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Integrating Climate Change into Macroeconomic Analysis:

A Review of Impact Channels, Data, Models, and Scenarios

Pritha Mitra, Mehdi Raissi, Bruno Versailles, Samuele Centorrino, Maksym Ivanyna, Koralai Kirabaeva, Emanuele Massetti, Mariza Montes de Oca Leon, Ha Nguyen, William Oman, Nooman Rebei, Filippos Tagklis, Alice Tianbo Zhang, Christoph Ungerer, Javier Uruñuela López, and Sha Yu.

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Authorized for distribution by Pritha Mitra
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ABSTRACT: Climate change poses significant and diverse impacts on countries' macroeconomic and financial stability, resulting in complex macro-critical policy challenges. Consequently, where significant, country-level macroeconomic analysis may need to integrate climate change-related impacts and policies. This paper reviews (i) climate change and related policies' channels of impact on the real, fiscal, external, monetary, and financial sectors over various time horizons and (ii) corresponding data sources, models, and climate scenarios that could be applied in assessing the impact of physical climate risks as well as adaptation, transition, and mitigation policies. The paper concludes with considerations for future work..

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Contents

1. Introduction

Climate change is affecting countries' macroeconomic and financial stability through various channels and to different degrees. The impact can be significant for some countries. Against this backdrop, some country authorities and stakeholders are seeking to integrate climate change-related impacts and policies into country-level macroeconomic analysis. In support of these efforts, this paper outlines key channels through which climate change can affect the real, fiscal, external, monetary, and financial sectors. The paper also takes stock of relevant data sources, models, and climate scenarios—with a focus on those applied by the International Monetary Fund (the Fund)—that could be useful in assessing the impact of physical climate risks as well as adaptation, transition, and mitigation policies.[2]

The challenges posed by the global nature, uncertainties, and complexity of climate change must be carefully considered.

- Climate change has a wide range of inter-related impacts, manifesting both in ***gradual long-term shifts in climate*** and through changes to the frequency and intensity of ***extreme weather events*** (Box 1).
- The macroeconomic effects of climate change will unfold over different ***time horizons***. The increasingly frequent and intense extreme weather events (heat waves, cold snaps, droughts, floods, storms, wildfires, landslides) can have significant near- to medium-term effects. Slow-moving, long-term shifts in climate (e.g., sea-level rises, changes in precipitation patterns, and acceleration of warming trends) are often overlooked in near- to medium-term projections, but they can have significant effects, especially over longer periods.[3]
- Climate change affects ***real, fiscal, external, monetary, and financial*** sectors. Prudent planning requires understanding and, sometimes, quantification and incorporation of these effects into country-level analysis (baseline and/or alternative scenarios).
- In addition to the economic effects of a changing climate, the ***adaptation and mitigation policies*** countries adopt over the coming years may have important macroeconomic implications across economic sectors and, when relevant, need be integrated into country-level macroeconomic analysis.
- When macro-critical, the effects on specific sectors, such as **agriculture** and **energy systems,** should also be included in the analysis and discussions.[4]
- Application of realistic and consistent ***climate scenarios*** is essential. While climate scenarios are inherently uncertain, they are critical for integrating the effects of gradual global warming in country-level analysis, including long-term macroeconomic projections and Debt Sustainability Analysis (DSA). Scenarios are also essential for understanding the macro-financial implications of physical risks,[5] mitigation policies, and risks related to a country's transition to a low-carbon economy.

Much progress has been made in illustrating the macroeconomic effects of *climate change* and *climate policies.* In large part, the focus has been in illustrating the macroeconomic consequences and impact channels of natural disasters (including extreme weather events) and adaptation policies—for example, the Debt-

[2] NGFS (2024a) undertakes a model stocktaking exercise for the central banking community.

[3] In this paper, near-, medium- and long-term are defined with respect to the Fund's macroeconomic projection horizon. Near-term=1–5 years; medium-term=5-10 years; and long-term=years 10+. This differs from the medium-term defined in climate change scenarios (10-30 years) or the long-term which encompasses the end of the century.

[4] More broadly, the possibility of tipping points and cascading effects as well as the interaction between climate change and other environmental threats (e.g., biodiversity loss) are a source of uncertainty in impact assessments.

[5] In the financial sector, the span of slow-moving long-term shifts in climate (chronic risks) to the sudden, extreme weather events (acute risks) are all referred to collectively as *physical risks*.

Investment-Growth-Natural-Disasters (DIGNAD) model, the Climate Macroframework Toolkit (CMT) or the Natural Disasters Debt Dynamics Tool (ND_DDT). Several tools and models are also very helpful in studying the medium- to long-term macroeconomic effects of mitigation policies or transition risks—for example the Climate Policy Assessment Tool (CPAT) and the IMF-ENV model. The Global Macroeconomic Model for Energy Transition (GMMET) is suitable for short- to medium-term mitigation analysis. The macroeconomic effects of slow-moving long-term climate shifts—which are essential for assessing the potential avoidance of income losses due to climate action—are modeled in the GDP Impact Assessment Toolkit developed by Centorrino, Massetti, Raissi, and Tagklis (2025)—and used inter alia by the Quantitative Climate Risk Assessment Fiscal Tool or Q-CRAFT.

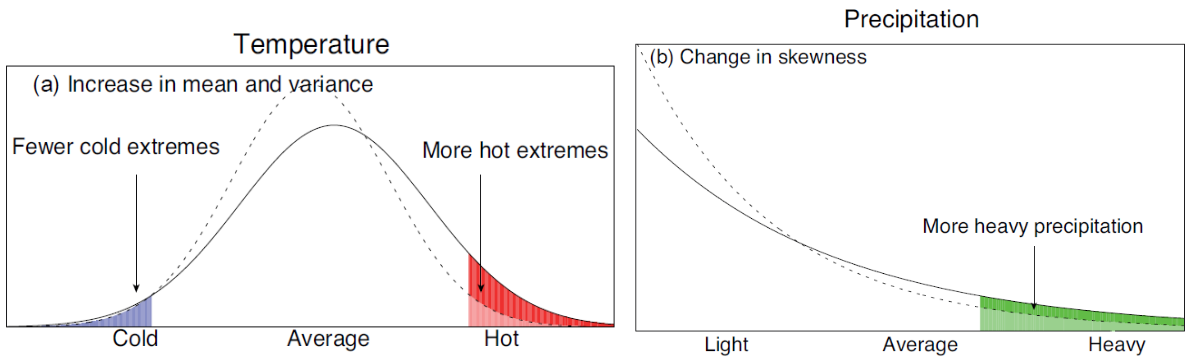
However, important gaps remain in country-level macroeconomic impact analysis of climate change and related policies. First, certain areas of modeling have yet to be explored or are facing challenges. For example, integration of long-term global climate change impacts into near-term macro-financial analysis is challenged by its reliance on high-resolution geographical coverage and detailed sectoral data. Similarly, the growth effects of changes to the frequency and intensity of extreme weather events and climate variability for a given country have not yet been systematically quantified (instead the literature primarily quantifies monetary damages or losses from past disasters largely sourced from the EM-DAT database). Second, most existing models and tools, even those widely applied, are often difficult to operationalize without extensive expert support. More generally, updating certain types of models with new data can be cumbersome, hindering their responsiveness to evolving circumstances. Finally, for countries where climate change impacts are macro-critical, country-level macroeconomic projections typically have not yet fully incorporated climate change considerations—beyond certain climate policies such as carbon pricing or subsidy reforms. In part, this reflects the challenges in systematic translation of model results into country-specific projections.

The remainder of this paper is structured as follows. Section 2 conceptualizes the impact of climate change on the macro economy, including a focus on different time horizons, sectors (real, fiscal, external, monetary, and financial), climate scenarios, and channels of impact. Section 3 and Annex 1 discuss key tools and models that have been used to link climate to macroeconomic outcomes—spanning an assessment of data sources and model/tool strengths, limitations, and usability relative to climate policy needs of a country (e.g., adaptation, transition, and mitigation issues). Section 4 provides some initial steps and considerations in bringing together the coverage of the previous two sections to support country-level macroeconomic analysis—including macroeconomic projections.

Box 1. Terminology

Weather refers to atmospheric conditions over short periods of time (e.g., temperature and precipitation).
Climate is the long-term (30 years) average and variability of weather (World Meteorological Organization).
Climate change is a "change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer (IPCC, 2021, Annex VII)."
Extreme weather events (heat waves, cold snaps, droughts, floods, storms, hurricanes, tornadoes, wildfires, landslides) can be caused by a variety of factors, including natural climate variability, human-induced climate change, and recurring natural climate patterns such as El Niño and La Niña.

Figure 1.1. Probability Density Functions of Temperature and Precipitation Move with Climate Change



Source: IPCC AR5 (p. 138).
Notes: The probability density function (PDF) of daily temperature tends to be Gaussian, and PDF of daily precipitation has a skewed distribution. Dashed lines represent a previous weather distribution and solid lines a changed climate. The probability of occurrence, or frequency, of extremes is denoted by the shaded areas.

2. Climate Change, Climate Policies, and Macroeconomic Outcomes

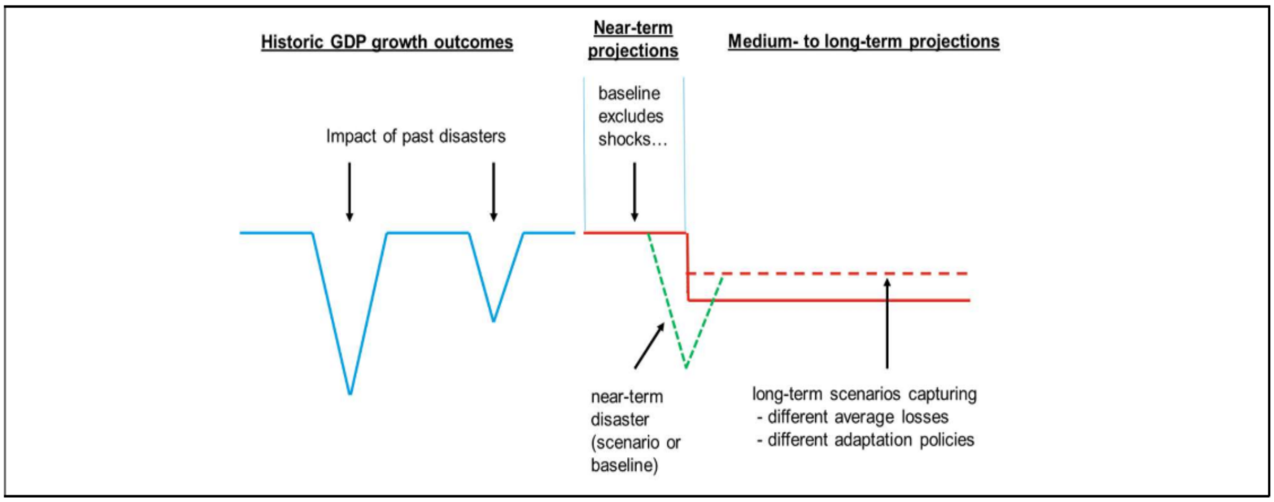
This section discusses how climate change—spanning from gradual long-term shifts in climate to more frequent/intense, extreme weather events—and climate policies could affect macroeconomic outcomes. The focus is on channels of impact in the real, fiscal, external, monetary, and financial sectors and how the extent of the effects hinges on the underlying climate scenario assumptions.

The multifaceted nature of climate change encompasses slow-moving long-term shifts in climate, variability in weather patterns, and more frequent/intense extreme weather events.[6] The effects of each, and their interactions, could be incorporated in economic growth projections but at different time horizons (Figure 1). GDP growth and its volatility can be impacted by extreme weather events (heat waves, cold snaps,

[6] While climate change can also bring limited potential benefits, such as longer growing seasons in certain regions or new economic opportunities, these are often outweighed by the broader risks and damages.

droughts, floods, storms, wildfires, landslides) and inter- and intra-annual variations in temperature and precipitation patterns over the near- to medium-term horizons. Gradual temperature increases (global warming) can affect long-term GDP growth persistently, but the impacts are not necessarily visible in near-term projections. Climate policies for adaptation and mitigation will also have important implications for macroeconomic projections (e.g., feedback effects on growth). Overall, the impact of climate change and associated policies will vary from country to country, depending on their climatic shifts and vulnerabilities, capacity to adapt, and the extent of ongoing global mitigation policies.

Figure 1. Illustrative Growth Projections/Scenarios with Disaster Impacts

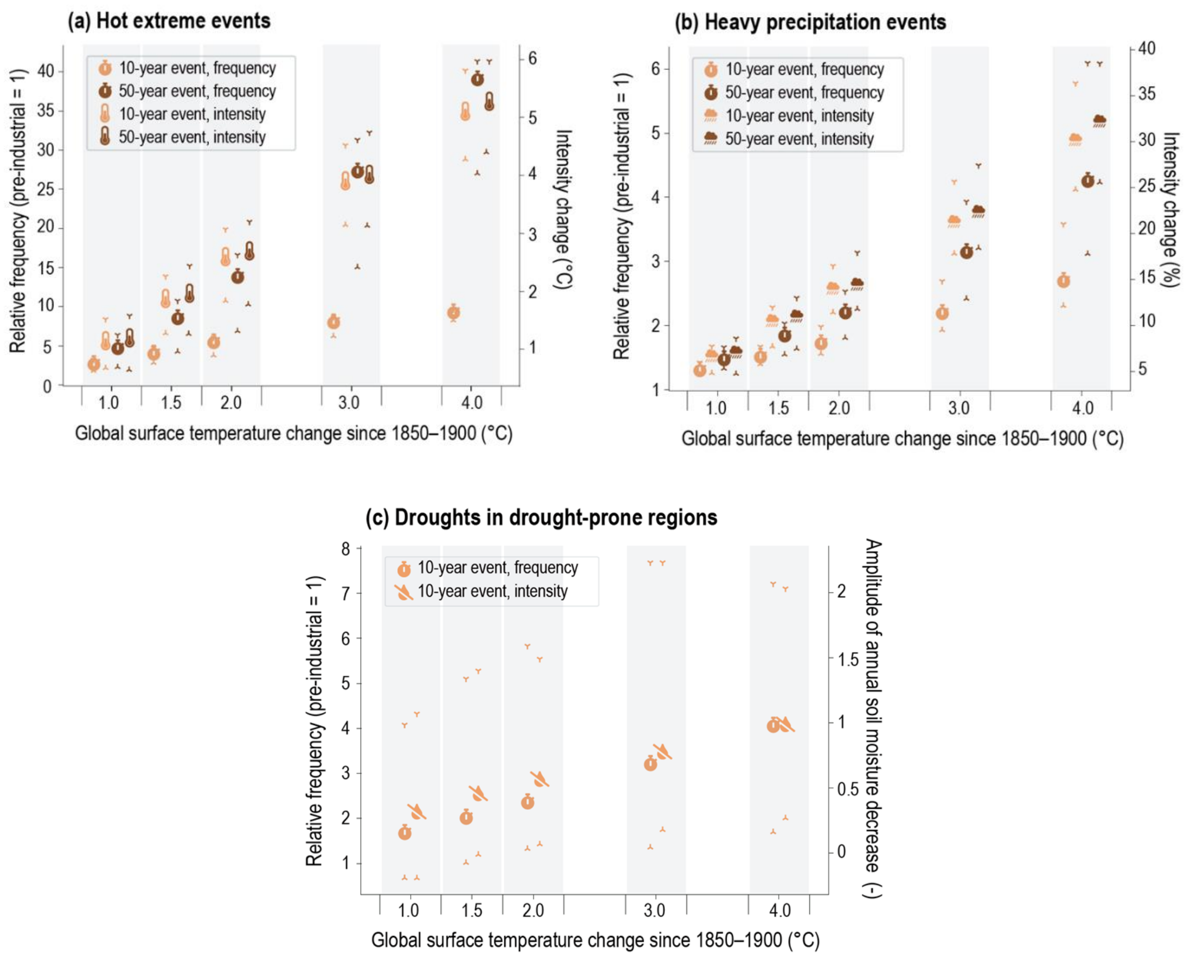


Source: IMF (2016), as modified by Aligishiev, Bellon and Massetti (2022)

The relationship between slow-moving climate shifts, extreme weather events, and variability in weather patterns (inter- and intra-annual) is not merely one of cause and effect but a dynamic interplay where each can amplify the impacts of the other. For example, a warmer atmosphere holds more moisture, leading to heavier precipitation and more intense storms. Similarly, higher temperatures exacerbate the severity of heatwaves. Changes in global circulation patterns can lead to altered precipitation, exacerbating droughts in some regions while increasing flood risks in others. The gradual increase in sea levels contributes to more destructive storm surges during hurricanes and tropical cyclones, leading to increased coastal flooding. The Intergovernmental Panel on Climate Change (IPCC)[7] AR6 Physical Science Report highlights a clear increase in frequency and intensity of extreme weather events as global average temperatures rise (Figure 2). Moreover, the report shows that the impacts of climate change on extreme weather events exhibit significant regional variability, with some areas more prone to specific types of events than others.

[7] IPCC is a United Nations body that assesses climate change science and provides governments with scientific information to help develop climate policies.

