temperature increases generally, while accounting for the many other features that differentiate one region from another (Auffhammer, 2018). These methods are strongly grounded in data, reflecting real-world responses, and the econometric approach allows a causal (rather than correlative) interpretation of the effects of weather on societal outcomes (Carleton and Hsiang, 2016). In some cases, the effects of long-term climate change are directly measured (e.g. some GDP impact studies), but in other cases the calibration relies on the effects of weather variation, When studies that rely on weather variation are projected into the future under climate change, these studies rely on economic theory to support the assumption that the effects of climate and weather are similar (Hsiang, 2016).

A frequent criterion for econometric calibrations is that a component of the weather events is 'unexpected': that is, agents cannot plan for the specific level of temperature rise, precipitation or other hazard. This is referred to as a 'weather shock', and weather shocks are superimposed onto a backdrop of gradual climatic changes. In the text, we refer to weather shocks and temperature shocks when these are used to estimate macroeconomic outcomes. In some cases, such as for GDP impacts, we highlight that these are interpreted as applying to all changes in temperature, not only temperature shocks.

A.3. GDP impact methodology

A.3.1. Projection of econometric models

We collected temperature-related coefficients and standard errors (or covariance matrices, where available) for 85 econometrics from 15 studies published in 2012–2022 that estimate the observed link between GDP and weather or climate. All the included studies use panel econometric methods to causally identify the effects of temperature shocks in the historical record. Models were weighted by their ability to project future losses. The list of studies is shown in Figure A.3.3.

Models were then projected with observed and projected future temperatures and with temperatures from resampled years between 1940 and 1959, and immediate impacts were defined as the difference.

The econometric and projection methodology used for these studies constrains the range of hazards that are accounted for in their results. First, they describe the impact of both temperature shocks and (based on either specific modelling or economic theory) gradual temperature trends. In the text, we refer to this as 'temperature change'. Second, they do not account for precipitation-driven effects. This is because precipitation is controlled for within the model calibrations, but we do not use this in the projection process because of the uncertainty in precipitation. It is also an empirical outcome that temperature changes, and not precipitation, drive the vast majority of GDP impacts (Waidelich et al., 2024). Third, some hazards that are driven by temperature may only be partially included in the results because they are not well-represented in the historical record. This is the case with wildfires and tundra melt, since these effects have only emerged as prominent hazards in some areas in recent years.

The effects of sea-level rise and coastal storm surge are modelled separately, as described in section A.3.3.

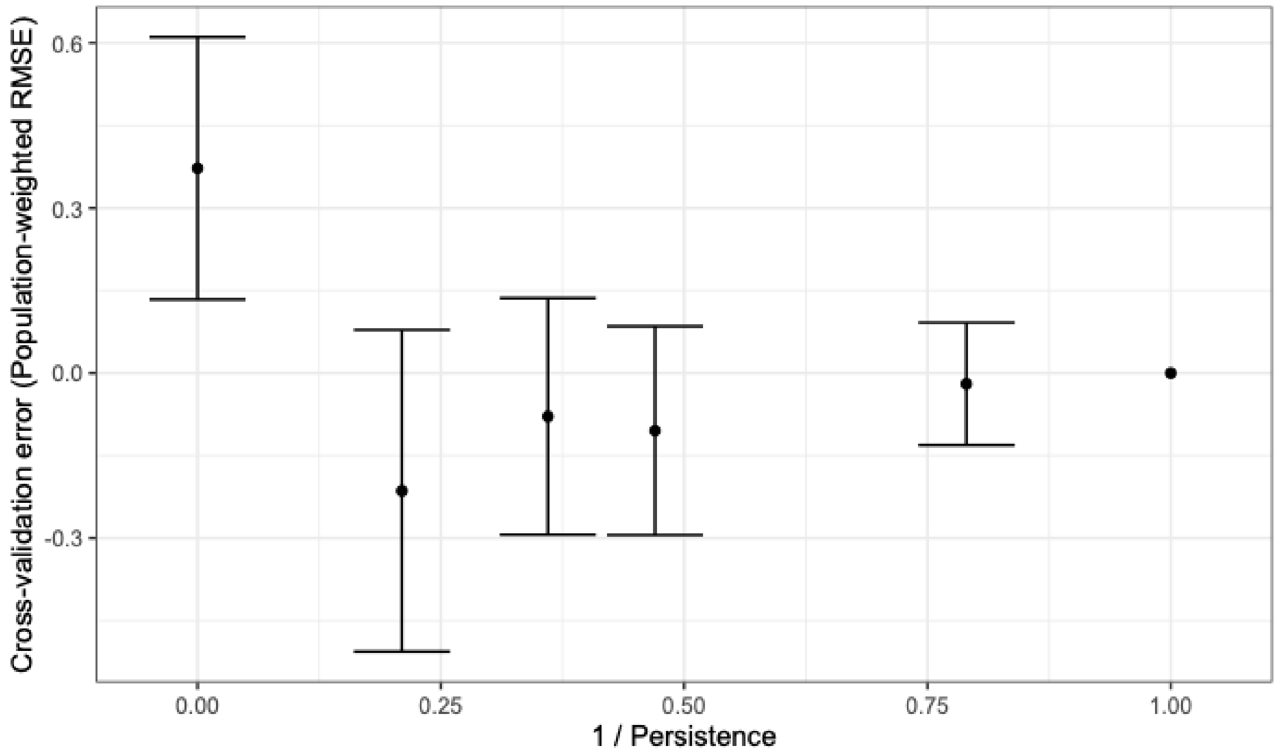
Monte Carlo projections were performed for each model, with draws from the multivariate uncertainty and from the historical resampling.

A.3.2. Meta-analysis of estimates

We projected all models under six levels of partial persistence. The direct impact from model o is $ImmediateImpact_{oitm}$ for country *i*, year *t* and Monte Carlo draw *m*. The partially persistent effect, parameterised by ω, was calculated as $CumulativeImpact_{oitm} = \sum_{s \leq <t} (1 - \omega)^{t-s} ImmediateImpact_{oitm}$. We then performed cross-validation by evaluating the performance of each model under each level of persistence for years that each model had not observed when it was calibrated. As most models were calibrated with data that ended in 2014 or earlier, ten years or more of data was usually available for this purpose. We used this measure of performance because skill in future projection is the key criterion we needed to project results to 2050.