Figure 2. Frequency and Intensity of Extreme Weather Events as a Function of Global Warming



Source: IPCC (2021, p.83).

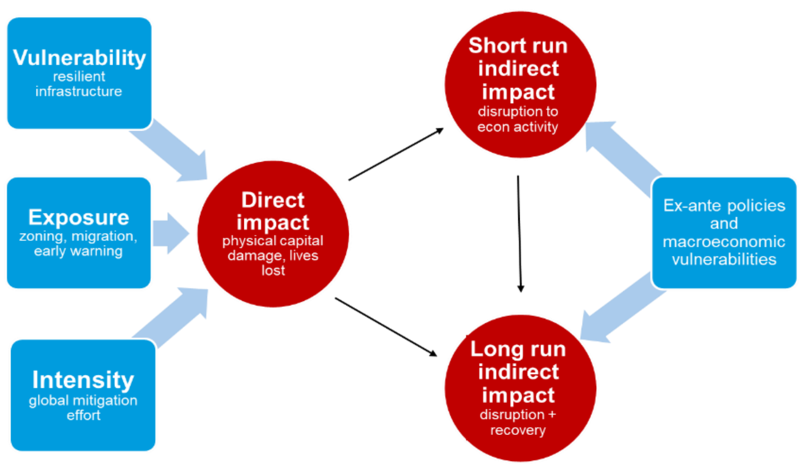
Notes: Extreme weather events change with warming levels. (a) Changes in the frequency (left scale) and intensity (in °C, right scale) of daily hot extremes occurring every 10 and 50 years. (b) As (a), but for daily heavy precipitation extremes, with intensity change in %. (c) Changes in 10-year droughts aggregated over drought-prone regions, with drought intensity (right scale) represented by the change of annual mean soil moisture, normalized with respect to interannual variability. Limits of the 5%−95% confidence interval are shown in panels (a – c).

Macroeconomic Effects of Climate Change

A gradual long-term shift in weather patterns (e.g., global warming, altered precipitation patterns, sea level rise) has long-term effects on economic growth. On the *demand* side, the potential future losses from, for example, a persistent rise in average temperatures or sea levels can encourage precautionary savings, greener consumption (e.g., fuel-efficient cars), or relocation. Investment decisions of businesses may be impacted by uncertain demand for existing goods and services, as well as prospects for new ones. On the *supply* side, persistent global warming could decrease long-term growth by lowering Total Factor Productivity growth through several key channels. These include a decline in agricultural crop yields, a reduction in labor productivity stemming from decreased physical and cognitive performances, as well as increased mortality and morbidity.[8] Additionally, global warming may slow capital accumulation due to permanent or long-term damage to capital and land, or an accelerated rate of capital depreciation. Lastly, it can lead to reduced capital productivity, as certain brown assets, such as coal power plants, may need to be retired before the end of their useful life, resulting in stranded assets. Overall, the impact of all these factors on economic growth and, subsequently, other economic variables could be significant in the long term.

In contrast, extreme weather events—especially with intensified frequency and severity—can have significant effects on economic growth and its volatility in both the near- and long-term (Figure 3).[9] The immediate and direct impact could be damage to infrastructure, property, and agricultural production; disruptions to energy supply, transportation, and logistics; and injuries and loss of life. The impact depends on the intensity or strength of the event (e.g., wind speed of a tropical storm); exposure of physical and human capital to the event; and countries' vulnerability (i.e., how protected they are against weather shocks). In turn, there could be multiple and longer-term indirect effects, sometimes resulting in only a partial recovery (i.e., scarring).[10]

Figure 3. Impact of an Extreme Weather Event on the Macroeconomy



Source: IMF staff.

- On the *demand* side, extreme weather events could reduce household wealth, private consumption, and business investment—notwithstanding mitigating factors such as insurance. At the subsequent rebuild phase, the reconstruction investment and restocking of consumer goods could boost demand. The impact could be lasting if, for example, household and corporate balance sheets are severely damaged. Business confidence might also plummet, triggering financial market selloffs that raise investment costs and further dampen domestic demand.
- On the *supply* side, these events could damage inventories, capital stocks, and infrastructure as well as human capital. The need to clear destroyed buildings, roads, and debris and time to rebuild and restart

[8] For instance Graff Zivin and Neidell (2014) (impact of temperature fluctuations on labor time allocation), and Deschenes and Moretti (2009) (impact of extreme weather events on morbidity).

[9] The terms "extreme weather events" and "disasters" are used interchangeably. Disaster is a broader concept, including man-made and natural phenomena, which may not be related to weather or climate change per se (for example, earthquakes or technological disasters).

[10] Botzen, Deschenes, and Sanders (2019) has more details. Migration is another channel through which climate change affects the economy (e.g., from changes to the labor supply, to social assistance needs in places that receive migrants, to balance of payments impacts through remittances); Cruz and Rossi-Hansberg (2024) elaborates.

production persistently reduce total factor productivity.[11] Domestic and international trade could suffer from disruptions to supply chains, transportation routes, or communication networks and a shortage of imported inputs, in particular commodities. Climate change could also intensify resource competition and exacerbate civil and inter-state conflicts.

Inflation would also be affected. In the near-term, supply shortages from damaged agricultural production and trade disruptions could raise prices of goods and services—particularly for food, energy imports, and other commodities. Over the long-term, the size and persistence of the effects on supply relative to demand will play an important role (Annex 2).

The balance of payments—comprising current, capital, and financial accounts—is impacted through various channels (Table 1). Regarding the current account and beyond the immediate impact of trade disruptions on exports, a country's *ability* to produce goods and services for exports could be adversely affected. For instance, extreme weather events can inflict long-term damage on tourist destinations. Likewise, prolonged recovery from damage to domestic food production could result in increased food imports. The capital and financial accounts are similarly affected. Foreign investors' reactions to changes in the economic growth prospects of the impacted country may be compounded by climate-related risks and uncertainties, resulting in lasting changes to foreign direct investment (FDI) and portfolio investment flows. Amid extreme weather events, foreign aid and insurance payments could mitigate the near-term impacts, even though increasing risk premia might reduce payouts as climate risks escalate. Additionally, climate change challenges in other countries can affect net remittances received by the affected country. Overall, these balance of payments pressures will influence the exchange rate and subsequently a country's competitiveness.

The combined effects of the above will have significant implications for employment, fiscal balances, and financial markets (Table 2, Figure 4). Reduced activity in labor-intensive economic sectors, such as agriculture and tourism, will negatively affect employment and income inequality. Decreases in income and employment will impact tax revenues, including income and corporate taxes, consumption taxes (e.g., Value Added Taxes), and excises. Government spending, driven by automatic stabilizers on the expenditure side like unemployment benefits and certain forms of social assistance, will rise. Contingent liabilities may increase due to state-owned enterprises being adversely affected by climate change. Faced with extreme weather events, the public sector may need to offer social assistance as climate change drives up private disaster insurance premia, leaving more consumers uninsured.[12] Public Private Partnerships (PPPs) and Power Purchasing Agreements (PPAs) can also expose the government to significant fiscal risks.[13] Weakened fiscal balances and lower economic growth could result in higher debt-to-GDP ratios and increased sovereign spreads. In the financial sector, higher non-performing loans (partly due to the weakened balance sheets of households and corporations) could elevate banking sector risks. Subsequent rises in lending rates could further dampen economic activity. Higher underwriting risks for insurers could result in reduced insurance coverage in vulnerable regions and impair asset values.

[11] Hallegatte and others (2022), Hallegatte and Vogt-Schilb (2019) and Hallegatte, Jooste, and McIsaac (2022).

[12] Insurance can help mitigate the financial impact of disasters, but climate change is driving up premia, making coverage unaffordable for the vulnerable. If insurers exit the market due to pricing difficulties, private markets could collapse. Governments may need to provide subsidies or guarantees to maintain affordable insurance to the vulnerable, which could increase public expenditure. If insurers go bankrupt, the government may have to bail them out or increase spending to support affected individuals.

[13] For example, PPP hydroelectric dams might not generate sufficient electricity due to reduced water inflow or may shut down due to high-water levels from heavy rain, leading to government liabilities and requiring power purchases by the government at higher rates.

Table 1. Climate Change Impacts on Balance of Payments

Current Account	Capital and Financial Account
Trade in Goods and Services • *Exports:* Disrupted production of agricultural goods; reduced energy exports owing to transition risks or infrastructure damage; disruptions to services like tourism due to extreme events. Increased exports of transition metals. • *Imports:* Increased food imports due to crop failures or climate-induced scarcity; higher import costs for disaster relief supplies and equipment; increased imports of adaptation technologies (e.g., drought-resistant seeds, seawalls); lower fossil fuel imports; increased imports of transition metals, and equipment for green energy. **Income and Transfers** • *Investment Income:* Uncertain impact on returns depending on context. • *Remittances:* Decreased when there is climate-induced displacement/migration of emigrated workers. Increased if only home country is affected. • *(Re)insurance:* Private insurance payouts may decline as weather-related insurance premia increase and the market collapses. Public insurance payout may increase, depending on donor financing availability (in certain cases, such payouts would affect the capital account).	• *Capital transfers:* May increase with international aid or climate-related donations. • *Foreign Direct Investment (FDI):* Reduced inflows due to risks/uncertainties. • *Portfolio Investment:* Outflow of investments due to climate-related financial risks. • *Public sector borrowing and other capital*: Increased borrowing and inflow of international financial assistance (too much public borrowing could also increase risk premia or lead to downgrades).
Indirect • *Economic Growth:* Negative impact on growth owing to reduced net exports and net financial inflows. • *Exchange Rate:* Cumulative impact of balance of payments changes can affect exchange rate, influencing competitiveness.	

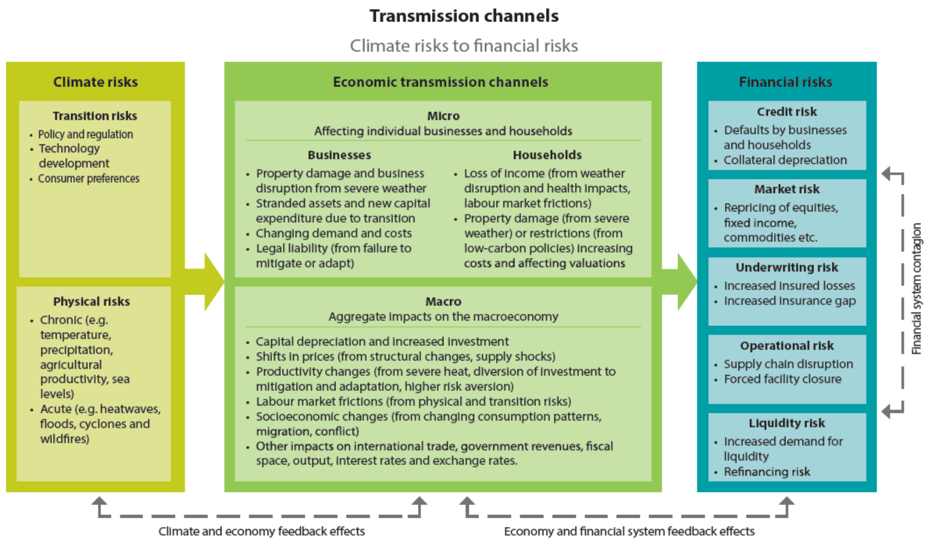
Source: IMF Staff.

Table 2. Climate Change Impacts on Public Finances

Non-discretionary impact *Exogenously driven by climate change*	**Discretionary impact** *Endogenously driven through climate policies*
Direct • Public spending to replace damaged infrastructure or buildings. • Social transfers to households affected by natural disasters and displaced people, especially for the uninsured. • Materialization of explicit contingent liability, e.g., insurance schemes backed by state guarantees and the collapse of private insurance markets without state subsidies or guarantees. **Indirect** • Reduced tax revenue due to GDP losses. • Increased health care spending due to heatwaves, air pollution, and waterborne diseases linked to climate change. • Materialization of implicit contingent liabilities, e.g., support to financial institutions in distress, including casualty and catastrophe insurers. • Impact on sovereign capacity to honor debt obligations over time (e.g., due to budgetary funds reallocation towards recovery and reconstruction).	• Public investments and subsidies to *mitigate* climate change. • Revenue from carbon pricing and savings from phasing out of energy subsidies. • Adaptation investment/subsidies to protect existing infrastructure from sea-level rise, extreme weather, and changing precipitation patterns. • Natural disaster emergency spending, including compensation for financial losses of economic agents, and repairing and rebuilding assets. • Build-up of buffers or contingency funds.

Source: IMF staff; European Commission (2020, Box 5.3).

Figure 4. Impact of Climate Change and Policies on Financial Sector



Source: NGFS 2023a.

Macroeconomic Effects of Climate Policies

Climate policies can influence various aspects of economic growth. Climate physical risks call for adaptation and mitigation actions by households, companies, and governments. These actions, or policies, reduce damages implicitly and affect both demand- and supply-side drivers of growth explicitly. For example, government spending on reconstruction after an extreme weather event stimulates consumption and investment while also restoring physical capital. Energy-saving regulatory changes would have similar effects (e.g., installing energy efficient windows). Pricing climate-related externalities (e.g., carbon pricing, excises, and other taxes and levies) could potentially lower real incomes and consumer spending. However, fiscal revenues generated form carbon pricing can finance substantial investments in energy transition (e.g., green electricity generation) and adaptation (e.g., resilient roads). In turn, these investments could stimulate demand in specific sectors and transform the stock of capital. More generally, economic structures may change resulting from new incentives for research and development (e.g., green energy technologies) and job reallocations. Education and social policies will be key to ensuring a just transition from high- to low-carbon sectors and will have macroeconomic effects.

The balance of payments effects will be wide-ranging (Table 1). For instance, following an extreme weather event, implementation of disaster relief, and reconstruction policies can boost imports of basic goods and services. Meanwhile, the structure of imports could shift due to resilience-building (e.g., imports of drought-resistant seeds), the energy transition (e.g., imports of solar panels) or changes in economic structures (e.g., changes in types of goods produced). For similar reasons, the export base could also change. Capital and financial accounts will be shaped by financing flows related to climate policies—ranging from disaster relief grants for governments to private sector borrowing in support of resilience-building and the energy transition.[14]

For most countries, climate policies could have long-term benefits for public finances though near-term costs may be high (Table 2). Mitigation policies involving taxes (e.g., on carbon, fuel excises) and phasing out energy subsidies would create some fiscal space. However, typically, this will be insufficient to cover costs of rebuilding existing public infrastructure (after an extreme weather event), upgrading its climate resilience, and meeting new infrastructure needs due to climate change. Roads, bridges, water systems, sanitation, irrigation, flood barriers, early warning systems, and solar or wind electricity generation are some examples of this type of infrastructure. Building climate resilience and supporting a green transition will also entail stepping up spending on social assistance, green subsidies (e.g., for research and development), health care, education, and emergency buffers. Ultimately, these types of spending will significantly reduce the macroeconomic impact of extreme weather events, variability in weather patterns (intra- and inter-annual), and long-term shifts in weather patterns—minimizing associated future fiscal revenue losses and spending needs. Positive spillovers to economic development will amplify these long-term benefits.[15]

Debt levels and ratios will broadly mirror fiscal developments; however, the materialization of contingent liabilities could quickly worsen debt dynamics. In the near-term, climate policy-related fiscal spending needs (net of revenue-generating measures) will be large. Avenues for gaining fiscal space, such as reprioritizing non-essential spending or securing additional grants, may be limited. Governments are likely to take on more debt, which will also increase its service costs. The potential for financial engineering that links climate action to reduced sovereign debt premia is uncertain. Climate-vulnerable countries will likely face higher financing costs (Klusak et al. 2023 and Cevik and Jalles 2022). However, over the long-term, climate-resilient economic growth will reduce future debt needs and benefit sovereign debt premia. The materialization of contingent liabilities linked to cleanup efforts after natural disasters or increased social assistance spending in response to rising climate shocks could worsen debt dynamics.

Climate policies and their impact on the rest of the economy are consequential for monetary policy and the financial sector (Figure 4). The effectiveness of monetary policy may vary depending on the inflationary source.[16] For example, its impact may be limited in managing the initial effects of higher fuel prices (e.g., carbon taxes or phasing out of fossil fuel subsidies). In response to natural disasters, the monetary authorities may choose to prioritize price stability over immediate economic stimulus (Cantelmo et al. 2024), especially when fiscal policy is accommodative. However, it may have a larger role to play in managing shifts in prices resulting from structural changes in the economy. Financial sector risks could initially rise if business profits, and household wealth are adversely affected by climate policies. In particular, the transition to green energy could result in stranded assets in fossil fuel exporting countries with negative consequences for the balance sheet of financial institutions involved in the fossil fuel sector.

[14] For instance, the 2022 IMF External Sector Report uses a simulation-based approach to evaluate how global climate change mitigation policies could impact external balances over the coming decade (IMF 2022a).

[15] With well-designed climate-fiscal policies centered around carbon pricing, global decarbonization could result in fiscal impacts that range from moderately positive to moderately negative in high-income countries. Middle and low-income countries typically experience net fiscal effects that are predominantly positive and large (Black et al. 2024).

[16] Inflationary pressures from mitigation policies are likely modest (IMF 2022b). Radzewicz-Bak et al. (2024) explore the role of the financial sector in the Middle East and Central Asia in facilitating climate-related policies.

Scenarios Analysis

A variety of scenarios—reflecting different narratives of the future and the corresponding evolution of GHG emissions (and global warming)—can influence the analysis of physical risks and assessments of necessary mitigation efforts:

- **SSP-RCP Scenarios:** The Shared Socioeconomic Pathways (SSP) combined with Representative Concentration Pathways (RCP) provide a framework for "climate model"[17] runs under different courses of development (e.g., population and education; urbanization; and economic growth) and emissions trajectories (hence, warming levels).[18] The outcome of climate models are crucial for assessing the long-term macroeconomic impacts of global warming. For instance, a particular SSP-RCP pathway may imply a rapid increase in temperatures and more frequent and intense weather events (obtained from climate models) with significant implications for economic growth, the external, fiscal, and financial sectors as well as for debt sustainability (excluding tipping points that make the destabilization of the global climate system irreversible).
- **NGFS Scenarios:** The Network for Greening the Financial System (NGFS) has developed seven long-term scenarios for climate risk analysis in the economy and the financial sector (NGFS, 2023a) and is in the process of developing short-term scenarios. The long-term scenarios are categorized into four *transition types:* Orderly, Disorderly, Hot House World, and Too Little Too Late. While all seven NGFS long-term scenarios are nested within the SSP2 narrative (Box 2), each scenario includes specific assumptions about climate policies and technological advancements. These variations in policy stringency result in different emissions trajectories and ultimately, different levels of global warming. For instance, the NGFS "Hot House World" category encompasses "NDCs" and "Current Policies" scenarios, implying warming projections of 2.3°C and 3°C, respectively. With an increase in policy stringency, future climate outcomes would improve (e.g., "Net Zero 2050 (1.5°C)" and "Below 2 Degrees").[19]
- **IEA Scenarios:** The International Energy Agency (IEA) has developed three scenarios that explore how the energy system might evolve under different policy settings: (1) *Stated Policies Scenario (STEPS)* reflects current policy settings based on a sector-by-sector and country-by-country assessment of the energy-related policies that are in place, as well as those that are under development; (2) *Announced Pledges Scenario (APS)* assumes that all climate commitments made by governments and industries around the world, including NDCs and longer-term net zero targets, will be met in full and on time; and (3) *Net Zero Emissions (NZE) by 2050 Scenario* sets out a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050. The difference between the STEPS and the APS highlights the "implementation gap" that needs to be closed for countries to achieve their announced targets. The difference between the APS and the NZE highlight the "ambition gap" that needs to be closed to achieve the Paris Agreement goals.
- **Customized Scenarios:** Analysts, including at the Fund, often develop customized scenarios to assess climate risks or mitigation policies of individual countries or regions. These scenarios may incorporate elements of SSP-RCP, NGFS, or IEA scenarios, but they are tailored to the unique circumstances of the

[17] Specifically, climate models simulate the physics, chemistry and biology of the atmosphere, land and oceans in detail, and require some of the largest supercomputers in the world to generate their climate projections.

[18] More precisely, climate scenarios describe how the future might unfold under different levels of radiative forcing and socio-economic pathways. As most countries cannot individually influence the trajectory of average temperature increases, the choice of the global climate scenario(s) is crucial as assumptions to feed into physical risks impact assessments.

[19] Gardes-Landolfini et al. (2023) argue that the NGFS climate scenarios should better reflect: (1) pullbacks in climate mitigation policies and increased carbon lock-in in fossil fuel infrastructure and policymaking; (2) the decreasing likelihood of continuous cost reduction in renewable energy technologies; and (3) the likely intensification of macroeconomic shocks amid increasing geoeconomic fragmentation and the associated policy responses.

country or region being analyzed. At times they are taken directly from authorities' projections (e.g., from NDC packages).[20] An example is climate risk analysis in Financial Sector Assessment Programs (FSAPs), where Fund analysis at times deviates from NGFS scenarios—including by investigating the impact of low likelihood but plausible tail risks. For example, the FSAPs for the Philippines, Mexico, and the Maldives have employed higher warming scenarios to assess climate-related physical risks. Other examples of tail risk analysis include the impact of 1-in-100-year flood event in Mexico and 1-in-500-year tropical cyclone in the Philippines.

The choice of scenario often depends on the specific area of analysis:

- **Physical Risks:** Changes in the climate system projected by climate model runs participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6) under select SSP-RCP pathways is appropriate for physical risk assessments (Box 2). Notwithstanding the inherent uncertainty that comes with the SSP-RCP pathways, they allow for a uniform global temperature increase assumption to be applied in macroeconomic analysis (including damage estimates). Against this backdrop, the recommended baseline climate scenario for application in Fund analysis of physical risks is SSP2-4.5 (warming of 2.7°C by 2100 with a very likely range of 2.1°C to 3.5°C; Figure 5). This is largely in line with the global temperature pathways under current policies as well as assessments of the impact of both conditional and unconditional Nationally Determined Contributions (NDCs).[21] Recent analysis (Black, Parry, and Zhunussova, 2024), based on the implementation of current policies, suggests the world appears set to experience a temperature increase at the upper bound of the First Global Stocktake. This stocktake estimated that the global temperature increase could fall in the range of 2.1-2.8°C by 2100 based on NDC commitments from about 2 years ago. The choice of baseline climate scenario is periodically updated for consistency with current policies and actual warming. Two alternative climate scenarios complement the baseline. First, an optimistic scenario such as SSP1-2.6 which is consistent with the Paris Agreement (global warming below 2°C). Second, a pessimistic scenario like SSP3-7.0 which is characterized by policy reversals and faster warming.

Figure 5. Changes in Global Surface Temperature under Different SSP-RCP Scenarios

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

Source: IPCC AR6 Physical Science Report.

Notes: Reports temperature differences relative to the average global surface temperature of 1850 – 1900 in °C.

- **Transition Risks and Mitigation Actions:** As part of the IPCC's Sixth Assessment Report (AR6), there has been a comprehensive exercise to collect and assess quantitative, model-based scenarios related to the

[20] Several FSAPs, including those for the UK, Mexico, Kazakhstan, and Japan, have leveraged or built upon NGFS scenarios to assess climate-related financial risks (Laliotis and Lamichhane, 2023).

[21] Fully implementing efforts implied by unconditional Nationally Determined Contributions (NDCs) would put the world on track for limiting temperature rise to 2.9°C. Conditional NDCs fully implemented would lead to temperatures not exceeding 2.5°C above pre-industrial levels (United Nations Environment Programme, 2023).

mitigation of climate change—a collection of 3,131 peer-reviewed scenarios (including from NGFS up to October 2021) with data on socio-economic pathways, greenhouse gas emissions, and sectoral transformations across energy, land use, transportation, and industry sectors. These scenarios are also mapped into temperature categories that align with the three climate scenarios discussed above (baseline and two alternative scenarios). These can, in turn, inform the macro-financial assessment of transition risks and mitigation actions, and complement the IEA's STEPS scenario which is used inter alia by IMF-ENV and CPAT (IMF 2024 provides an example of an application to Australia).

- **Country-Specific Risks:** Customized scenarios can help identify the unique physical risks and vulnerabilities of individual countries or regions, and analyze country-specific or regional climate policies. At the Fund, this includes in the context of Financial Sector Assessment Programs (FSAPs).

Box 2. Scenarios and Climate Models

As background, the key types of socioeconomic and emission scenarios include:

- **SSPs (Shared Socioeconomic Pathways)** describe potential future pathways of societal development, focusing on population and education, urbanization, and economic development. They provide a framework for understanding how different socioeconomic conditions could influence greenhouse gas emissions and climate change. However, SSPs without RCPs lack a specific quantitative translation to temperature. Consequently, SSPs are quantified for both no-climate-policy reference scenarios and mitigation scenarios that follow similar radiative-forcing pathways as RCPs (Box Figure 2.1). There are 5 main SSPs, each representing a different narrative of how the future might unfold:
  - SSP1: Sustainability—Taking the Green Road (low challenges to mitigation and adaptation). This is a world of green growth and income inequality.
  - SSP2: Middle of the Road (medium challenges to mitigation and adaptation), where historical patterns of development are continued throughout the 21st century.
  - SSP3: Regional Rivalry—A Rocky Road (high challenges to mitigation and adaptation). This represents a fragmented world of resurgent nationalism.
  - SSP4: Inequality—A Road Divided (low challenges to mitigation, high challenges to adaptation). This is a world with little investment in education or health in poorer countries coupled with a fast-growing population and increasing inequalities.
  - SSP5: Fossil-Fueled Development—Taking the Highway (high challenges to mitigation, low challenges to adaptation). This is a world of rapid and unconstrained growth and energy use.
- **RCPs (Representative Concentration Pathways)** describe possible trajectories of future radiative forcing in watts per meter squared (the warming effect caused by greenhouse gases) based on different levels of global emissions. They provide a basis for climate model simulations, allowing scientists to project future climate changes under various emissions scenarios. However, RCPs without explicit SSPs assume an unspecified socio-economic context (e.g., energy and land-use). There are

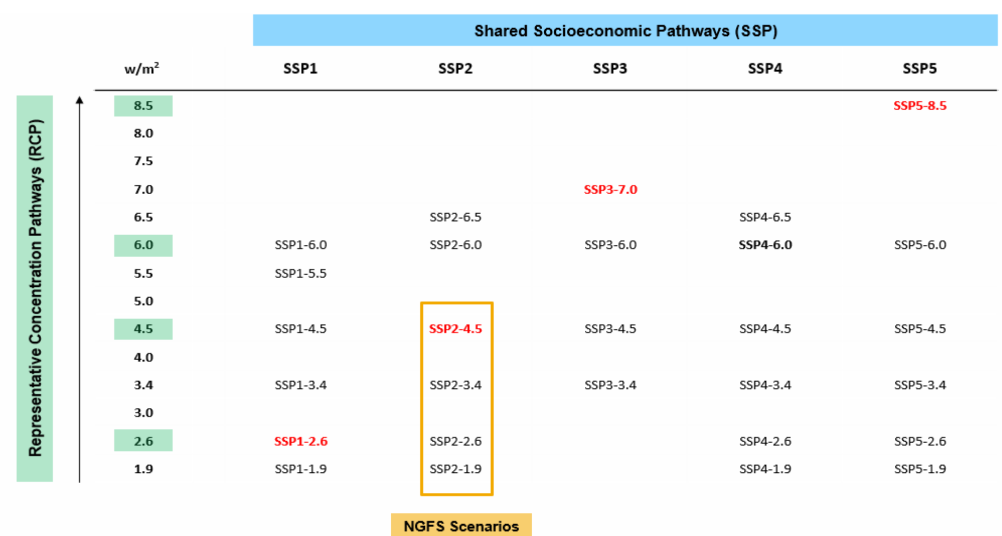
4 main RCPs, each named for its approximate radiative forcing in 2100:

- RCP 2.6: Very low forcing level, consistent with limiting warming to 2°C.
- RCP 4.5: Intermediate forcing level.
- RCP 6.0: Higher forcing level.
- RCP 8.5: Very high forcing level, representing a scenario with continued high emissions.

Six different integrated assessment models (IAMs) are used to translate SSP marker scenarios into estimates of future energy use and global GHG emissions, as well as how different climate mitigation targets (defined by radiative forcing levels analogous to the RCPs) can be achieved through policies. SSPs and RCPs, in turn, provide input data for climate model simulations (including as a part of the Coupled Model Intercomparison Projects, or CIMP for short: a framework for coordinated climate change experiments). Not all SSP-RCP combinations are plausible. For tractability, the reference SSP-RCP scenarios do not consider feedback from climate change or associated impacts. This makes them particularly relevant for subsequent impact analysis because it facilitates the superposition of physical climate changes on top of the SSP-RCP scenarios to derive consistent estimates of impacts (or adaptation).

- **NGFS (Network for Greening the Financial System) Scenarios** provide specific guidance on macro-financial implications of climate risks. They use a combination of WEO short-term GDP projections and SSP2 long-term GDP projections but vary in technology deployment and climate policies to reach different emissions levels and temperature pathways. The NGFS scenarios are also mapped into RCP emissions trajectories for comparison. They focus on the implications of different climate scenarios for financial stability and the transition to a low-carbon economy. They were developed by a group of central banks and supervisors, and include the following categories (7 scenarios in total):
  - Orderly (Low Demand; Net Zero 2050 (1.5°C); Below 2 Degrees)
  - Disorderly (Delayed Transition)
  - Hot house world (NDCs; Current Policies)
  - Too little, too late (Fragmented World)

Box Figure 2.1. RCP-SSP Scenario Matrix and Relation to NGFS Scenarios



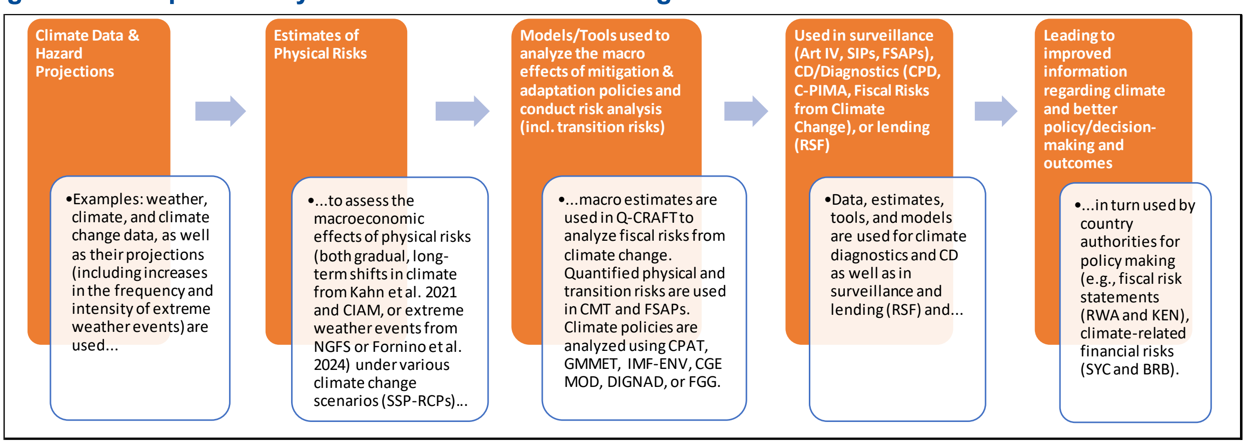
Sources: IMF Staff; Riahi *et al.* (2016, 2017); O'Neill et al. (2014, 2017, 2020); NGFS (2023a).

3. Climate-Macro Models and Tools

This section surveys climate-macroeconomic models and tools, with a focus on those frequently used at the Fund. The emphasis is on their strengths, limitations, and usability, including those applied to investigate the impact of adaptation and mitigation policies as well as transition issues.

During recent years, significant progress has been made in integrating the impact of climate change and climate policies into macroeconomic models and tools. As an example, Figure 6 explains how different types of climate-macroeconomic resources complement each other in the Fund's surveillance and analytical work, lending, and capacity development. Historical data on weather, climate, and climate change can be used to estimate the macroeconomic effects of physical risks (e.g., slow-moving long-term shifts in climate and sudden extreme weather events) under various climate change scenarios. These estimates are then used in macro-structural models or tools for calibration of key behavioral parameters (and shocks), or risk analysis, and contribute also to the evaluation of various climate policies (which, by themselves have macroeconomic effects). Empirical estimates are also part of climate diagnostic exercises, including the IMF's Climate Policy Diagnostic (CPD). These diagnostics are complementary to the World Bank's Country Climate and Development Reports (CCDR) which integrates climate and development considerations (including detailed sectoral analysis). Climate-related risk analysis (both financial and fiscal) also relies on climate data and quantified physical risks (e.g., Q-CRAFT alternative scenarios or FSAPs).

Figure 6. Complementary Resources for Climate Integration at the IMF



Source: IMF staff.

Quantifying the Macroeconomic Effects of Slow-Moving Long-Term Shifts in Weather Patterns

The literature focuses on several approaches to quantify the macroeconomic impacts of climate change, each with unique strengths and weaknesses. These methods include Integrated Assessment Models (IAMs); Computable General Equilibrium (CGE) models; and econometrics.