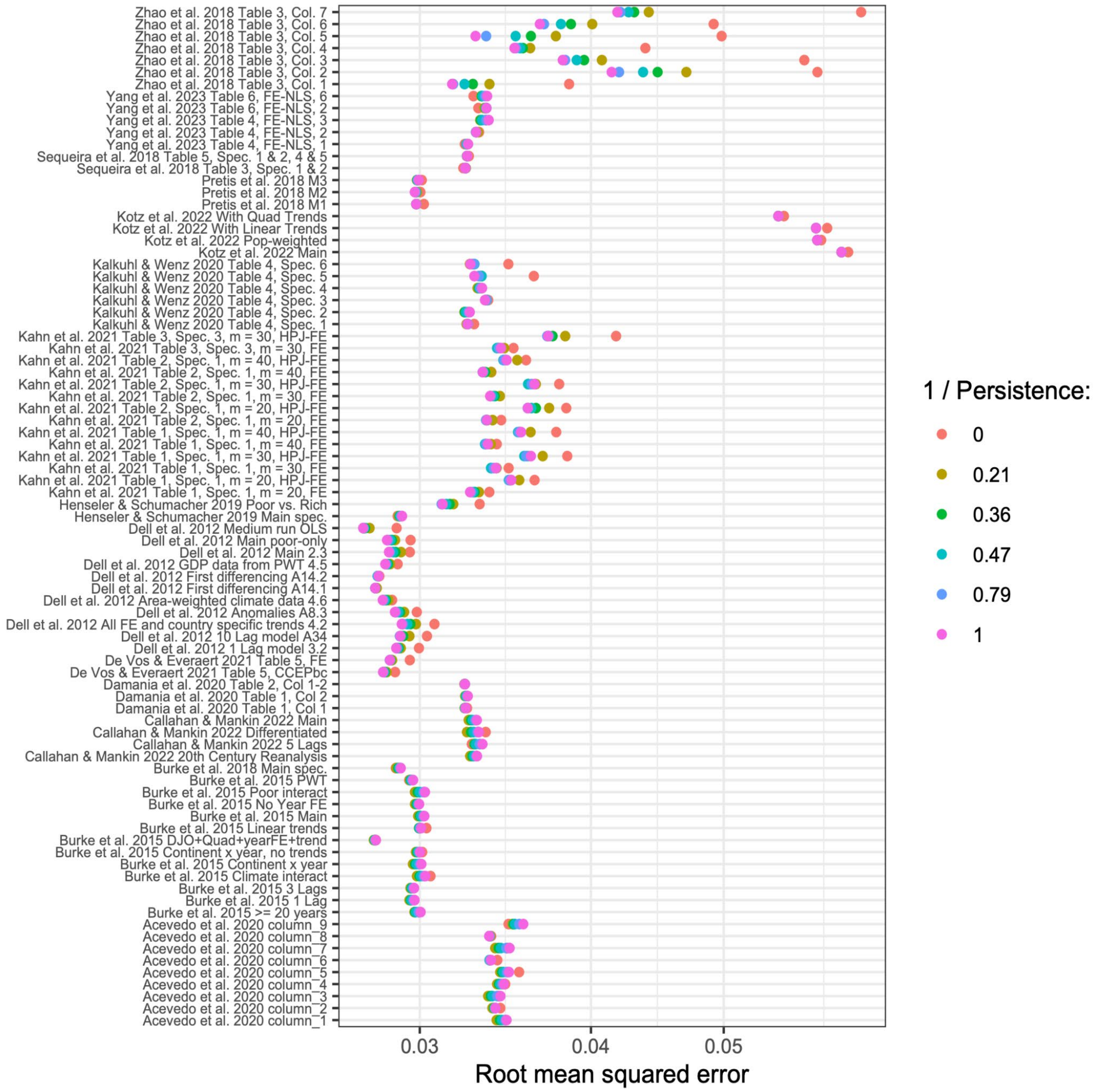
Specifically, we used the insight that GDP growth rates were well-represented by $Growth_t = \alpha Growth_{t-1} + Poly_3(t)$. We projected this out of both the cumulative impact results and the observed growths, and then evaluated the difference between the residuals of each. We selected the persistence level that produced the lowest root-mean-squared error (RMSE), which was $\omega = 0.21$.

Figure A.3.1. Cross-validation error, across all models, according to the level of persistence.



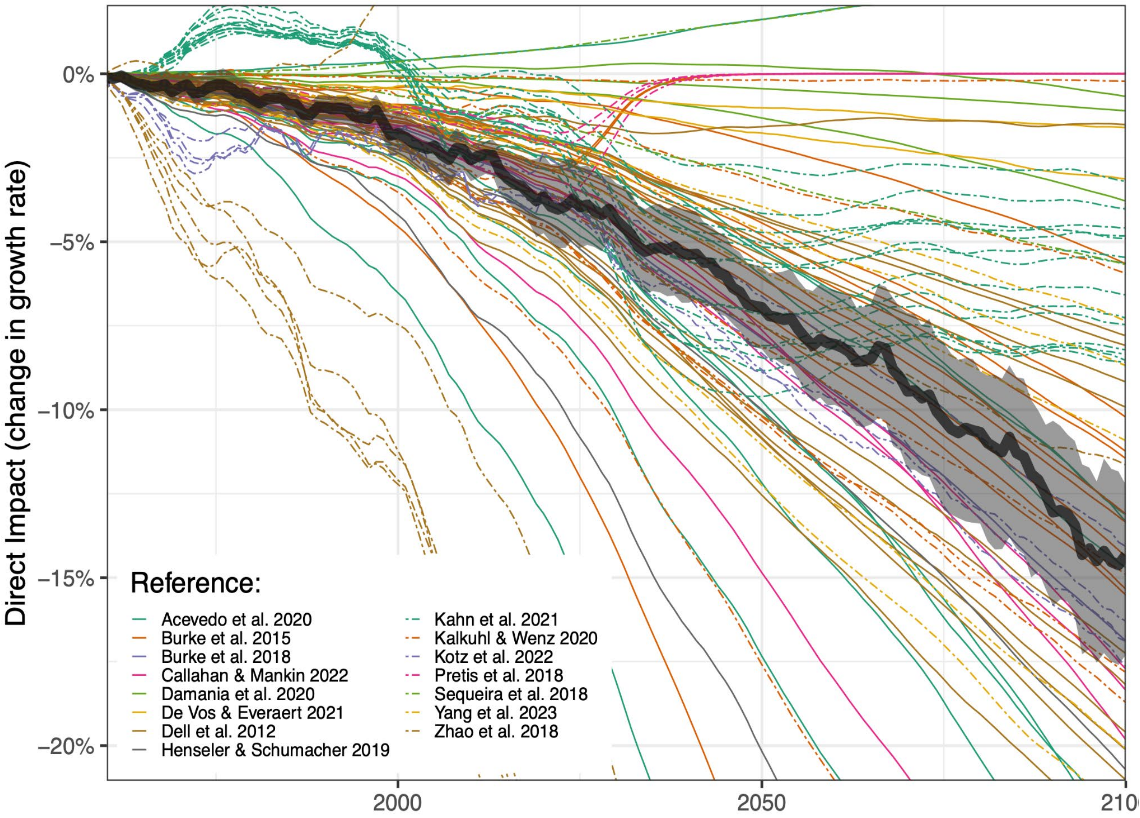
We then combined the models by constructing an empirical distribution function, randomly drawing from distributions for each model. The random draws were weighted according to the inverse of their root-mean-squared-error from the cross-validation exercise. These values are shown in Figure A.3.2.