- **Integrated Assessment Models** rely on enumerative methods and expert elicitation to estimate the income loss from climate change. IAM modelers collect and add up regional-sector damage estimates (e.g., to agriculture, health, or infrastructure) from microeconomic studies, valuing physical impact assessments from the sciences, or expert elicitation. A damage or loss function is embedded in IAMs to determine the economic impact of rising temperature, usually expressed in terms of lost GDP or consumption. While this approach captures diverse damages, *it may not fully account for price changes and interactions between sectors (i.e., general equilibrium effects)*.
- **Computable General Equilibrium** models capture the impacts of climate change on economic activity through changes in the stock of inputs (e.g., labor by changing migration patterns, capital and land), factor productivity (capital, labor, land, and/or total), and demand for goods and services (energy, health, and/or tourism). CGE models have either a dynamic recursive structure or a full forward-looking rational expectations structure. They include price changes and market interactions between sectors but *in most cases omit non-market and catastrophic impacts and transition costs*. The economic modules embedded in the IAMs can be taken from CGE or Dynamic Stochastic General Equilibrium (DSGE) models.
- **Econometric** models are increasingly used to assess the macroeconomic impact of climate and weather. More recent literature largely uses panel data models to estimate the macroeconomic effects of temperature increases. However, approaches vary depending on whether temperature changes affect the *level*, or the *growth rate*, of GDP. Figure 7 depicts the potential impact of a permanent temperature increase compared to historical averages (ΔT > 0). This temperature increase is likely to result in a loss of GDP: once temperatures stabilize, the economy can then either resume growth at the trend rate (blue line) leading to a permanently lower GDP level compared with the original trajectory (represented by the dotted line), or the loss can be so severe that it reduces the trend growth rate of GDP (red line). *A major criticism of econometric models is their inability to account for tipping points (e.g., collapse of the Greenland and West Antarctic ice sheets; abrupt thawing of the permafrost; death of all tropical coral reef systems; and collapse of the Labrador Sea current), non-market damages (e.g., mortality, conflicts, food insecurity), and spillover effects. Meanwhile, inference about future damages based on past data is also fraught with difficulty and uncertainty*.

Figure 7. Level vs. Growth Effects of Temperature Increases

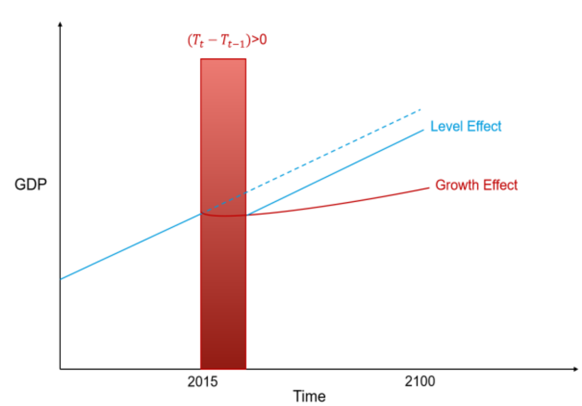
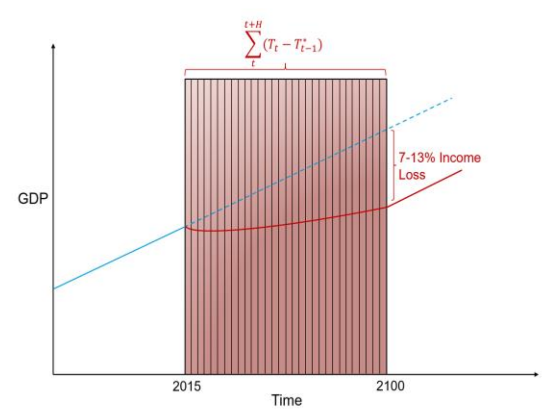


Figure 8. Level vs. Growth Effects of Persistent Temperature Increases



Notes: Figure 8 shows the results in Kahn et al. (2021) under a high-emissions scenario with and without climate variability.

While understanding the economic impact of global warming is crucial for climate policy, the most used estimates in the literature differ by an order of magnitude. The wide range of estimates arises from a disagreement about whether a temperature increase will affect GDP levels or GDP growth rates and from different model specifications (including how extreme weather events, climate variability, and adaptation are considered). Most IAMs, CGEs, and econometric models that relate temperature to GDP levels yield income loss estimates that are relatively small. An exception is Kotz et al. (2024) where climate physical risks affect the level of GDP persistently in large magnitudes. Studies that relate temperature to GDP growth (possibly nonlinearly), show that a shift to a higher (non-decreasing) temperature reduces output growth significantly (with compounding level effects over time) relative to a "no further warming" baseline. [22] Burke et al. (2015) consider a panel specification with quadratic climate variables in regressions and find that GDP growth peaks at annual average temperature of 13°C and then declines as temperatures rise further. This means that a one-off permanent increase in temperature can create a long-lasting divergence in cross-country economic growth globally, with hot countries growing ever poorer and cold countries experiencing faster growth as they warm.[23]

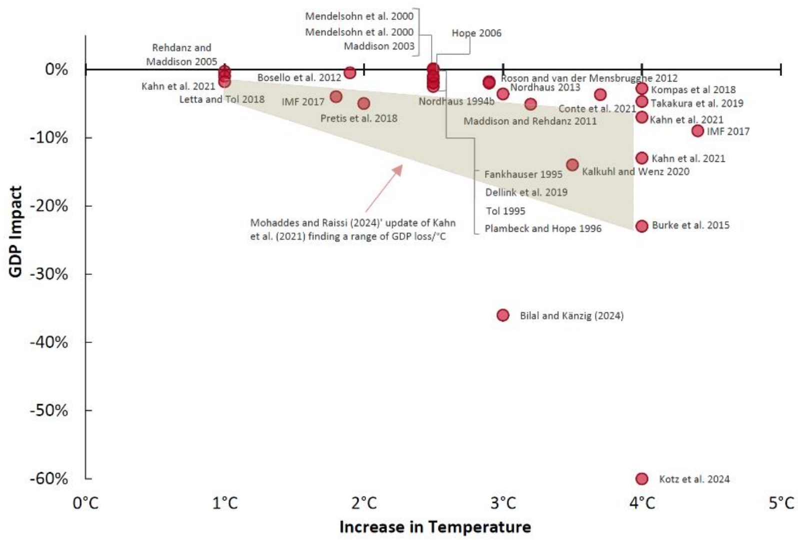
Kahn et al. (2021) establish a crucial distinction between a one-off shift to permanently higher temperatures and persistent temperature increases (i.e., climate vs. climate change). According to Tol (2024), Nath, Ramey, and Klenow (2024), and Kahn et al. (2021), the hypothesis that a one-off rise in temperature would affect the growth rate of the economy is theoretically inconsistent. Kahn et al (2021), therefore, link deviations of temperature (weather) from its 30-year rolling moving averages (climate) to GDP per capita growth and show that a persistent increase in temperature above its historical norm for an extended period of time (i.e., climate change) is associated with lower economic growth in the long run—suggesting that a temporary temperature shock will only have near-term growth effects but climate change, by shifting the long-term average and variability of weather, could impact an economy's ability to grow in the long-term (Figure 8). The impact on GDP per capita accumulates as long as temperatures keep rising and adaptation is gradual, but they will eventually plateau if temperatures stabilize. Kahn et al. (2021) show this by estimating annual income losses from climate change as an integral of weather shocks for 174 countries under different mitigation scenarios (Box 2), adaptation, and climate variability assumptions. These findings are in line with persistent growth hypothesis of Nath, Ramey, and Klenow (2024).

Prior research projects the GDP impact of temperature increases for some future year, typically 2100, assuming a "no further warming" counterfactual (e.g., Burke et al., 2015; Kalkuhl and Wenz 2020; Kotz et al. 2024). Since there are no pathways to a scenario in which baseline temperatures remain constant, Kahn et al. (2021) compare the per capita GDP impact of temperature increases under different climate scenarios to a baseline under which temperature in each country rises according to its historical trend of 1960–2014. To have better comparability to previous papers, Mohaddes and Raissi (2024) conduct an additional exercise in which income losses from temperature increases based on the 1960–2014 trends are compared to a scenario without climate change and with extremely slow adaptation. Figure 9 shows that the global income loss estimates in this case could be as large as 24 percent under a high emissions scenario. Country-specific estimates of annual income losses for individual countries can be downloaded from here.

[22] The Network for Greening the Financial Sector (NGFS) measures the global GDP impact of climate change relative to a baseline scenario "in which climate change does not occur". Burke et al. (2015) argue that "if future adaptation mimics past adaptation, unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100 and widening global income inequality, relative to scenarios without climate change".

[23] The "best estimate" of Burke et al. (2015) indicates that per capita GDP will be 63, 210, 247, 419, 516, 1413 percent larger in Germany, Sweden, Canada, Russia, Finland, and Mongolia because of climate change by 2100. It is also estimated that half of countries will lose more that 80 percent of their GDP (including Brazil, India, and most African and Southeast Asian countries). https://web.stanford.edu/~mburke/climate/map.php for country results.

Figure 9. Estimates of Global GDP Impact from Increases in Temperature



Sources: Kahn et al. (2021), Mohaddes and Raissi (2024), Tol (2024), and IPCC AR6 WGII Chapter 16, 2022.
Notes: Projected GDP per capita impact is for some future year, typically 2100. The shaded area represents the income losses from Mohaddes and Raissi (2024) with upper/lower bound assuming adaptation/no adaptation.

Quantifying the Macroeconomic Effects of Extreme Weather Events

Assessing the likely magnitude of the macroeconomic impact of extreme weather events informs the calibration of macro-climate models and helps in the evaluation of polices. By incorporating estimates from existing literature on the potential effects of these events, models can be calibrated more accurately, leading to better quality forecasts and policy recommendations. Costs associated with extreme weather can be categorized into: (i) the *immediate* damage to infrastructure (e.g., roads or houses) in USD terms or a share of GDP, and (ii) reduced economic activity (i.e., a decline in GDP) resulting from disruptions caused by weather events (e.g., difficulty of bringing produce to market because of road damage). Research by Hallegatte and Vogt-Schilb (2019) and Hallegatte, Jooste, and McIsaac (2022) offers valuable insights into these impacts. They suggest that, in developing economies, one third of the total impact of natural disasters on GDP arises from direct capital losses, while the remaining two thirds stem from reduced economic activity due to productivity shocks.

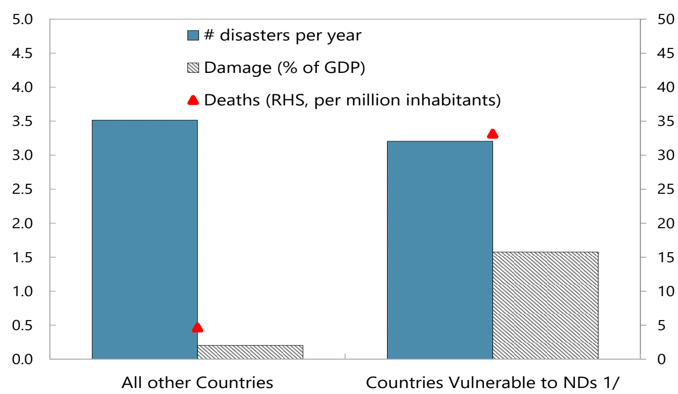
The *immediate* impact of natural disasters (including extreme weather events) can be obtained from reported historical losses and catastrophe models.

- **The EM-DAT is the most widely used source for historical losses from natural disasters.** It reports disaster-by-disaster monetary estimates of physical damages, number of people affected, and lives lost (Figure 10). EM-DAT collects data for six types of natural disasters that are linked to climate change (Table 3, top section). EM-DAT does not provide information on the impact of a natural disaster on economic activity. The data is often self-reported by local authorities or drawn from media reports, and hence it is subject to significant measurement error, especially in developing countries and in the far past.[24] Pondi, Choi, and Mitra (2022) develop a technique that provides a summary statistic per country from the different available EM-DAT variables that enables meaningful comparisons across countries.

- **Catastrophe models quantify the monetary value of immediate damages to physical capital resulting from extreme weather events.**[25] For instance, in the case of hurricanes, these models simulate a range of potential trajectories, varying in frequency and intensity, to assess the damages inflicted on physical assets along these paths. Initially developed for property insurance companies, catastrophe models specially focus on tail risk events (e.g., those that are expected to occur every 250 years or more).[26]

The immediate damage estimates from extreme weather events is sizable. While countries at all income levels are being hit by extreme weather events, losses are larger in developing countries (relative to the size of their economies), and especially so in countries highly vulnerable to natural disasters. Figure 10 illustrates that, while the number of natural disasters in this group is not significantly greater, the resulting damage in terms of GDP losses and fatalities is notably higher.

Figure 10. Frequency and Magnitude of Natural Disasters, 2000-2020



1/ Countries Vulnerable to Natural Disasters are identified based on table 1 of IMF (2019).
Source: EM-DAT, average 2000-2020 for the six climate-related natural disasters.

The impact of extreme weather events on *economic activity* can be analyzed through various methodologies. These studies primarily examine the post-disaster dynamics of key macroeconomic indicators—including GDP, its components, fiscal balance, and public debt— through econometric analysis and structural models (e.g., input-output models, CGE/IAMs):

- **Econometric studies** link macroeconomic outcomes to extreme weather events or their immediate damages (including from the EM-DAT database). These studies often rely on cross-country dynamic panel data models

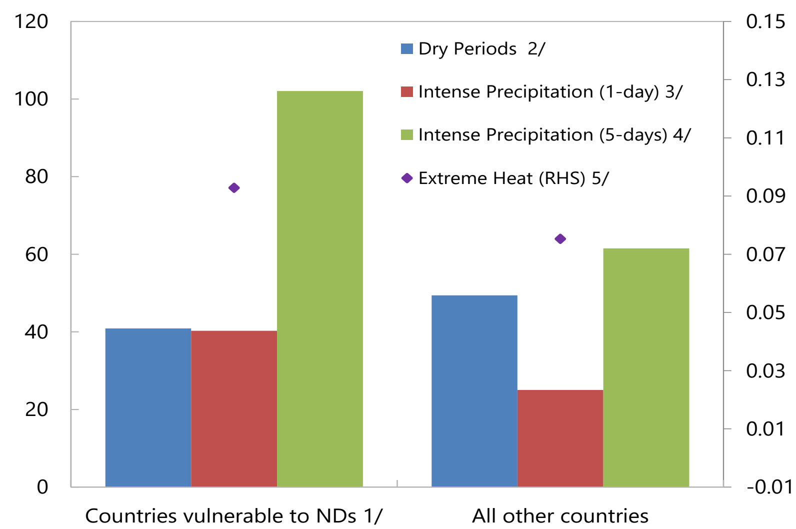
[24] Recent data tends to be of a better quality due to international efforts to standardize post-disaster needs assessments (GFDRR, 2013). Data from before 2000 are typically less reliable—as mentioned by EM-DAT itself. Acevedo (2016) complements this database by estimating a wind-damage function for hurricanes in the Caribbean and then uses this to infer damages for hurricanes that the EM-DAT database failed to register (mostly pre-1988).

[25] Pita (2022) for the history of catastrophe models and Lloyd's market association (2017) for an introduction.

[26] The development and maintenance of these models necessitate the collaboration of scientific and actuarial specialists. Consequently, insurance companies often depend on products of expert modeling vendors. Nasdaq for example has developed a Risk Modeling for Catastrophes platform where it offers different software solutions for reinsurance firms, brokers and financial institutions (Catastrophe (CAT) Risk Modeling Software | Nasdaq).

with a range of control variables, such as the state of the country's business cycle or availability of fiscal space. Recent examples of Fund research include Lee et al. (2018) for Pacific Islands; Fuje, et al. (2023) for a global sample; and Nguyen, et al. (2025). The paper by Akyapi, et al. (2022) uses machine learning techniques to select a parsimonious set of weather shocks (instead of EM-DAT) that significantly impact countries' GDP per capita growth (Figure 11).[27] Felbermayr and Groschl (2014) estimate a substantial negative impact of natural disasters on economic growth.

Figure 11. Frequency and Magnitude of Natural Disasters, 1990-2019 Average



1/ Countries identified as at risk of Major Natural Disasters as per Table 1 of IMF (2019).
2/ Largest number in a year of consecutive days with country average daily precipitation is < 1 mm.
3/ Maximum amount of rainfall in 1 day (in mm) in a given year.
4/ Maximum amount of rainfall over a 5-day period (in mm) in a given year.
5/ Share of grid-days with maximum daily temperature greater than 35°C.
Source: Akyapi et al. (2022).

- **Structural models:**
  - **Input-output models** use linkages between countries, regions, and sectors to measure the supply chain disruptions caused by an extreme weather event. These granular models generally assume unchanged behavioral responses of businesses and households to the events, and so are better suited for near-term impact assessments.
  - **CGEs and IAMs** rely on the results of econometric studies and input-output models, along with the immediate damage estimates. They feature forward-looking utility-maximizing households, profit-maximizing firms, and often government and external sectors, making them well-suited for long-term impact assessments and policy illustrations.

Catastrophe models are also being used to project damages from extreme weather events in the future. Natural catastrophe models for acute risks are based on three main components: (i) Hazards—the extreme weather events or physical risk causing the damage; (ii) Exposure—a spatial map of the objects exposed to

[27] Akyapi et al. (2022) construct a host of weather shocks from billions of daily temperature and precipitation observations to capture local and intra-annual shocks that are likely missed when averaging the variables over space and time (as in EM-DAT). Variables include the center and tails of the distribution of temperature and precipitation, heat and cold waves, droughts, and intense precipitation.

damage (e.g., assets and infrastructure); and (iii) Vulnerability—a function that allows an assessment of damage to the exposed objects.

Table 3. Approaches to Identifying and Measuring the Impact of Extreme Weather Events

	Natural Hazards	Geographical coverage	Economic Impact	Historical data?	Forward-looking?	Data Source
HISTORICAL DATABASE COVERING NATURAL DISASTERS						
EM-DAT database	• Droughts • Extreme Temperature • Floods • Landslides • Storms • Wildfire	Global	Immediate damage: enumeration of relevant reported information of damages in USD.	Yes (1980-current)	No	Various sources, incl. UN agencies, NGOs, reinsurance companies, research institutes, and press agencies.
ECONOMETRIC STUDIES USING EM-DAT 1/						
• Fuje et al. (2023)	Drought, Floods, Storms	164 countries	Reduced Economic Activity: Estimate of impact of natural disaster on change in economic growth (and fiscal variables) through panel regressions.	N/A	No 2/	Using EM-DAT
• Lee et al. (2018)	ND variable in regression constructed from ND-related EM-DAT hazards (incl. non-climate ones).	12 Pacific Islands		N/A	No 2/	Using EM-DAT
• Nguyen et al. (2025)		179 countries		N/A	No 2/	Using EM-DAT
HISTORICAL DATA ON EXTREME WEATHER EVENTS						
Akyapi et al. (2022)	164 variables derived from daily temp. & precipitation measures on global grid.	Global	Reduced Economic Activity: Impact of change of selected (via LASSO selection technique) weather variables on change in GDP per capita through panel regressions.	yes (1979-2019)	No	ERA5 dataset aggregated at daily level by Google Earth Engine.
FORWARD LOOKING STUDIES						
NGFS (2023a) Phase IV	• Heatwaves • Droughts • Floods • TCs	Global (country-by-country)	All hazards get translated into damages via a macro-economic model. • Heatwave: labor productivity & demand • Drought: agricultural supply (crop yield) • Flood: capital loss • TC: capital damage	No	Yes, applied to NGFS scenarios: • Current Policies • Delayed • Net-Zero	• Heatwaves: wet bulb temp. • Droughts: SPEI • Floods: ISIMP • TCs: IBTrCAS (EM-DAT loss data also used)
Fornino et al. (2024)	• Floods • TCs	• Floods: 183 countries • TCs: 89 countries	Immediate damage (via DFs) • Floods: Huizinga et al. (2017) • TCs: Eberenz et al. (2021)	No	Yes, applied to: • SSP1-2.6 • SSP2-4.5 • SSP5-8.5	Jupiter Intelligence.

1/ The examples shown here are just three of many studies that use EM-DAT to investigate econometrically the impact of natural disasters on growth. All three are authored by Fund staff and have been used in operational work.
2/ However, regression coefficients could be used to project future GDP losses, but would need to be combined with assumptions about probabilities about future NDs.
Notes: DF = Damage Function, SPEI = Standardized Precipitation Evaporation Index, IBTrACS = International Best Track Archive for Climate Stewardship, ISIMIP = Inter-Sectoral Impact Model Intercomparison Project.
Source: IMF Staff.

Box 3. Financial Stability Analysis of Climate Risks

Financial stability analysis of climate risks encompasses a thorough examination of the climate-macro nexus. This assessment involves the following sequencing: (1) qualitative diagnostics of climate risks; (2) crafting climate scenarios tailored to both the country in question and its financial system; and (3) assessing financial stability risks (Adrian et al., 2022) through stress testing of financial institutions. It uses an econometric methodology to bridge macroeconomic scenarios and financial institutions risk parameters (e.g., indicators of credit risk such as NPLs, probability of default, and loss given default).

Beyond the use of climate-macro models, the analysis of financial stability also relies on climate-micro approaches. The micro approach delves into the effects of climate risks on individual firms and households by leveraging detailed income and balance sheet data at the individual or firm level. This approach allows for an in-depth examination of specific locational nuances and sectoral disparities. It encompasses the integration of detailed disclosures from borrowing companies and the differentiation in exposure levels of lenders. However, this granular approach demands extensive data.

The global financial stability community, along with numerous national regulators, is actively engaged in developing tools to evaluate the impact of climate change on financial stability. The Financial Stability Board (FSB) is developing conceptual frameworks and establishing metrics to monitor climate-related financial risks and their cross-border and cross-sectoral propagation (FSB, 2023). The NGFS has developed seven long-term climate scenarios and is currently developing additional short-term scenarios (NGFS 2023a&b). Many jurisdictions have either adopted these NGFS scenarios directly or have developed their own stress testing exercises based on the NGFS framework (BOE; ECB; FSB; and Board of Governors of the Federal Reserve System). Most of these exercises focus on banks, though a few jurisdictions, such as France, have also examined risks in the insurance sector.

At the Fund, the Financial Sector Assessment Program (FSAP) has been piloting climate risk analysis for several years. For instance, the FSAPs of Chile, Colombia, Mexico, Norway, the United Kingdom, Kazakhstan, and Japan have evaluated the transition risks posed by climate change mitigation and their implications for the financial sector (Grippa and Mann, 2020; Laliotis and Lamichhane, 2023; Sever and Perez-Archila, 2021). Additionally, the FSAPs of Mexico, the Philippines, Maldives, and the Netherlands have examined country-specific physical risks, such as typhoons in the Philippines, tropical cyclones and floods in Mexico, sea level rise and coastal floods in the Maldives, and floods in the Netherlands (Dolk, Laliotis, and Lamichhane, 2023; Hallegatte and others, 2022). The Fund's typically aims to undertake four climate FSAPs a year.

Until now, the emphasis in the stress testing literature has predominantly been on banks, given their central role in most financial systems. While banks are critical, it's important to note that property, catastrophe, and crop insurers, as well as reinsurers, are also significantly vulnerable to physical risks stemming from climate change. These entities typically operate on annual contracts, allowing them to adjust premia rapidly in response to changing risks from natural disasters. However, in the long run, climate change could render insurance unaffordable or even lead to the collapse of insurance markets, rather than merely accumulating losses among insurers. This scenario could result in increased direct financial burdens on the affected populations and the government.

Quantitative exercises have primarily aimed at understanding the extent of climate risks within the financial system as an exploratory endeavor. The inherent uncertainty and variability of climate scenarios, methodologies, and the wide range of impact estimates have led most national authorities and international standards bodies to approach climate risk analysis as an exploratory endeavor. While some jurisdictions, notably the ECB, are beginning to discuss prudential measures specific to climate risks, this remains an exception. The Basel III standards, revised in April 2024, do not introduce capital charges for climate risks but do expect supervisory bodies to monitor them in the same manner as other risks (Melo, Seal, and Salomao, 2024).

NGFS (2023a), in its phase IV of assessing climate physical risks, models the impact of floods, tropical cyclones, droughts, and heatwaves. It then uses a macroeconomic model (NiGEM) and three NGFS scenarios to project future capital damages and productivity losses. Fornino et al. (2024) similarly estimate forward-looking economic damages from floods and tropical cyclones for three IPCC scenarios (details on these two studies can be found in Table 3, bottom rows). This type of modeling is also being extensively used in FSAPs (Table 4 and Box 3). The Coalition for Disaster Resilient Infrastructure (CDRI) has a resilience index that focuses on a globally comparable set of financial risk metrics for infrastructure assets, and which also has some forward-looking elements (Cardona et al. 2023).

The economic impact of extreme weather events is likely to increase with climate change in the absence of far-reaching adaptation efforts. As frequency and intensity of extreme weather events increase with climate change, past data becomes less reliable for predicting future economic performance. Moreover, the future impact will be influenced by a country's adaptation efforts: zoning, migration, and early warning policies to reduce exposure; and investment in resilient infrastructure. Sectoral studies report climate adaptation investment returns (benefit-cost ratios) as high as 100 to 900 percent (Hallegatte, Rentschler, and Rozenberg, 2019; GCA, 2018).[28] At the macro level, Aligishiev et al. (2022) use a cost-benefit analysis approach to come up with an estimate of the annual cost of adapting existing public assets at 0.25-0.6 of GDP above current levels of public investment on average (with a large variation across countries). This adaptation effort would not be able to reduce the estimated/expected damages from extreme weather events by more than half under current climate scenarios before the cost of investments outweigh their benefits.[29]

Physical risk analysis in stress testing of the financial system

The FSAP climate risk analysis includes the financial stability assessment of the impact of rare extreme weather events on the financial system (Box 3). Typically, financial stability analysis, especially stress testing, concentrates on "unlikely but plausible" tail risks. Rare extreme weather events (occurring once every 100—500 years) are examples. Most of these exercises focus exclusively on one type of weather event at a time (e.g., floods, storms, droughts, wildfires, dike breaches). Assessing the impact of "compounded risks" that consider multiple types of weather events or the consecutive occurrence of the same type of event over time is a nascent and still emerging area in the disaster-damage literature.

[28] Investing in nature-based solutions or "green" infrastructure can be the most efficient way to build resilience, along with providing co-benefits like climate change mitigation, local economy support, and better health (Browder and others, 2019; IUCN, 2017). For example, wetland, and oyster reef restoration is the most cost effective way to reduce coastal flooding damage across the U.S. Gulf of Mexico coast (Reguero and others, 2018), as in many other locations, and without coral reef annual damage from coastal flooding around the world would double (Beck and others, 2018).

[29] The impact of extreme weather events is typically larger in the near-term than in the long-term. For example, droughts in Sub-Saharan Africa have been linked to conflict and fragility, and hurricanes to persistent output declines in the Caribbean (Hendrix et al., 2023; Hsiang and Jina, 2014).

FSAPs quantify the immediate damage inflicted on physical capital by using external catastrophe models. These estimates then help evaluate climate-induced macroeconomic effects on financial system stability (Table 4). Recognizing the impracticality of developing in-house catastrophe risk models, the Fund has opted to integrate external models from the World Bank,[30] open-source platforms like CLIMADA, and projections from NGFS, among others. These models provide detailed maps of damages to physical capital. The *micro assessment* of physical risks necessitates comprehensive data regarding the loan or securities exposure of individual borrowers or industries, in addition to their geographical locations. Such an exercise initially estimates how physical capital damages impact the financial health of borrowers, including via reassessment of their collateral values, and translates them into potential credit losses to the lenders. If such detailed data are not available, one can choose the *macro-climate approach* by aggregating the damages at the country level and using them as inputs (e.g., capital depreciation shocks) in structural macro models (e.g., the Global macro-Financial Model or country specific DSGE models to produce macro scenarios for FSAP stress tests) to assess the health of the financial system.

Table 4. Examples of Fund Risk Analysis of Extreme Weather Events

Exercise	Event Type	Climate/ Hazard/ Damage Model	Climate-Macro/Micro Model
Philippines FSAP	Typhoons	GCM and RCM examined and selected by the national weather agency (existing study). The catastrophe risk model (co-developed by WB) estimated damage to buildings and infrastructures.	Macro approach. Indirect impact—capital depreciation and persistent TFP shock using a single-country DSGE model.
Uruguay FSAP	Coastal floods	Coastal climate indicators downscaled from GCM and a high-resolution terrain model from the Coastal National Adaptation Plan. Asset exposure based on data from the Credit Registry and the National Office of Internal Audit.	Macro approach. Capital depreciation using the FSGM. Micro approach. Authorities' data (for corporates and households, as well as loan-level banks' exposures from the Credit Registry) were used to quantify banks' loans-at-risk to households and corporates affected by coastal floods.
Mexico FSAP	Tropical cyclones and floods	Damage estimates by WB using: (1) downscaled exposure data featuring the spatial distribution of capital stock; (2) hazard by return period based on CLIMADA's approach for wind, and Fathom hazard maps for flood, and (3) Huizinga et al., (2017) damage functions for flood and Eberenz et al. (2021) damage function for tropical cyclone.	Macro approach. Capital depreciation, persistent TFP shock, unemployment and equity market shocks using GFM.
Maldives FSAP	Coastal floods	Damage estimates by economic activity/sector considering: (1) exposure at the administrative level, which includes population density, industrial presence, and tourism infrastructure; (2) hazard by return period from storm surge plus sea level rise; and (3) Huizinga et al., (2017) damage functions differentiated by sector.	Micro approach. Considering direct impact to portfolios backed by immovable assets by sectors from banks with sector damage estimates.
Netherlands FSAP	Coastal and riverine floods	Flood maps designed in collaboration with Dutch climate experts; damage estimates based on Deltares damage curve methodology considering climate conditions and flood protection reinforcement plans.	Macro approach. Capital depreciation, persistent TFP shock, and house prices shock using GFM.

Source: IMF Staff.

Notes: FSGM = Flexible System of Global Models, GCM = General Circulation Model, GFM = Global macro-Financial Model, RCM = Regional Climate Model, TFP = Total Factor Productivity.

Quantifying the Macroeconomic Effects of Climate Policies

Several models and tools have been developed to analyze the macroeconomic effects of *climate policies.* Some focus on *mitigation* policies, including challenges and opportunities presented by the transition

[30] The World Bank offers disaster risk financing and insurance (DRFI) program, which supports governments to implement financial protection strategies and provides sovereign disaster risk financing, agricultural insurance, and property catastrophe risk insurance, among others. In this context, they develop country-specific catastrophe risk models with external vendors for some countries.

to a lower-carbon economy, and others focus on *adaptation* policies. These models, alongside public debt and fiscal/financial stability risk assessment tools, provide a comprehensive toolkit for analyzing the macroeconomic effects of *climate policies*.

Mitigation Models/Tools

The Fund employs several key models/tools in evaluating mitigation policies. These models/tools are instrumental in understanding the macroeconomic effects of different mitigation policies and how they can contribute to the global effort to cut emissions and pursue a low-carbon energy transition (Table 5, Annex 1).

The Climate Policy Assessment Tool (CPAT) has been used extensively for mitigation policy analysis within the Fund and by country authorities. CPAT covers 200 countries and provides comprehensive assessments of the effects of alternative climate mitigation policies, including carbon pricing, fossil fuel subsidy reform, energy price liberalization, excise and methane taxes, feebates, and performance standards. Modelled impacts include effects on energy consumption, prices, emissions (GHGs and local air pollutants), revenues, mitigation or welfare costs, GDP, distributional impacts on households (impacts across income deciles, urban vs. rural) and industries, and co-benefits of climate mitigation policy. Emissions projections and behavioral equations in CPAT are carefully parameterized. CPAT also has a very detailed power sector supply model, including country-specific data on generation technologies and levelized costs with investment dispatch responses. A variety of additional models feed into CPAT which allow for more granular, technology-specific analysis (e.g. for transport and industrial sectors), impacts on international trade and emissions leakage, and policy analysis for broader sectors (e.g., forestry, agriculture, and extractives). GDP impacts are assessed in a reduced form way using fiscal multipliers from the World Bank's models and empirical studies.

IMF-ENV has also been used in many country applications within the Fund to explore the medium to long-term macroeconomic effects of climate change mitigation policies. As a multi-region and multi-sector recursive dynamic global CGE model of the real economy, IMF-ENV is specifically designed for medium- to long-term assessment of climate, energy, and trade policies. The model is underpinned by a database covering 160 countries and regional aggregates, along with 65 commodities. For single- and multi-country applications, the model's baseline is carefully calibrated using country-specific data on macroeconomic variables, energy dynamics, and emission pathways. IMF-ENV is well-suited to simulate the emissions, macroeconomic, sectoral, and cross-border effects of many climate policies across the power, industry, transport, and forestry sectors. This includes carbon pricing schemes for all greenhouse gases, renewable subsidies, feebates, regulations, energy efficiency standards, and border carbon adjustment mechanisms. Additionally, it can analyze trade policies such as tariff changes and trade agreements, as well as energy policies including fossil fuel subsidy reforms, tax incentives, and various regulations. Furthermore, IMF-ENV can be linked with partial equilibrium models to enrich the depth of results and provide nuanced perspectives relevant to specific country contexts. For instance, it can be soft-linked to microsimulation models to evaluate household distributional effects and to land-use change models that address agricultural and biofuel policy impacts.[31]

The Global Macroeconomic Model for the Energy Transition (GMMET) examines the near- to medium-term macroeconomic effects of climate change mitigation policies. It is a large-scale non-linear New-Keynesian DGE model that is designed to study the impact of mitigation policies (global with spillovers across countries and domestic effects) and energy shocks on sectoral and macroeconomic variables in the near- to

[31] The CGE model of Khabbazan and von Hirschhausen (2021), or CGE-MOD, performs similar analyses to IMF-ENV, including carbon pricing, emission trading systems, carbon border adjustment mechanisms, and energy transition.

medium-term. GMMET is less granular than IMF-ENV or CGE-MOD but explicitly models expectations (i.e., future policies matter for agents' decision-making today) and can be used for near-term analysis (of nominal variables, output gap, external sector, and public finances) and the role of stabilization policies.[32]

Finally, the Carbon Price Tool (CPT), via a user-friendly interface, estimates the effects on prices and government revenue collection of implementing carbon pricing. Based on global input-output tables (the core of any CGE model), it considers the ripple effects throughout global supply chains and can thus provide insights on trade patterns and competitiveness issues. However, CPT does not include behavioral responses and has constraints on the use of production factors and other macro equilibrium conditions.