Figure A.3.2. Random draws weighted according to the inverse of their root-mean-squared-error from the cross-validation exercise



The projected impacts under this level of persistence and the resulting partial persistence damages, in population-weighted terms, are shown in Figure A.3.3.

Figure A.3.3. Partial persistence projections of each model



A.3.3. Coastal impact

We extracted damages by adaptation case, cost type, SSP, quantile and year, summed to the country level from Depsky et al. (2023). This model describes the impacts of sea-level rise inundation and storm surge on populations, capital, and ecosystems. Storm surge is calibrated using historical return periods and does not account for the potential changes in storm frequency under climate change. Future damages from storm surge do, however, include the additive effect of rising sea level on extreme sea levels during storm surges. For the main results, only the market cost types “inundation” and “stormCapital” were used, and these were summed. SSPs and quantiles were pooled to describe uncertainty.

$log\ c_{itm} \sim N(\beta_{im} + \gamma_{im}(t - 1960), \eta_{im})$ and emulated damages were calculated as $SLRImpact_{itm} = -(exp\ (\beta_{im} + \gamma_{im}(t - 1960)) - exp\ (\beta_{im}))\ /\ GDP_{it}$, normalised by the World Bank 2019 USD PPP GDP, so that damages were 0 by construction in 1960. Values for the years after 2010 were produced by the calibrated emulation model.

A.3.4. Trade spillovers

Log-point impacts were translated into fractional changes with $LocalLevelImpact_{itm} = exp\ (CumulativeImpact_{itm} + SLRImpact_{itm}) - 1$. The Eora26 MRIO transaction matrix for each year was aggregated nationally by summing within each 26x26 industry block, and summing across columns of the value added and final demand matrices. We then calculated total sales as the row sums of the transaction matrix plus the final demands, and GDP as the value added plus the final demand. The total global impact, accounting for spillovers, was then $GlobalTotalDomarImpact_{tm} = \sum_i\ (TotalSales_{it} LocalLevelImpact_{itm}\ /\ \sum_i\ GDP_{it})$. The additional spillover effect was:

$$AdditionalDomarImpact_t = GlobalDomarImpact_{tm} - \sum_i LocalLevelImpact_{itm}\ GDP_{it} / \sum_i GDP_{it}$$

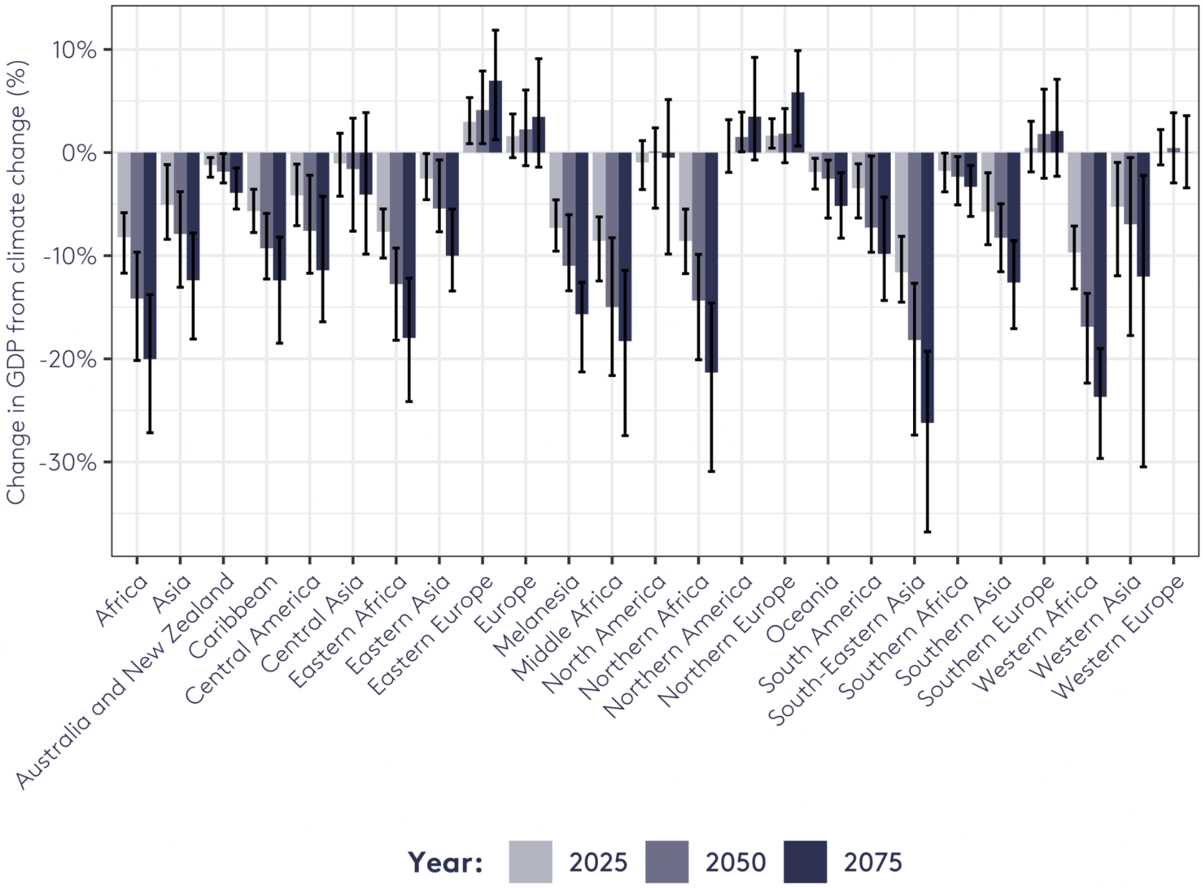
We also calculated the free on board export value lost for each year, assuming a direct relationship between losses in country j and its exports to all other countries: $ExportLoss_{it} = (\sum_j FOBValue_{ijt}\ LocalLevelImpact_{itm})/\sum_j FOBValue_{ijt}$. We then found the factor that would scale the sum of $ExportLoss_{it}$ to equal the $AdditionalDomarImpact_t$, took the average scaling value across years and applied this $ExportLoss_{it}$ to calculate the trade loss.

A.3.5. Additional results and context

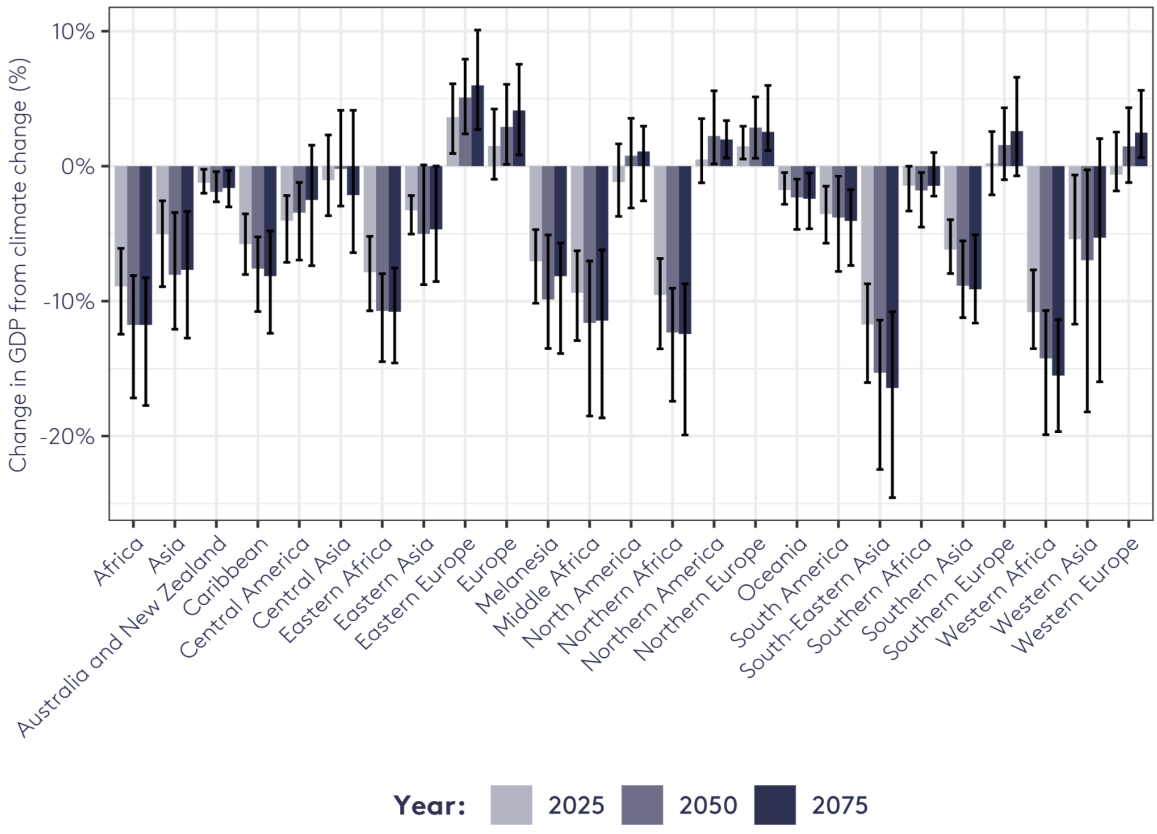
Most impacts were attributable to local temperature rise. Overall, sea-level rise and storm surge only added 0.1 pp to GDP losses globally and 1 pp GDP to trade spillovers (although the effects could be much greater for individual countries). Only historically observed adaptation was included. The analysis was performed on data for 1940 to 2100, with an emphasis on 2050, to draw out medium-term risks. Results were reported as 20-year averages relative to 2040–2059.

Figure A.3.4. Loss in GDP due to warming since 1960

a) Percentage losses in GDP from temperature shocks under high emissions (SSP3-7.0) by region and year

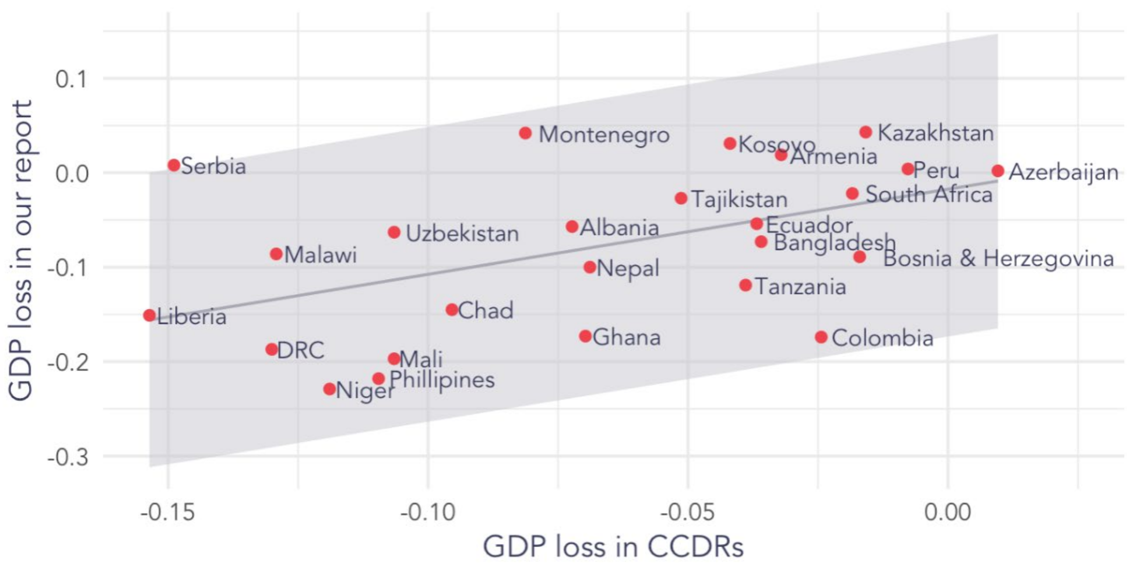


b) Percentage losses in GDP from temperature shocks under low emissions (SSP1-2.6) by region and year



Note: The estimate is based on econometric studies and only accounts for temperature shocks and sea-level rise. Error bars show the interquartile range.

Figure A.3.5. Comparison of the percentage losses in GDP under a high-emissions scenario in 2050: World Bank's CCDR versus our study