Table 5. Mitigation and Transition: Models and Tools

Name	Main use for IMF staff	Country focus	Model Type	Key References and Country Applications
Climate Policy Assessment Tool (CPAT)	Surveillance / CD / lending (RSF)	Single- or Multi-country	Technoeconomic Energy-Macro model (+toolkits)	Reference: Black et al. (2023). Applications: Multilateral surveillance, AIVs (e.g. China, Mexico, Canada, UK, Germany, France, India, Indonesia), Regional analyses (Departmental Papers and Regional Economic Outlooks), WPs, SCNs, Capacity Development, Fiscal Monitor, training, and other products.
IMF-ENV	Surveillance	Multi-country	Recursive-Dynamic Computable General Equilibrium	Reference: Chateau et al. (2025). Applications: Multilateral surveillance, Article IVs (e.g., Canada, India, Indonesia, Italy, Mexico, Poland, Saudi Arabia, South Africa, USA), and FSAPs (Germany, Mexico, Japan, Kazakhstan).
CGE-MOD	Surveillance	Multi-country	Computable General Equilibrium	Reference: Khabbazan and von Hirschhausen (2021). Application: Middle East fossil fuel exporting countries.
GMMET	Surveillance	Multi-country	Dynamic General Equilibrium	References: IMF (2022b), Carton et al. (2023). Application: Macroeconomic impact of decarbonization policies.
Carbon Pricing Tool (CPT)	Surveillance / CD / lending (RSF)	Single-country	Partial equilibrium	Reference: Guilhoto et al. (2024).

Source: IMF Staff.

Adaptation Policies and Resilient Investment

The Fund uses several models/tools to evaluate the impact of adaptation policies. Table 6 provides an overview of the key models developed at the Fund and their applications. Table 7 details the main characteristics of these models. The last three columns of Table 7 feature select 'one-off' models that have not been applied extensively by Fund country teams but have several desirable features.

DIGNAD is the Fund's most widely applied model for analyzing the macroeconomic impact of adaptation policies in the face of natural disasters. The Debt-Investment-Growth and Natural Disasters (DIGNAD) model—developed by Marto, Papageorgiou, and Klyuev (2018)— is complemented by a toolkit with excel interface for ease of use (Aligishiev et al, 2023). DIGNAD incorporates labor and three distinct types of capital in its production function: (i) standard public capital, (ii) resilient public capital, and (iii) private capital. Resilient public capital, while more expensive than (i), offers greater resilience in the face of natural disasters, creating an investment-return trade-off. The DIGNAD set-up is being further developed, for example by adding heterogeneous households to look at distributional impacts (Mendes-Tavares et al., 2022).

[32] The G-Cubed model of McKibbin was used in Chapter 3 of the October 2020 WEO (with the help of the author), but subsequently not maintained/backstopped within the Fund.

In countries prone to frequent and severe natural disasters, expectations about such shocks can impact the long-term equilibrium levels of macroeconomic aggregates. There are two strands of DSGE models that address this issue, each distinguishing between standard and resilient capital. The first is the Markov-switching model of Fernandez-Corugedo, Gonzalez-Gomez and Guerson (2023; FGG) which has been applied to several countries. The second approach developed by Cantelmo, Melina, and Papageorgiou (2023) applies a different solution method (Taylor projection) and is calibrated for an average disaster-prone country, though it has not yet been applied to any specific country. Endegnanew et al. (2025) adopts a similar methodology and applies it to Mozambique. Compared to DIGNAD, these models are less frequently used.

The specification and subsequent calibration of the production function can be modified to capture the growth effects of both climate change and extreme weather events. Nonlinear DSGE models can account for the long-term effects of Natural Disasters. DIGNAD can be modified to capture the GDP losses associated with gradual climate changes, such as temperature increases. Specifically, the DIGNAD model tailored for Madagascar's Climate Macroeconomic Assessment Program (CMAP) incorporates this feature by modeling a gradual and permanent decrease in Total Factor Productivity calibrated according to the estimates of Kahn et al. (2021). While other applications of DIGNAD have not yet adopted this approach, the Q-CRAFT tool uses temperature-growth estimates to explore the long-term fiscal risks from climate change.

Table 6. Adaptation Policies and Resilient Investment: Models and Tools

Name	Main use for IMF staff	Country focus	Model Type	Key References and Country Applications
DIGNAD	Surveillance / CD / lending (RSF)	Single-country	DGE (deterministic)	Reference: Marto et al. (2018). Applications: Niger, Benin, St. Lucia, Rwanda, Madagascar, Uganda, Bangladesh, Solomon Islands, Timor Leste, Samoa, Kenya, Vanuatu, Maldives, Barbados.
FGG Model	Surveillance / lending (RSF)	Single-country	DSGE	Reference: Fernandez-Corugedo et al. (2023). Applications: Dominica, Peru, St. Vincent & Grenadines, Grenada, Bahamas, Jamaica, Panama, Honduras, Dom. Rep., Nicaragua, Costa Rica, St. Lucia.
CKZ Model	Surveillance / lending (RSF)	Single-country	Neoclassical Growth Model	Reference: Chen et al. (2024). Applications: Ghana, Egypt, Brazil.
C-FARM model	Surveillance / lending (RSF)	Single-country	DGE	Reference: Baptista et al. (2023). Applications: Nepal, Niger, AFR-RES departmental paper (SSA-wide).
Climate Macro-framework Toolkit (CMT)	Surveillance / CD / lending (RSF)	Single-country	Excel-based tools	Ongoing Capacity Development Activity in Middle East and Asia.

Source: IMF Staff.

The macroeconomic effects of climate change fundamentally revolve around issues that are both sector-specific and macro-critical. Research has evolved to refine macro models to reflect this perspective. The challenge lies in maintaining a general equilibrium framework to analyze macroeconomic aggregates while ensuring the model remains tractable. The model developed by Chen, Kirabaeva, and Zhao (2024; CKZ) successfully responds to this challenge. The model focuses on addressing climate change impacts on food security, by segmenting the economy into an agricultural sector and the rest of the economy, and examining both damages incurred and corresponding adaptation policies. This makes the model relevant to countries where agriculture is the predominant conduit for climate-related damages. Endegnanew et al. (2025) expand the scope to include agriculture, manufacturing, services, and energy, attributing all damages to TFP shocks. Additionally, the spatial model of Baptista, Spray, and Unsal (2023; C-FARM) distinguishes between food and non-food sectors and explores a range of coping mechanisms.

The World Bank has a comparative advantage in sector-specific modeling of climate change. Their CGE models, such as MANAGE, are used as the central modeling tools to incorporate the results and insights from different specialized teams: energy, agriculture, land, risk management (natural disasters), poverty, gender, education, waste, transportation, urban economics, and health. These model findings have been used in Country Climate and Development Reports (CCDRs, the World Bank's climate diagnostic). Estimates from the CCDR using the MANAGE model were adopted for DIGNAD and DSA calibrations in the preparation of Benin's request for an RSF arrangement (IMF Country Report 2024/003).[33]

The Climate Macroframework Toolkit (CMT) integrates estimates of the impact of natural disasters within a macroeconomic framework. The CMT is designed to assist in incorporating the quantitative effects of natural disasters into macroeconomic projections. Among other sources, it applies estimates from Nguyen et al. (2025) on the impact of natural disasters on key macroeconomic variables.

Table 7. Key Features of Adaptation Models and Tools (highlighted in green)

Model Features		DIGNAD	FGG	CKZ	C-FARM	Mendes-Tavares, Guo & Guerson (2022)	Cantelmo, Melina & Papageorgiou (2023)	Endegnanew et al. (2025)
Impacts	Public Capital	green	green	green	red	green	green	green
	Private Capital	green	green	green	green	green	green	green
	Standard vs. Resilient Capital	green	green	green	red	green	green	green
	Growth	green	green	green	red	red	green	red
	Long Term Effects	red	green	green	red	red	green	green
	Food Security	red	red	green	green	red	red	red
	Migration and Remittances[1]	red	green	red	green	red	red	red
Fiscal Policy	Range of Instruments	green	green	red	red	green	red	green
	Distributional Analysis / Informality	red	red	red	green	green	red	green
	Debt Sustainability implications	green	red	red	red	red	green	red
	Endogenous Risk Premia	green	green	red	red	green	green	green
Incomplete Markets		green	green	red	red	green	red	green
Financial Frictions		red	green	red	red	red	red	red
Spatial		red	red	green	green	red	red	red
Sectoral Coverage[2]		red	red	green	green	green	red	green

[1] The DIGNAD model can accommodate remittances through an extension, as applied to the Philippines.

[2] Beyond one composite output good (i.e., explicit modeling of sectors such as food, agriculture, etc.)

Source: IMF Staff.

Public Debt and Fiscal Risk Models and Tools

Fund staff has also developed a range of easy-to-use models and tools for fiscal analysis. Key among these are tools for debt sustainability analysis, assessment of fiscal risks from slow-moving increases in temperatures, discussion of fiscal rules in the context of natural disasters, and consideration of debt dynamics amid the energy transition (Table 8).

Debt sustainability analysis is a requisite for the Fund's bilateral engagement with countries. The review of the Sovereign Risk and Debt Sustainability Framework (SRDSF) in 2021-22 resulted in the creation of an

[33] World Bank (2022) provides an overview of World Bank climate-macroeconomic models.

adaptation and mitigation module that delves deeper into the impact of climate policies on debt dynamics. Additionally, there is a stress test tailored to natural disasters.[34] The Natural Disasters Debt Dynamics Tool (ND_DDT) leverages the EM-DAT data for natural disasters and WEO/IFS data for macro-fiscal variables for scenario analyses. The tool also presents econometric estimates of shocks to these macro-fiscal variables (Nguyen et al., 2025). One of the primary advantages of the ND_DDT is its user-friendliness, making it easily accessible by authorities (e.g., Seychelles' 2024 budget report).

Table 8. Public Debt and Fiscal Risk Models and Tools

Name	Main use for IMF staff	Country focus	Type of Model	Key References and Country Applications
SRDSF LT Climate Risk Modules	Surveillance / lending (RSF)	Single-country	Partial equilibrium	Reference: SRDSF Guidance Note (section E. Climate Change Module). Application: Relevant countries that use the SRDSF.
NDs Debt Dynamics Tool (ND_DDT)	Surveillance / CD	Single-country	Partial equilibrium	Applications: Costa Rica, Seychelles.
Q-CRAFT	Surveillance / CD	Single-country	Partial equilibrium	Reference: Tim and Rahman (2024). Applications: Armenia, Azerbaijan, Bangladesh, Georgia, Jamaica, Kenya, Morocco, Rwanda, Seychelles, The Netherlands, and Uganda.
Calibrating Fiscal Rules in Presence of NDs	Surveillance / CD	Single-country	Partial equilibrium	Reference: Akanbi et al. (2023). Applications: ECCU.
Public Debt Dynamics During the Climate Transition	Surveillance	Single-country	General Equilibrium	References: IMF (2023), Garcia-Macia et al. (2024). Applications: model has been calibrated for a typical AE or EM in these two publications. Application for Colombia ongoing.

Source: IMF Staff.

The Quantitative Climate Change Risk Assessment Fiscal Tool (Q-CRAFT) supports governments and country teams in quantifying macroeconomic and fiscal risks associated with climate change. To evaluate the potential fiscal impacts of climate change, Q-CRAFT has been designed to project stylized macroeconomic and fiscal forecasts for 169 economies under different climate scenarios through 2099. Q-CRAFT establishes a baseline macro-fiscal scenario using a straightforward production function and the debt dynamics equation. It utilizes available budgetary, economic, and demographic data, along with assumptions that users can easily adjust. Following this, cross-country empirical estimates—using the Kahn et al. (2021) methodology and Centorrino et al. (2025)—regarding the effects of persistent temperature increases on GDP per capita under various climate scenarios, are applied to the baseline. This approach allows for the projection of key fiscal indicators, such as the debt-to-GDP ratio, up to 2099 under different climate scenarios.

The design of fiscal rules needs to account for the potential occurrence of natural disasters. A toolkit created by the Fund staff introduces a methodology that incorporates natural disaster risks into the calibration of fiscal rules within a stochastic framework (Akanbi et al., 2023). For instance, medium-term debt anchors will be set lower in countries with a higher probability of natural disasters. Additionally, the toolkit considers climate investment and other mitigation mechanisms.

The fiscal implications of transitioning to net zero emissions by mid-century are analyzed in a model designed for the 2023 Fiscal Monitor. A tractable DGE model is developed that quantifies the fiscal impacts of various climate policy packages aimed at reaching net-zero by mid-century, including public investment, subsidies, and carbon pricing. The model is calibrated for a typical advanced economy and a representative

[34] Similar work is currently being done for the review of the LIC DSF.

emerging market. The model accounts for the sensitivity of borrowing costs to rising debt levels, which is relevant for many emerging market economies. In addition, the model considers technological spillovers via the effect of learning-by-doing externality and the impacts of investment bottlenecks, which in turn has implications on debt dynamics.

Financial Stability Analysis of Transition Risks

The financial system impact of transition risks are evaluated using an array of modeling tools. In addition to models surveyed in Table 5, FSAPs have employed the Global Macrofinancial Model (GFM) and the Integrated Policy Framework (IPF) model for transition risk analysis. These models take outputs from a climate-macro model to generate a wider spectrum of macrofinancial variables. Additionally, when micro-level data (e.g., corporate balance sheets) are accessible, an "integrated micro-macro modeling framework" that combines climate-macro models with firm-level models can be utilized, as exemplified in the FSAPs of Mexico, Kazakhstan, and Japan (Table 9). This approach typically involves three steps: deriving transition scenarios from a Computable General Equilibrium (CGE) model (e.g., IMF-ENV and ENVISAGE); conducting firm- or industry-level stress tests to estimate the evolution of corporate borrowers' credit risk; and performing bank stress tests that use corporate borrowers' industry-specific defaults to evaluate the impact on banks.

Table 9. Examples of IMF Transition Risk Analysis in FSAPs

Exercise	Transition Scenarios	Climate-Macro, Micro Model
Norway FSAP	Carbon pricing	Transition risks modeled along three transmission channels: (1) direct firm-level impact via changes in profits, (2) macro impact via the impact on oil revenues using a SVAR, (3) impact on shareholder portfolios.
UK FSAP	NDC, 1.5°C with Carbon Dioxide Removal, Net-Zero 2050	Macro approach. Transition policies simulated in a global CGE model (GTAP-E) to capture macro and sectoral impacts. Micro approach. Heterogenous impact within sectors captured at the company level in the Climate Credit Analytics model suite.
Mexico FSAP	2°C, delayed transition	Integrated micro-macro approach. Transition policies simulated using IMF-ENV to derive macroeconomic and sectoral impacts and carbon price paths; macro effects used as input into a firm-level model to assess the impact on firm's balance sheets and credit risk indicators.
Kazakhstan FSAP	NDC, Orderly 1.5°C, Disorderly 1.5°C, Net-Zero 2050	Integrated micro-macro approach. Transition policies simulated using IMF-ENV to derive macro and sectoral impacts and carbon price paths; macro effects used as input into a firm-level model to assess the impact on firm's balance sheets and credit risk indicators. Macro approach. Oil price and endowment shocks simulated in a DSGE model (IPF).
Japan FSAP	Fragmented World, Net-Zero 2050	Integrated micro-macro approach. Transition policies simulated using IMF-ENV to derive macro and sectoral impacts and carbon price paths; macro effects used as input into a firm-level model to assess the impact on firm's balance sheets and credit risk indicators.

Source: IMF Staff.

Financial stability risk analysis accounts for the potential impact of abrupt shifts in expectations regarding the transition path, which can lead to significant asset price dislocations. This phenomenon, known as a "climate Minsky moment," occurs when there is a rapid devaluation of brown assets due to sudden changes in expectations influenced by factors like technological advancements and future policy changes. The UK FSAP explored this scenario, considering the climate Minsky moment to result from a swift recalibration of economic agents' expectations, leading to a sharp rise in both UK and global carbon prices. The analysis then examined the repercussions of these asset price shocks on credit and market losses for banks and non-bank financial institutions within a five-year timeframe.

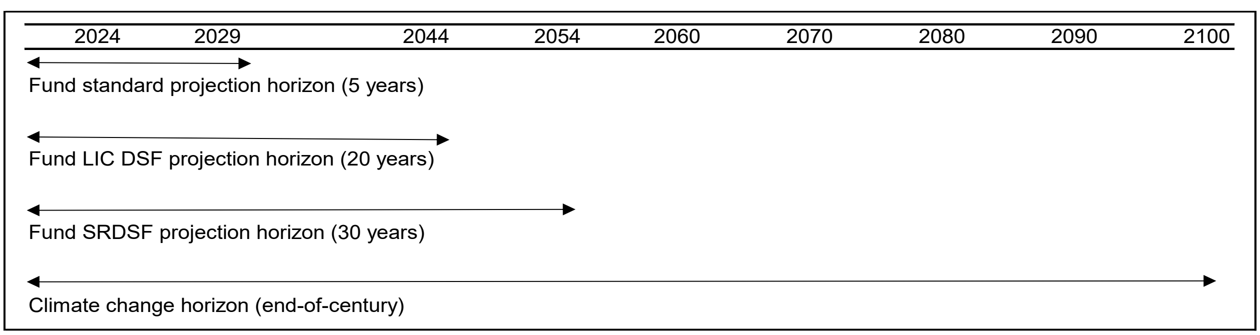
4. Considerations for Enhancing Climate–Macroeconomic Analysis at the Country-Level

The discussion of channels of impact in Section 2 and the survey of models/tools in Section 3 indicate that there is no one-size-fits-all approach to accounting for the impact of climate change and related policies in country-level analysis, including macroeconomic projections and risk scenarios. Nevertheless, a set of key considerations—that can be tailored to suit the unique contexts of different countries over time—could be useful in supporting the evolution of this work. This section outlines some of these considerations, applying the Fund context as an example.