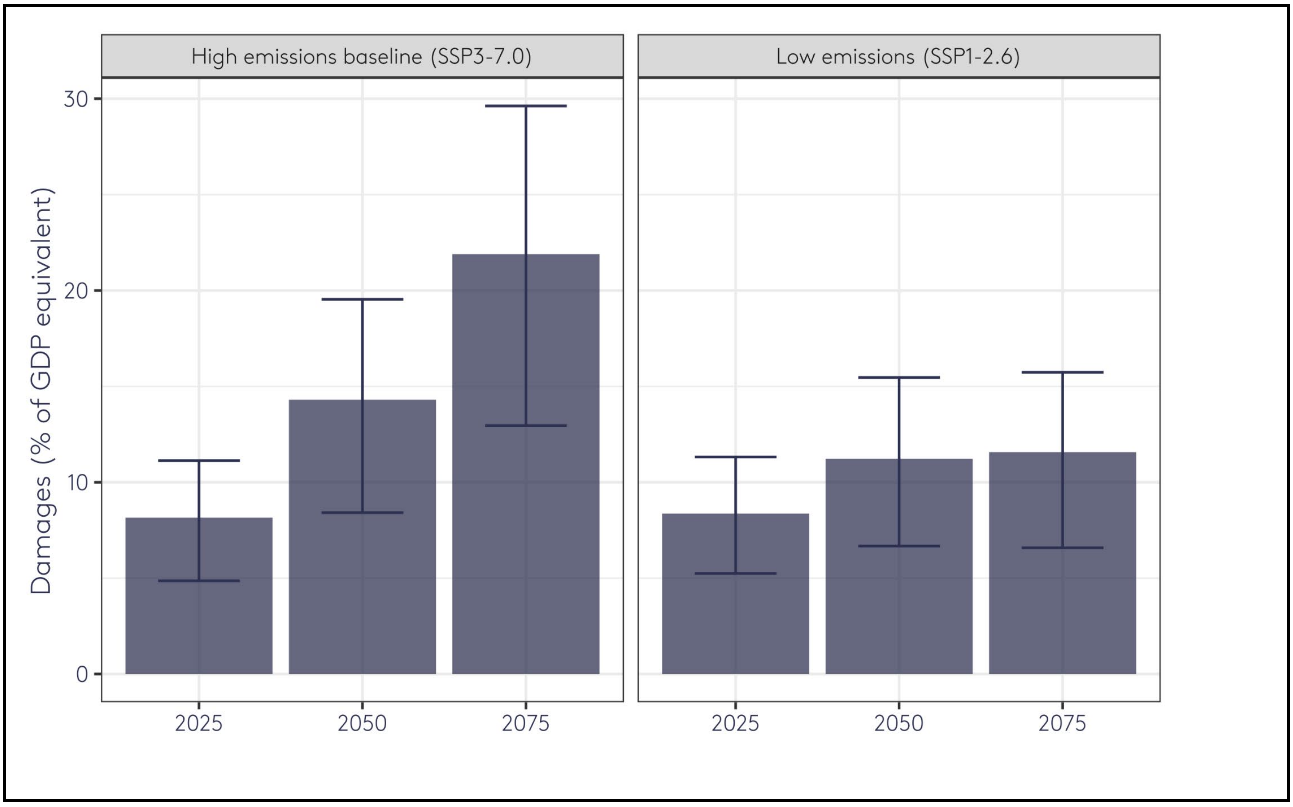


Note: GDP losses in a pessimistic scenario for the countries presented in Figure 16 of the World Bank Report 'People in a changing climate: From vulnerability to action' (2024f) and for the estimations for GDP loss in a low-mitigation scenario in 2050 of this report. The shaded area represents a 95% confidence interval.

A.4. Welfare methodology

We used the preferred synthetic damage function from Howard and Sterner (2025) and the underlying results on the components' damages that made it up. This was projected using the global temperatures as described in Section A.2.

Figure A.4.1. Welfare losses in GDP-equivalent terms by year and scenario



Source: *Damages from Howard et al. (2025) for 2025, 2050 and 2070 under high- and low-emissions scenarios. Error bars showed the interquartile range across climate and damage function uncertainty.*

These results are reported in terms of GDP-equivalent losses, which describes the drop in consumption, in terms of GDP per capita, that is equivalent to a given welfare loss. Here and in the section on direct GDP losses (which do not include non-market impacts), we treat percentage GDP and percentage GDP per capita losses as equivalent. This is because the population is assumed to be unaffected by climate change, so any loss to GDP (or GDP-equivalent) is driven by a loss in GDP per capita (or GDP-per-capita-equivalent).

To downscale global damages to the national level, we simulate 1,000 Monte Carlo draws of the GIVE (Rennert et al., 2022), META (Stoerk et al., 2025) and PAGE (Rising, 2026) social-cost integrated assessment models, which have country-level damages. In each case, we take total damages by country and year and divide by the model-estimated pre-damage GDP. We then take 1,000 Monte Carlo draws of the Howard and Sterner (2025) empirical relationship, as reflected in the graph above. For each model and year, we scale reported country-level damages so that their total matches the Howard and Sterner global damages. Then, for each country, we report the average and IQR, across both Monte Carlo draws and models.

A.5. Other impact synthesis

We applied a consistent approach to synthesise estimates of other impacts where multiple robust studies informed a given outcome, including integrated assessment model damages, labour productivity, total factor productivity growth, inflation rates and the Gini index. In these cases, we pooled all results at a national level and reported the distribution of estimates. That is, given multiple estimates X_{ip}, indexed by country i and paper p, we treated $\{X_{ip} \forall p\}$ as an empirical distribution with equal weighting. This distribution reflected both within-study uncertainty and across-study uncertainty. We then aggregated the results to regional levels for presentation.

The results from Klusak et al. assumed that countries adapted to warmer temperatures over a 30-year period and reductions in GDP (the major channel for sovereign credit changes in the model) were then driven by deviations between 30-year climatic average temperatures and observed temperatures.

It should be noted that the benefits of adaptation are inadequately integrated into creditworthiness evaluations and studies of the effects of climate change, and that this omission has consequences for countries' ability to secure the necessary investments.

The following table describes summary statistics about the features of the included macroeconomic studies. Each "Group" is a particular feature, and the "Variable" column shows common categories for that feature. For example, 54% of studies used an econometric calibration, 11% used a macroeconomic model, and the remaining 35% used other methods. The "All" column includes human and AI-reviewed studies, while the "No AI" column excludes AI-reviewed studies.

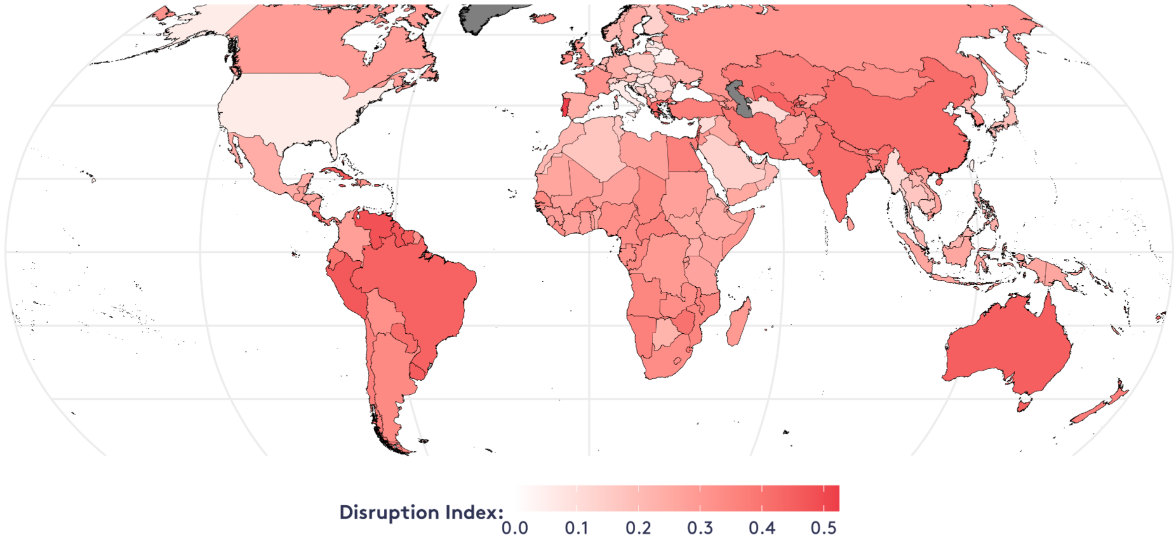
Table A.5.1. Summary statistics of the collected literature on macroeconomic and fiscal risks, with and without results from the AI methodology.

Group	Variable	All	No AI
Dataset	Count	174	47
Year	Minimum	2004	2017
Year	Maximum	2025	2025
Calibration approach	Econometric	54%	45%
Calibration approach	Macro-model	11%	43%
Hazard definition	Acute shocks	43%	45%
Hazard definition	Chronic trends	44%	49%
Impact persistence	Adaptive/partial	48%	15%
Impact persistence	Permanent	18%	17%
Space disaggregation	Global/single	36%	15%
Space disaggregation	Regional	33%	7%
Space disaggregation	Local	16%	13%
Impact interactions	Sequential	24%	17%
Impact interactions	Spatial	11%	0%
Impact interactions	Sectoral	18%	6%
Economic dynamics	Transitional	60%	0%
Economic dynamics	Adaptive	24%	55%
Climate features	Tipping points	3%	0%
Climate features	Other	10%	0%

A.5.1 Disruption index

To calculate a disruption vulnerability index, we used all macroeconomic and fiscal outcomes in our database that represent comparisons to historical outcomes or a counterfactual without climate change, which are also along a business-as-usual trajectory. We then translated these into a normalised ranking for each outcome, using the absolute value of the reported effects relative to the counterfactual or historical baseline. The ranking was performed within each outcome and across papers, regions and time. We then applied a LOESS through all these normalised values, and took the difference between the value in the years 2000 and 2050. This represents how much macroeconomic outcomes were expected to be disrupted between 2000 and 2050, as shown below.

Figure A.5.1. Normalised disruption index by country



A.6. Adaptation methodology

A.6.1. Synthesising estimates

In this section, we describe the process for generating distributions of adaptation outcomes from across the available studies.

The goal was to derive standardised and comparable metrics, specifically the Adaptation Effectiveness Ratio, Benefit-Cost Ratio (BCR) and Economic Internal Rate of Return (EIRR). The process was structured in three main stages: data cleaning, standardisation and the inference of key outcomes.

1. Data cleaning

The initial stage focused on correcting and aligning data from multiple sources to prepare for further analysis. Key steps included:

- Correcting data entries: we identified and amended discrepancies in data expressions, such as "AdaptationImpact", by recalculating values using baseline levels from the same source and scenario.
- Handling missing values: for entries with missing central values but available ranges (low and high values), we imputed the central value by averaging the bounds.
- Filtering problematic entries: observations with ambiguously defined metrics or problematic data entries were identified and excluded from the analysis.

2. Standardisation

To ensure consistency across different studies and units, we standardised estimates at the national and sector level:

Unit conversion: measurements was converted into common units where possible. For instance, values originally given in "percentage points" were converted into percentages.

Aggregation: data was aggregated at the country or regional level to derive representative metrics that could be used for comparison across different contexts.

Filtering: observations with non-comparable units or conflicting expressions were excluded during this stage.

3. Inferring key outcomes

We focused on deriving critical adaptation metrics by applying mathematical and statistical techniques:

Estimation of Adaptation Effectiveness Ratio and EIRR: using known relationships and available metrics, such as Avoided vs. Baseline Impact and Total Benefits vs. Adaptation Cost, we derived the Adaptation Effectiveness Ratio and, where possible, the EIRR. Specifically, if EIRR was available but the BCR was not, we estimated BCR assuming a 5% discount rate as $(\frac{EIRR}{100})\, e^{\frac{EIRR}{100}} (\frac{e^{-0.05}}{0.05})$.

Error minimisation: we employed an error minimisation technique to solve for unknown parameters that aligned with observed data, particularly where direct measurements were missing.

Finally, the synthesised data was categorised into World Bank sectors and other relevant classifications to facilitate contextual analysis.

The error minimisation step is a key method that we adopted to fill in data gaps by using other available data. The goal of the algorithm below was to estimate α, the adaptation effectiveness ratio; β, the cost–benefit ratio; γ, the ratio of total benefits to loss benefits; all under ϵ, a discount rate. The discount rate is included in the equations below using $\eta = \frac{1}{1-\frac{1}{1+\frac{\epsilon}{100}}}$.

The error terms are defined as follows:

Error on TotalToLossRatio (prior set to 1): $err_0 = |\gamma - 1|$

Error for Adaptation Effectiveness Ratio (given as a percentage): $err_1 = \frac{\alpha}{\frac{[AvoidedImpact/BaselineImpact]}{100}} - 1$

Error for AvoidedImpact relative to BaselineImpact: $err_2 = \frac{\alpha}{\frac{[AvoidedImpact]}{[BaselineImpact]}} - 1$

Error for BCR based on TotalBenefits to AdaptationCost: $err_3 = \frac{\beta}{[TotalBenefits/AdaptationCost]} - 1$

Error for BCR based on AvoidedImpact to AdaptationCost: $err_{3b} = \frac{\beta}{\left(\frac{[AvoidedImpact/AdaptationCost]}{\gamma}\right)} - 1$

Error for BCR based on AvoidedImpact to Cost: $err_{3c} = \frac{\beta}{\left(\frac{[AvoidedImpact]}{[AdaptationCost]}\times\gamma\right)} - 1$

Error considering Capital and Operational Expenditure: $err_{3d} = \frac{\beta}{\left(\frac{[AvoidedImpact]}{\sum([CapExCost]+[OpExCost]\times\eta)}\times\gamma\right)} - 1$

Error based on AvoidedImpact to AdaptationCost: $err_4 = \frac{\beta}{\frac{[AvoidedImpact]\times\gamma}{[AdaptationCost]}} - 1$

Error for AvoidedImpact relative to Capital Expenditure: $err_{4b} = \frac{\beta}{\left(\frac{[AvoidedImpact]\times\gamma}{\sum([CapExCost]+[OpExCost]\times\eta)}\right)} - 1$

Error for Discounted Sum of TotalBenefits minus AdaptationCost: $err_5 = \frac{(\beta-1)\times\eta}{\frac{[DiscountedSum(TotalBenefits - AdaptationCost)]}{[AdaptationCost]}} - 1$

Alternate Error for Discounted Sum of AvoidedImpact minus AdaptationCost: $err_{5b} = \frac{(\beta-1)\times\eta}{\frac{[DiscountedSum(AvoidedImpact)]-[AdaptationCost]}{[AdaptationCost]}} - 1$

Error for TotalToLossRatio: $err_6 = \frac{\gamma}{\left(\frac{[AvoidedImpact]}{\left(\frac{[TotalBenefits/AdaptationCost]\times[AdaptationCost]}{[AdaptationCost]}\right)}\right)} - 1$

The overall function to be minimised is the square root of the sum of squared errors:

$$\sqrt{\sum_{k=0}^{n} err_k^2}$$

$$= \sqrt{err0^2 + err1^2 + err2^2 + err3^2 + err3b^2 + err3c^2 + err3d^2 + err4^2 + err4b^2 + err5^2 + err5b^2 + err6^2}$$

Wherever values were left at their prior, the observations were dropped.