Bringing climate change-related considerations into country-level macroeconomic analysis can enhance the realism and depth of projections and policy advice. This process centers around a comprehensive analysis that covers key macroeconomic sectors and their interrelations. At the Fund, the emphasis is on the real, fiscal, external, and monetary and financial sectors (Box 4).[35] Nuanced judgement (including behavioral responses) may also be applied. Important elements to consider include:

- **Time horizon:** It is critical to distinguish between the *near-term* and *long-term macroeconomic effects* of climate change. For example, projections in most of the Fund's major publications (flagships, regional economic outlooks, and staff reports) cover a 1-to-5-year time horizon (Figure 12). An exception is the debt sustainability framework (DSF), where the DSF for low-income countries (LIC DSF) projects over a 20-year horizon and the climate change module of the sovereign risk DSF (SRDSF) projects over a 30-year horizon (Box 5). However, climate change unfolds over several decades in different forms, necessitating choices about what to include in projections at various time horizons, as well as what to discuss as alternative scenarios or in stress testing.
- **Frequency of Updates:** Regular updates to analysis are essential to account for the increase in *frequency and intensity of extreme weather events* with climatic shifts (especially for climate-vulnerable countries and small island developing states) and the evolving nature of *adaptation and mitigation policies* a country adopts.

Figure 12. Timeframes Relevant for Climate and Macroeconomic Projections



[35] At the Fund, country-level macroeconomic projections are based on a financial programming framework that comprises four main macroeconomic sectors (real, fiscal, external, and monetary and financial) and their interlinkages, based on accounting and behavioral relationships.

- **Baseline vs Alternative Scenarios:** Each country faces distinct climate challenges (including inward spillovers from global/regional developments) and a unique combination of climate policies.
  - Where significant and macro-critical, macroeconomic effects of increases in frequency and intensity of extreme weather events, variability in temperature and precipitation, and ongoing or expected climate policies should be included in baseline projections. At the Fund, this approach aligns with the treatment of non-climate-related issues and policies. The potential economic implications of global or regional climate policies, such as the effects of global energy transition on fossil fuel exporters, could also be considered.
  - While stress testing (e.g., in DSFs or FSAPs) focuses on assessing the impact of tail risks, alternative scenario analysis emphasizes the significance of global policy actions and their effects on warming trends, as well as the impacts of each country's own climate policies. For example, the impact of policies under consideration with large implementation uncertainty could be assessed under alternative scenarios. These scenarios could also be extended to global adaptation policies or can complement baseline projections by illuminating risks and uncertainties associated with global mitigation efforts. Alternative scenarios can include optimistic and pessimistic global warming outcomes (e.g., SSP1-2.6 and SSP3-7.0 as discussed in Section 2), reflecting different global mitigation policies, especially those of the largest emitters. Given the relevant timeframes, such scenario analysis could typically be included in a country's DSF (at a minimum).

Box 4. Climate and Country-Level Macroeconomic Projections

The Fund's country-level macroeconomic projections are typically made using a combination of historical economic data, sectoral consistency checks, and scenario and policy analysis. The projections rely on a set of global assumptions, including on commodity prices and policies adopted by large economies. Overall, the process involves several key steps that could be *adjusted for the impact of climate change and related policies*:

1. Data Collection and Diagnosis

The first step is gathering reliable data on the country's macroeconomic and *climatic* conditions.

2. Key Macroeconomic Sectors and Variables

The Fund's country-level macroeconomic projections involve the real, fiscal, monetary and financial, and external sectors which could be adjusted for *climate* considerations. Box Figure 4.1 lists key variables in each sector and examples of how some of these variables could be impacted:

- **GDP growth.** Typically, GDP levels are projected based on a demand-side (e.g., consumption, investment, government spending, trade) or a supply-side (e.g., agriculture, manufacturing, services, trade, government) approach. *Projections of the demand- or supply-side components could be adjusted for the economic impacts of increased extreme weather events.*
- **Inflation Rate.** *Adjustments can be made for price increases related to near-term impacts of extreme weather events on domestic food production (which could also result in increased food imports) and longer-term climate-induced supply chain changes.*
- **Fiscal Balances.** Government revenue and spending can be impacted in a variety of ways. *Consider carbon taxes which have a direct impact on revenues or an indirect impact on the tax base through reduced GDP growth. The net impact from reduced public spending (e.g., phasing out fossil fuel subsidies) and increased spending (e.g., climate-resilient infrastructure and social assistance) also*

needs to be accounted for. Resulting changes in the fiscal balance could impact borrowing needs and debt dynamics.

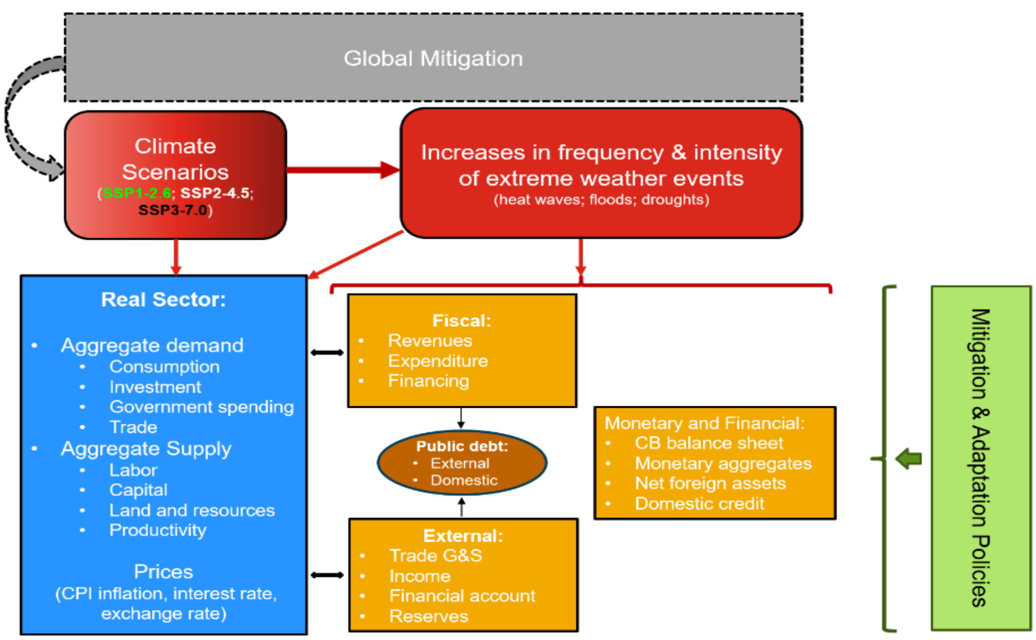
- **Balance of Payments.** *Climate policies could affect trade (e.g., exports of agricultural products, imports of food or carbon-intensive goods), and net financial flows (e.g., remittances, external climate finance).* These, in turn, have an impact on the balance of payments, international reserves, and the exchange rate.
- **Asset Valuation.** *The physical impact of climate change, the level of private infrastructure resilience to it, and access to insurance can affect the value of private sector assets.* Subsequently, there could be effects on domestic credit and foreign investment among other financial sector variables.

3. Scenario Analysis

The baseline scenario underlies the Fund's published macroeconomic projections. Alternative scenarios are applied to assess upside and downside risks relative to the baseline; and are used internally or published.

- **Baseline Scenario:** These are assumptions on global and domestic economic conditions and policies—reflecting a continuation of current policies. *From a climate change perspective, key factors that could be considered are country-specific temperature increases and weather shocks, global and domestic mitigation efforts (under current policies), and global economic conditions that may affect climate finance.*
- **Alternative Scenarios:** *These could include the impact on individual countries from changes in baseline assumptions on global mitigation efforts or on climate-related trade and investment policies of large economies.*

Box Figure 4.1. Climate and Key Macroeconomic Sectors



Source: IMF Staff.

Box 5. Debt Sustainability Frameworks and Climate

Climate issues feature prominently in Debt Sustainability Frameworks (DSFs). Both the Sovereign Risk DSF (SRDSF) and the Low-Income Countries DSF (LIC-DSF) extend their analysis beyond the IMF's standard 5-year projection horizon and incorporate specific climate-related aspects.

The two climate change modules of the SRDSF Guidance Note (SRDSF GN), one for adaptation and one for mitigation, consider projections over a 30-year horizon. The SRDSF also triggers a natural disaster stress test if either the country is a small state or the following criteria apply: (i) two natural disaster events in a three-year window; (ii) cumulative economic loss of at least 5 percent of GDP caused by the natural disaster events in that window).

- The LIC-DSF considers a 20-year horizon and was last updated in 2018. The LIC DSF triggers a natural disaster stress test for "small developing natural disaster-prone states and LICs that meet a frequency (2 disasters every 3 years) and economic losses (above 5 percent of GDP/year) criteria, based on EM-DAT database during 1950-2015" (2018 LIC DSF Guidance Note).The Guidance Note was updated in 2024, with a section dedicated to climate change.

The objective of the climate change modules of the SRDSF is "*to inform judgement on debt-related risks arising from policy commitments (or recommendations) to address climate change*" (SRDSF GN, p.84). "*A standard scenario would be developed for which fiscal costs of adaptation and mitigation measures would be added as a deterministic shock from t+6 onwards. (..) A customized scenario would allow adjusting financing terms of the climate investments, underlying PB assumptions, and the LT growth path to country-specific circumstances*" (SRDSF GN, p.85). The SRDSF considers these scenarios only in the LT-modules, with the results being interpreted solely in a qualitative sense.

A key (implicit) assumption in the SRDSF adaptation module is that climate-related investments completely offset income losses from climate change: "*implicit assumption that adaptation investment exactly cancels any negative impact of climate change on growth*" (SRDSF GN, p.87). This implies that countries investing in adaptation will be inadvertently penalized in their DSAs as such investments are costly and count as additional spending (i.e., deteriorating the fiscal balance and potentially increasing the risk premia), but no corresponding increase in resilience or decrease in default probability are anticipated. Similarly, the mitigation module only considers investments amongst a package of climate policies. If adaptation or mitigation investment is constrained by the lack of fiscal space or financing, tradeoffs require careful consideration, including the costs of climate inaction in alternative scenarios.

A key step to address the above issue is to depart from unchanged long-term growth paths in DSF projections. Most countries are likely to experience some form of structural transformation in the coming decades due to a confluence of economic forces, including energy transition, demographics, productivity convergence (primarily for Emerging Markets and Developing Economies), and the gradual impact of climate change on growth. The three climate scenarios in Section 2 can be utilized to gauge the levels of uncertainty in global warming over the next decades. The Q-CRAFT is particularly helpful in illustrating the longer-term macro-fiscal implications of various climate scenarios, including their impacts on debt dynamics under different adaptation assumptions.

On the policy side, the incorporation of climate *mitigation and adaptation policies* in DSFs should ideally extend beyond investment (the current focus of SRDSF climate modules). The baseline macroeconomic projections should include the impact of climate policies that have been enacted, are underway, or are likely to be adopted—as country teams do for other policies (e.g., pension reforms)—and how they can be financed while safeguarding macro-fiscal stability.

The following steps may be useful for a wide variety of countries and situations:

- **Determining the major physical climate risks the country is facing, along with policy measures that have been enacted, are underway, or are likely to be adopted**. Useful country-specific summaries of the main physical climate risks can be obtained from diagnostic studies such as the World Bank's CCDR and the IMF's CPD, Climate-Public Investment Management Assessment (C-PIMA), or FSAPs (Section 3). In addition, the Fund's country-specific panel charts (Annex 3) provide valuable insights for assessments, highlighting the balance across adaptation, mitigation, and transition policies, and helping prioritize relevant data sets and analyses for different country contexts.
- **Identifying key channels through which physical climate risks and climate policy measures, determined in the previous step, may impact the macroeconomy.** This includes measuring the change in frequency and intensity of extreme weather events with climatic shifts, specifying the macro-sectoral channels of impact (Section 2), and the sequence in which other variables are affected (Box 4). Projected changes to the frequency and intensity of extreme weather events can be obtained from various sources, including the 6th Assessment Report of the IPCC (Figure 2), Fornino and others (2024), and Massetti and Tagklis (2025). However, adjustments typically need to be made for each country's unique circumstances.
  - Structural models (e.g., CGE and other models in Section 3) can effectively illustrate the impact of physical climate risks and related policies on key macroeconomic variables, including growth and its drivers. These models facilitate the assessment of the relative magnitude of impact across different channels.
  - Excel-based 'tools' that focus on a specific macroeconomic sector (e.g., real, fiscal, or external) or issue (e.g., public debt) can also inform the dynamics of key variables following the realization of physical climate risks or adoption of climate policies.
- **Quantifying the impact of physical climate risks and related policies on key macroeconomic variables (identified in the previous step).** The quantification can be done by applying a combination of estimates/models/tools (Section 3) and judgement. Tables 10 and 11 provide a thematic representation of some relevant estimates/models/tools. Nonetheless, translating the results from models and tools into country-level macroeconomic projections can be challenging considering the multitude of other driving factors beyond climate change. IMF (2025b) describes a probability-based country-specific approach applied to Seychelles.[36]
  - It is first necessary to quantify the impact of physical climate risks on key macroeconomic variables (e.g., GDP growth). For slow-moving climate shifts, the country-specific counterfactual estimates of Kahn et al. (2021)—which has been updated for the latest climate scenarios by Mohaddes and Raissi (2024) and Centorrino, Massetti, Raissi, and Tagklis (2025)—can be directly applied to annual GDP growth projections (Section 3). Estimates from Akyapi, Bellon, and Massetti (2022) as well as Felbermayr and Groschl (2014) can inform historical GDP growth effects of some extreme weather shocks.[37] Monetary damages/losses

[36] Long-term growth assumptions in the 2023 DSA's for Vanuatu and Tonga were adjusted downwards to take into account future natural disasters, using a probabilistic approach based on Lee et al. (2018).

[37] Projections of the increase in the frequency and intensity of some weather shocks can be obtained from a Climate Database developed by Massetti and Tagklis (2025) (e.g., for extreme heat, heavy precipitation, or the number of consecutive dry days under different climate scenarios). Fornino and others (2024) provide similar statistics for tropical cyclones and floods. NGFS (2023a) report similar information for cyclones, droughts, floods, and heatwaves under different long-term NGFS scenarios for 49 countries.

from tropical cyclones and floods are found in Fornino and others (2024); or the NGFS (2023a) for cyclones, droughts, floods, and heatwaves under different long-term NGFS scenarios for 49 countries. However, damage/loss estimates do not readily translate into impacts on GDP growth (requiring further research). The 6th Assessment Report of the IPCC, and the CMT can also inform the calibration of extreme weather events (Section 3).

- The impact on other variables (consumption, investment, fiscal deficit, and public debt) can be estimated from behavioral equations or derived from interrelations across variables and sectors. Quantification of effects can also be facilitated by structural models after careful calibrations (e.g., DIGNAD or CGE)—which provide the relative dynamics of key macroeconomic variables after an extreme weather event—or tools such as the CMT. When data is lacking or modeling is complicated, an aggregate of model/ tool results for similar countries could be considered (i.e., a *synthetic* country analysis).[38]
- The effects of ongoing or planned climate policies should be included in macroeconomic projections. The direct impact of some policies is relatively straightforward to apply. For example, the revenue impacts of carbon taxation can be measured like any other changes in tax policy.[39] Indirect effects of the carbon tax on other macroeconomic variables, such as GDP growth, may be quantified by applying models and tools as described in the bullets above and Section 3.

Any climate-related changes to macroeconomic projections should only be considered if they are truly additional and consistent with macro-fiscal stability. For example, public investment should only be increased by the net amount of new investments in renewable electricity after deducting the previously planned hydrocarbon-based investments (which are being replaced by renewables). Even if the substitution of one type of investment for another type implies no net gain in investment, this might have other macro consequences that do not net out—for example on jobs. Furthermore, assessments of necessary adaptation or mitigation investment needs often necessitates navigating complex trade-offs, particularly when a country lacks the fiscal space to implement all identified adaptation investments (Box 6 provides a relevant example from Costa Rica).

[38] The "IMFE -- Integrating Macro Forecasting Env." supports design of internally consistent scenarios. It can also make projections using impulse-response functions (IRFs) of existing non-climate models. This work can be extended to climate-macro models over time.

[39] Measurement of the impact could also be facilitated with the results of CPAT or CPT.