A.6.2. Summary statistics

Table A.6.1 provides statistics summarising the features of the adaptation studies included. Each "Group" is a particular feature, and the "Variable" column shows common categories for that feature. For example, 86% of studies report ex-ante adaptation outcomes and 36% report ex-post outcomes, with the overlapping 22% reporting both. The "All" column includes both human and AI-reviewed studies, while the "No AI" column excludes AI-reviewed studies.

Table A.6.1. Summary statistics of the collected literature on adaptation returns, with and without results from the AI methodology.

Group	Variable	All	No AI
Dataset	Count	104	30
Ante/post?	Ex-ante	86%	73%
Ante/post?	Ex-post	36%	20%
Planning process	Present	37%	27%
Soft options	Present	7%	17%

A.6.3. Stylised adaptation under uncertainty

To explore how future uncertainty interacts with long-term adaptation investments, we develop a stylised but informative analysis to compare potential adaptation strategies. While adaptation is most effective when paired with strong global mitigation, the absolute benefits of adaptation are reduced. However, Figure A.6.1 walks through the multiple economic arguments for proactive adaptation, rather than a reactive 'wait-and-see' approach. On the left is shown the current state of uncertainty around future warming, as driven by climatic and policy uncertainty. By 2050, much of this uncertainty will be resolved, and decisions today can be based on the multiple possible future outcomes.

If high levels of warming are experienced in 2050, following our baseline scenario (right column of figure A.6.1), adaptation investments strongly pay off. Investing according to the recommendations laid out in UNEP (2025) results in both large avoided losses and large co-benefits. The wait-and-see strategy invests significantly in adaptation, as hazards emerge, but avoided damages are much lower because the investments only start after the risks are observed.

There are also significant avoided losses under a high mitigation scenario (centre column), since significant warming has already happened. Here, the wait-and-see strategy results in much lower investment costs, but it also foregoes many of the potential co-benefits of adaptation action.

Since proactive adaptation is preferred under both possible futures, it is the dominant strategy. While this outcome relies on co-benefits, even actors that only count avoided losses have a strong motivation to engage in proactive adaptation. Since total damages will be higher under a low mitigation future, proactive adaptation will minimize losses in this worst-case future, when damages matter the most. This is the motivation for a precautionary principle of proactive action. In practice, making proactive adaptation decisions does involve challenges (see earlier discussion on decision making under uncertainty), but the message that it is preferable to waiting is robust.

Strategic trade-offs in adaptation

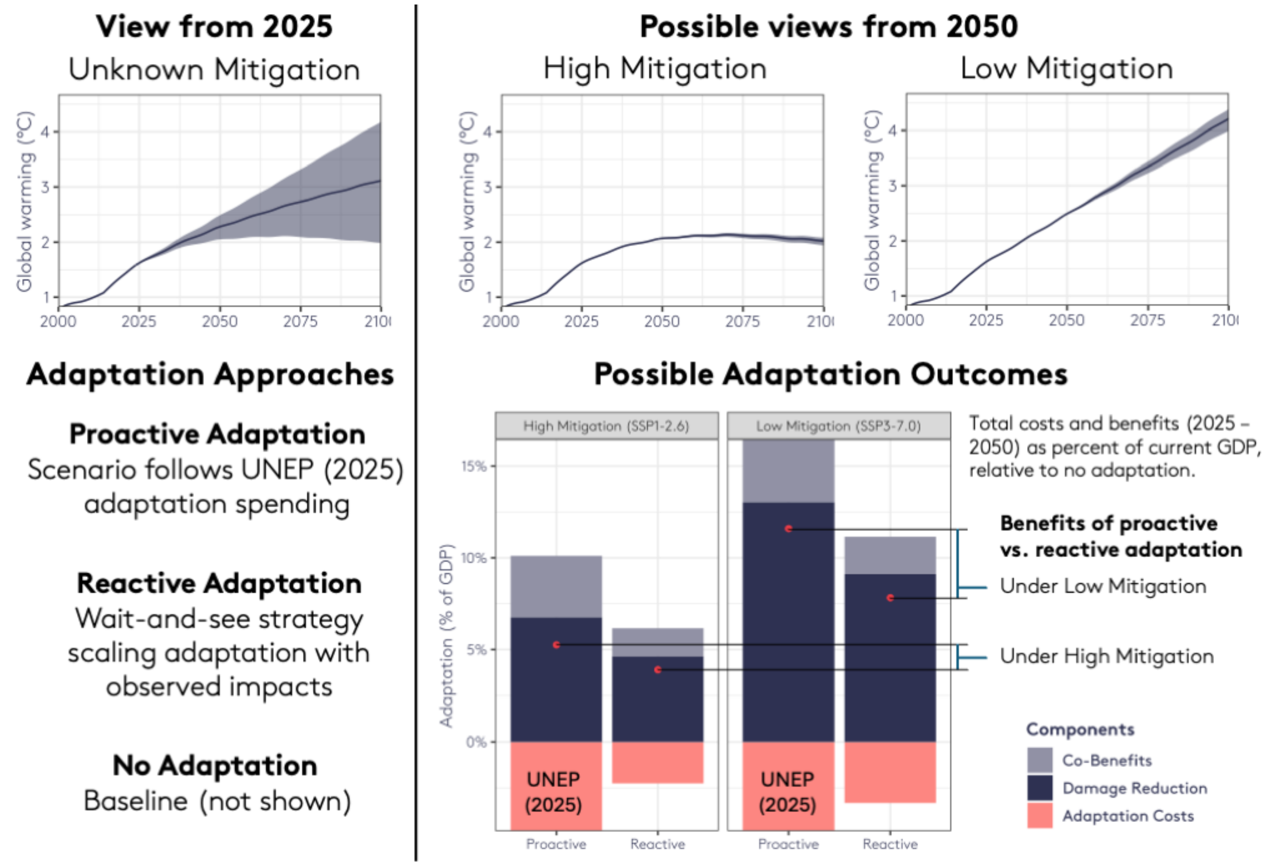


Figure A.6.1. Projected hazards (top row) and the outcomes of adaptation strategies. Middle and right columns correspond to possible futures within the range of uncertainty. The proactive strategy follows recommended adaptation investment, and produces the highest damage reductions and co-benefits. The reactive adaptation strategy (or wait-and-see) invests only to the extent that hazards reach high levels, with a delay. Co-benefits do not depend upon the realised mitigation pathway, but damage reduction depends on the extent of damages. Damage reduction is set to the median adaptation effectiveness ratio of 25%, and total benefits follow the benefit–cost ratio of 4, phased in after 5 years over the next 25 years

A.7. Data availability

The prepared inputs, diagnostic outputs, produced data files and generated figures are available in a Zenodo repository at: 10.5281/zenodo.17309465.

The quantitative syntheses performed for this report are based on data from the papers in Table A.7.1, below.

Table A.7.1. Studies included in quantitative syntheses for the report (each synthesis is represented by multiple rows, as labelled in column 1)

Synthesis	Reference
GDP	Dell M, Jones BF, and Olken BA (2012) Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3), 66-95.
GDP	Burke M, Hsiang SM, and Miguel E (2015) Global non-linear effect of temperature on economic production. *Nature*, 527(7577), 235-239.
GDP	Pretis F, Schwarz M, Tang K, Haustein K, and Allen, MR (2018) Uncertain impacts on economic growth when stabilizing global temperatures at 1.5 C or 2 C warming. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 376(2119), 20160460.
GDP	Burke M, Alampay Davis WM, and Diffenbaugh, NS (2018) Large potential reduction in economic damages under UN mitigation targets. *Nature*, 557(7706), 549-553.
GDP	Sequeira TN, Santos MS, and Magalhães M (2018) Climate change and economic growth: a heterogeneous panel data approach. *Environmental Science and Pollution Research*, 25(23), 22725-22735.
GDP	Henseler M and Schumacher I (2019) The impact of weather on economic growth and its production factors. *Climatic Change*, 154(3), 417-433.
GDP	Kalkuhl M and Wenz L (2020) The impact of climate conditions on economic production. Evidence from a global panel of regions. *Journal of Environmental Economics and Management*, 103, 102360.
GDP	Acevedo S, Mrkaic M, Novta N, Pugacheva E, and Topalova P (2020) The effects of weather shocks on economic activity: what are the channels of impact? *Journal of Macroeconomics*, 65, 103207.
GDP	Damania R, Desbureaux S, and Zaveri E (2020) Does rainfall matter for economic growth? Evidence from global sub-national data (1990–2014). *Journal of Environmental Economics and Management*, 102, 102335.
GDP	Kahn ME, Mohaddes K, Ng RN, Pesaran MH, Raissi M, and Yang JC (2021) Long-term macroeconomic effects of climate change: A cross-country analysis. *Energy Economics*, 104, 105624.
GDP	Kotz M, Levermann A, and Wenz L (2022) The effect of rainfall changes on economic production. *Nature*, 601(7892), 223-227.
GDP	Callahan CW, and Mankin, JS (2022)Globally unequal effect of extreme heat on economic growth. *Science Advances*, 8(43), eadd3726.
GDP	Zhao X, Gerety M, and Kuminoff NV (2018) Revisiting the temperature-economic growth relationship using global subnational data. *Journal of Environmental Management*, 223, 537-544.

GDP	De Vos I and Everaert G (2021) Bias-corrected common correlated effects pooled estimation in dynamic panels. *Journal of Business & Economic Statistics*, 39(1), 294-306.
GDP	Yang Y, Jia F, and Li H (2023) Estimation of panel data models with mixed sampling frequencies. *Oxford Bulletin of Economics and Statistics*, 85(3), 514-544.
Labour Productivity	Australian Government (2023) *2023 Intergenerational Report: Australia's future to 2063* (ISBN 978-1-925832-81-5).
Labour Productivity	Rode A, Baker RE, Carleton T, D'Agostino A, Delgado M, Foreman T, Gergel DR, Greenstone M, Houser T, Hsiang S, Hultgren A, Jina A, Kopp RE, Malevich SB, McCusker KE, Nath I, Pecenco M, Rising J, and Yuan, J (2022) *Labor disutility in a warmer world: The impact of climate change on the global workforce* (SSRN Scholarly Paper No. 4221478). Social Science Research Network.
Labour Productivity	Taha RT, Abed MQ, Alamro L, and Muhsin AI. (2024) Statistical methods for analyzing economic impacts of climate change. *Journal of Ecohumanism*, 3(5), 385–405.
Labour Productivity	World Bank (2023) *Côte d'Ivoire country climate and development report* (World Bank Group Report No. 40560). The World Bank Group.
Labour Productivity	World Bank Group (2022) *G5 Sahel Region Country Climate and Development Report* (Country Climate and Development Report). The World Bank Group.
Labour Productivity	World Bank (2022) *Malawi – Country Climate and Development Report: Sectoral impacts of climate change in Malawi: Deep dive on land, water, agriculture, energy, infrastructure, and health*. The World Bank Group.
Labour Productivity	Li J, Naikal EG, Kerr T, and Hallegatte S (2024) *Rising to the challenge: Success stories and strategies for achieving climate adaptation and resilience*. The World Bank Group.
Labour Productivity	World Bank (2023) *Republic of Congo Country Climate and Development Report - Diversifying Congo's Economy: Making the Most of Climate Change*. The World Bank Group.
Total Factor Productivity Growth	Letta M and Tol R (2019) Weather, Climate and Total Factor Productivity. *Environmental and Resource Economics*, 73, 283-305.
Total Factor Productivity Growth	Bakkensen, and Barrage (2018) *Climate Shocks, Cyclones, and Economic Growth: Bridging the Micro-Macro Gap*. NBER Working Paper 24893.
Total Factor Productivity Growth	Liang XZ, Wu Y, Chambers RG, Schmoldt DL, Gao W, Liu C, ... and Kennedy JA (2017) Determining climate effects on US total agricultural productivity. *Proceedings of the National Academy of Sciences of the United States of America*, 114(12), E2285-E2292.
Inflation Rate	Kotz M, Kuik F, Lis E, and Nickel C (2024) Global warming and heat extremes to enhance inflationary pressures. *Communications Earth & Environment*, 5(1), 116.
Inflation Rate	Boirard A, Gayle D, Löber T, Parisi L, Payerols C, and Schets E (2022) *NGFS Scenarios for central banks and supervisors*. Network for Greening the Financial System.
Gini Index	AIM model from Emmerling J, Andreoni P, Charalampidis I, Dasgupta S, Dennig F, Feindt S, ... and Tavoni M (2024) A multi-model assessment of inequality and climate change. *Nature Climate Change*, 14, 1254-1260.

Gini Index	E3ME model from Emmerling J, Andreoni P, Charalampidis I, Dasgupta S, Dennig F, Feindt S, ... and Tavoni M (2024) A multi-model assessment of inequality and climate change. *Nature Climate Change,* 14, 1254-1260.
Gini Index	GEM-E3 model from Emmerling J, Andreoni P, Charalampidis I, Dasgupta S, Dennig F, Feindt S, ... and Tavoni M (2024) A multi-model assessment of inequality and climate change. *Nature Climate Change,* 14, 1254-1260.
Gini Index	Imaclim model from Emmerling J, Andreoni P, Charalampidis I, Dasgupta S, Dennig F, Feindt S, ... and Tavoni M (2024) A multi-model assessment of inequality and climate change. *Nature Climate Change,* 14, 1254-1260.
Gini Index	NICE model from Emmerling J, Andreoni P, Charalampidis I, Dasgupta S, Dennig F, Feindt S, ... and Tavoni M (2024) A multi-model assessment of inequality and climate change. *Nature Climate Change,* 14, 1254-1260.
Gini Index	ReMIND model from Emmerling J, Andreoni P, Charalampidis I, Dasgupta S, Dennig F, Feindt S, ... and Tavoni M (2024) A multi-model assessment of inequality and climate change. *Nature Climate Change,* 14, 1254-1260.
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