Table 10. Models/Tools for Climate Physical Risk Assessments

3 Climate Scenarios	SSP1-2.6 (Paris - Optimistic)	Increasing Global Mitigation Efforts SSP2-4.5 (Baseline)	SSP3-7.0 (Hot World - Pessimistic)
Tools (all excel-based) and Estimates 1/ Slow-moving climate shifts	• GDP Impact Assessment Toolkit, Q-CRAFT *Both use estimates from Kahn et al (2021) to translate temperature increases under climate scenarios into growth outcomes (with possibility of adjusting for varying global adaptation speed) 2/* • CIAM (based on Diaz, 2016) 3/ *Estimates costs of sea-level rise.*	• GDP Impact Assessment Toolkit, Q-CRAFT • NGFS (2023a) *Uses estimates from Kalkuhl and Wenz (2020) to translate warming under SSP2 scenarios into growth outcomes for 49 countries.* • CIAM (based on Diaz, 2016) 3/	• GDP Impact Assessment Toolkit, Q-CRAFT
More frequent/intense extreme weather events	• Fornino and others (2024) *Provides damage estimates for floods (183 countries) and tropical cyclones (89 countries).*	• Fornino and others (2024) • NGFS (2023a) *Estimates losses form cyclones, drought, floods, and heatwaves under different SSP2 scenarios.*	
	• CMT *Uses estimates from Nguyen et al. (2025). These losses are not explicitly linked to climate scenarios.*		

Source: IMF Staff.

1/ Short explanation of estimates used are only provided once.

2/ The GDP Impact Assessment Toolkit updates the counterfactuals of Kahn et al (2021) under the latest IPCC climate scenarios to come up with GDP losses from temperature increases. Q-CRAFT incorporates these estimates into a consistency framework which also adds demographics and productivity to analyze the long-term effects of temperature increases on public finances.

3/ Estimates in Coastal Impact and Adaptation Model (CIAM) are reported for RCP 2.6 and RCP 4.5.

Table 11. Models/Tools/Estimates for Climate Policy Assessments 1/

	Macroeconomic (aggregate)		Sectoral		
			Fiscal and debt	External	Monetary/financial
Mitigation (including transition)	Non-Excel based	• GMMET • IMF-ENV • CGE-MOD • GFM	• Public Debt Dynamics During the Climate Transition		• Models used in IMF FSAPs to assess transition risks (table 4, table 9 and box 3 provides details)
	Excel-based	• CPAT • CPT	• Green Multipliers • SRDSF (LT Climate Risk Module: Mitigation)	• Fund tool under development to examine direct BOP implications of the energy transition	
Adaptation	Non-Excel based	• DIGNAD • FGG • CKZ • C-FARM			
	Excel-based	• CMT • C-SDG	• Q-CRAFT (adjusting adaptation speed) • Calibrating Fiscal Rules in the presence of Natural Disasters • SDG Costing • ND_DDT • SRDSF (LT Climate Risk Module: Adaptation)		

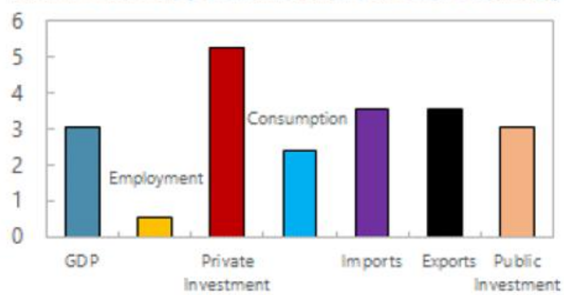
Source: IMF Staff.

Notes: 1/ Many of the models/tools herein can also be used for impact/risk assessments with proper calibrations.

Box 6. Costa Rica: FGG and Illustrating the Benefits of Resilient Infrastructure Investment

In Costa Rica, damages from natural disasters averaged 0.5-0.7 percent of GDP per year during 1998-2018. The FGG model was deployed to illustrate the long-term macro-fiscal and employment effects of increasing public investment in resilient infrastructure. This calibration involved public investment in resilient infrastructure of about 1.6 percent of GDP, at an additional cost of 0.4 percent of GDP relative to the existing baseline macroeconomic projections. Over the long-term, this yields a 3 percent increase in the level of GDP. The improved resilience reduces reconstruction costs and there are gross fiscal gains of 0.5 percent of GDP per year. Net steady-state gains amount to 0.1 percent of GDP (Table below). The macroeconomic projections for Costa Rica included a spending increase of 1.4 percent of GDP (consistent with fiscal sustainability and the National Adaptation Plan). Judgement was applied in the projections of GDP and employment effects, though the relative returns across variables were guided by the model results.

Long-Term Return of Public Investment in Resilience to Natural Disasters (Percent increase relative to no resilience)



Average Annual Fiscal Gains of Investment in Resilience
(In percent of steady state GDP)

Total Gains		**0.49**
Stock saving	Decrease in reconstruction spending after NDs	0.01
Flow saving	Moderation of output and tax revenue decline after NDs	0.02
Steady State	Increase in tax revenues due to higher output	0.46
Cost of resilience	Increase of public investment spending due to resilience cos	**0.40**
Net annual saving		**0.09**

Source: IMF staff estimates.
Note: The assumed government increases in resilient infrastructure are calibrated to reduce climate change-induced natural disaster damages to 20 percent of historical damages.

5. Future Areas for Consideration

Many areas of future or active research have been mentioned throughout this paper. A few key items are highlighted here.

- First, it is crucial to focus on understanding the near- and medium-term growth effects of extreme weather events—building on the important advances that have been made in measuring their economic damages and losses. Moreover, enhancing data collection on changes to the frequency and intensity of extreme weather events on an individual country basis under various climate scenarios will provide valuable insights into how these changes influence long-term economic growth.
- Second, future work could explore how to leverage existing results from the application of models to specific countries—studying the impacts of climate shocks and climate policy interventions—to inform analysis in similar countries (e.g., synthetic country analysis).

- Third, measuring the growth effects of inter-annual and intra-annual climate variability is essential for capturing their nuanced economic impacts.
- Fourth, future climate-macroeconomic model applications should consider the role of governments' institutional capacity. For instance, the IMF's Public Investment Management Assessments have shown that two-thirds of the public investment efficiency gap across countries can be attributed to variations in institutional capacity.
- Fifth, work is underway to incorporate environment and climate change considerations in macroeconomic statistical manuals—including the System of National Accounts, Balance of Payments Manual, Government Finance Statistics, and Monetary and Financial Statistics.
- Lastly, the role of technological developments/diffusion and green industrial policies in shaping the economic responses to climate change should be analyzed in more detail.

Annex 1. Analyzing Climate Mitigation Policies: IMF-ENV, GMMET, and CPAT

With a view to helping inform the choice of model applied in analyzing mitigation policies, this annex compares some key features across three key models. The annex begins with a focus on IMF-ENV and CPAT as they are the most applied models in the Fund's country-level analysis of mitigation policies. After that, the comparison is expanded to GMMET, which has been applied for the largest emitters and work is underway to extend it to other countries.

IMF-ENV and CPAT

Both IMF-ENV and CPAT can assess a wide range of climate mitigation policies. These include, to varying degrees, carbon pricing (carbon taxes on different activities/sources/gases, national and regional emission-trading schemes, border carbon adjustments), energy policies (subsidies, feebates, direct and indirect regulations), sectoral regulations (overall and sector-specific energy efficiency standards, requirements to install household heat pumps, EV subsidies, mileage-based taxes, regulatory and subsidy/feebates policies on land, fisheries, and forestry sectors, livestock taxes, methane fees), and new green technologies (Carbon Capture, Utilization, and Storage, Electric Vehicle penetration).

The two models vary in their approaches:

- IMF-ENV is a recursive dynamic Computable General Equilibrium (CGE) model of the global economy designed to look at macroeconomic impacts of climate mitigation and the green transition. It is a real economy model that is built on a database of Input-Output tables for 160 countries and regional groups with 76 commodities and coupled with bilateral trade flows data, tariffs and international transportation costs, and energy and GHG emissions by activity. In addition to sectors primarily focused on climate mitigation efforts, such as energy, extractives, and energy-intensive industries, the model also presents results for non-energy intensive sectors—which, given their economic significance, are particularly relevant in high policy ambition scenarios. The model is well-suited to study the domestic and cross-border macroeconomic effects of mitigation policies, as well as structural changes to the economy that result from ambitious decarbonization goals and their spillover effects to various regions across the world through a detailed representation of sectors and trade flows.[40]
- CPAT is designed to evaluate, for 200 individual countries, the, fiscal, welfare, environmental, distributional, and other effects of climate mitigation policies. The main power sector model contains forward-looking, county-specific detail on generation technologies, levelized costs, and dispatch while other sectors (transport, industry, buildings) contain reduced form representations of fuel demand and fuel intensity. CPAT is parameterized to generate emissions projections and policy impacts that are in the middle of a broad range of energy models and a large body of empirical evidence on fuel income/price responsiveness. The model is well suited to providing detailed estimates on the changes in the energy system induced by policy and to identifying tradeoffs in policy design across a range of metrics of concern, including economic efficiency,

[40] As it is general equilibrium, the model is internally consistent, ensuring that all markets are in equilibrium and macroeconomic balances are retained.

fiscal, and distributional impacts on households (equity-efficiency tradeoff), industries, and the co-benefits of climate policy (reduced air pollution deaths and congestion).

Key Features: IMF-ENV, GMMET, and CPAT

Key model features are summarized in Table 1 and some distinguishing points are elaborated here:

IMF-ENV

- IMF-ENV depicts how producers and consumers interact through behavioral equations. Firms minimize their production costs and respond to demand and price changes by deciding on an optimal mix of intermediate inputs and factors of production (land, vintaged capital, energy and labor). Incomes from production factors flow to households, who maximize their welfare and allocate their income to consumption and savings. Tax revenue supports government spending, and savings drive investment, ensuring demand and supply balance across income and spending items.
- The model provides impacts on a wide range of variables including real GDP, sectoral output and prices, changes in net trade patterns by sector for each bilateral trade partners, factor incomes (wages, returns to capital), sectoral and economy-wide labor demand, household consumption patterns, government revenues, market shares, electricity generation and composition, and energy demand and supply by fuel.
- The model links economic activity to environmental outcomes. Emissions of greenhouse gases (GHGs) and other air pollutants are directly connected to economic activities either through fixed coefficients, such as those for emissions from fossil fuel combustion, or through emission intensities that decrease (nonlinearly) with carbon prices—marginal abatement cost curves.
- The model can include damages from climate change at the sectoral or factor level (i.e., agricultural labor and/or capital, transportation services, energy supply) and/or at the aggregate level (real GDP effects, overall labor productivity reductions).[41] IMF-ENV is usually soft-linked to detailed energy models to account for country-specific characteristics of the electricity sector. It can also be linked to land models and connected to microsimulation models for distributional analyses.
- Ongoing model development focuses on creating an endogenous R&D and technology diffusion module, a depletion module to enrich the modeling of fossil fuels, and incorporating endogenous international capital flows.
- Typically, analysis applying this model involves staff from the Fund's Research Department for model calibration and simulations.
- Some shortfalls of the model:
  - IMF-ENV is a CGE model and, by design, follows a complex structure. This implies that choices need to be made, for example in the closure rules. Ongoing model developments focus on introducing alternate closure rules in the model to extend the sensitivity analysis of the results.
  - Given its focus on real economic flows, IMF-ENV has limited use in studying business cycle effects or assessing the financial and monetary consequences of climate policies.[42]

[41] This requires country-specific information on damages or income losses.

[42] However, FSAPs use IMF-ENV or other CGE models, coupled with financial and banking microdata to provide financial assessments of climate policies.

  - IMF-ENV focuses on medium to long-term equilibrium outcomes. Consequently, it is not well-suited to analyze short-term dynamics between two equilibria. GMMET is a complementary global general equilibrium model for short- to medium-term mitigation analyses.

GMMET

- As with CGE models such as IMF-ENV, GMMET depicts how producers and consumers interact through behavioral equations. However, GMMET is particularly suited to the short- and medium-term macroeconomic impacts, including the impact on output and employment, inflation, the external sector, and the fiscal accounts. The model includes Keynesian aggregate demand channels, in addition to its supply side features. The micro founded decision making in the model is done by forward looking agents with rational expectations. Agents face both real and nominal frictions, allowing the model to capture near- and medium-term responses.
- GMMET builds on the Global Integrated Monetary and Fiscal model (GIMF), the IMF's workhorse model for business-cycle and structural macroeconomic analysis. It is an annual, multi-region, large-scale structural New-Keynesian dynamic general equilibrium model. These models are traditionally used for quantitative short- and medium-term analysis of monetary and fiscal policy. The model has a well-articulated steady state, and therefore also features stock-flow consistency, which is important when discussing investment, government debt, and international flows in general.
- The focus of GMMET is on assessing the implications of mitigation polices on the macroeconomy and on emissions. This focus means the model captures various non-linear sectoral details of energy production, trade, and use by various sectors.
  - Fossil fuel mining, and especially the implied supply elasticity, is a key determinant for the effectiveness of a GHG price in reducing emissions. Therefore, the model features a fossil-fuel-specific modeling of mining sectors that allows to align the fuel-specific supply elasticity with empirical estimates.
  - The model features five electricity generation technologies that differ in their cost structure and emission intensities: Coal, fossil gas, nuclear power, hydroelectric power, and renewables.
  - GMMET captures a key real-world obstacle to increasing the share of renewables in electricity generation, being intermittency of electricity generation from wind and solar. Renewables are assumed to be paired with a flexible fossil-fuel-based backup (to cover periods of generation shortfalls from renewables). This structure is determined endogenously by a cost-minimization accounting for the variable and fixed costs and the distribution of weather regimes.
  - The model also features a dedicated transportation sector that distinguishes between combustion engine cars burning fossil fuel and electric vehicles running on electricity. The sector has stock-flow accounting of vehicle fleets and newly purchased vehicles, an explicit role for charging and fueling stations, and network externalities between electric vehicle adoption and the deployment of charging stations.
  - GMMET includes non-fossil fuel GHG emissions and the possibility to abate by sector specific emission abatement technologies.
- GMMET features a rich treatment of fiscal policy levers. To analyze to the macroeconomic impact of mitigation, the model allows for a wide set of GHG mitigation polices, including subsidies, regulatory measures, and GHG taxes that are sector-specific according to the respective GHG emissions intensity.
- Some shortfalls of the model:
  - GMMET abstracts from the benefits of avoiding GHG emissions (mitigating warming damages). The model focuses on the macroeconomic implications of different ways to achieve a given emission decline, not on assessing different emissions objectives.
  - GMMET is not a CGE model in spirit of IMF-ENV. Compared to CGE models, GMMET simplifies the sectoral breakdown of the economy and focuses instead on sectors that matter the most for mitigation

policies (fossil fuel mining, electricity generation and transportation) while keeping the manufacturing and service sectors highly aggregated.

CPAT

- CPAT projects forward future energy demand across sectors and fuels using assumptions on key drivers (GDP growth, income and price elasticities, technological improvements and costs) based on a large body of empirical evidence. CPAT can therefore convert NDCs in a consistent way across countries into emissions reductions below historical and future baseline emissions. CPAT evaluates policies against a wide range of metrics such as impacts on GHG emissions, fuel use, energy prices, revenue, mitigation/welfare costs, domestic environmental problems, distributional incidence across household income groups, and production costs in trade-exposed industries.
- GDP impacts are assessed in a reduced form way using fiscal multipliers from the WB's main macroeconomic model (MFMOD) which accounts for the business cycle, exchange rate, financial market, labor market, and other short-run effects, alongside empirical estimates.
- CPAT models the power, industry, transport, and building sectors. Moreover, a variety of supplementary models feed into CPAT, including dynamic models of capital adjustment in the vehicle and building sectors, mitigation in the forestry, agriculture, and extractives sectors, and a model of trade between each country and its main partners providing estimates of production, cost, and leakage estimates by key industry (including steel, cement, chemicals), country, and policy scenario.
- CPAT is a highly flexible spreadsheet-based model providing quick results that are readily explained in terms of assumptions about key underlying factors (e.g., fuel price responsiveness). CPAT is straightforward for users to learn and in the last year has been used by policymakers in 30 countries.
- Some shortfalls of the model:
  - CPAT does not include detailed impacts on output or investment for non-energy intensive sectors; nor impacts on inflation, trade (for non-energy goods), and employment.
  - Interactions among energy sectors, like the impact of electric vehicle transitions on electricity demand, are not explicitly modelled though there is ongoing work on these issues.
  - At the global level, CPAT does not explicitly model the downward pressure on international energy prices from mitigation policies causing significant reductions in global fuel demand.

Annex 1. Table 1. Key Features of Models (Key differences shaded in grey)

	IMF-ENV	CPAT	GMMET
Type of model	Dynamic Computable General Equilibrium (CGE) model	Excel-based economic model incorporating key technologies and parameterized to mid-range of broader energy modelling literature.	Structural New-Keynesian dynamic general equilibrium model
Sector and fuel coverage	76 sectors including agriculture, energy, extractives (fuel and minerals), energy-intensive and other manufacturing, public and private services, transport.	Covers main emissions-generating sectors, disaggregates15 energy goods, and 67 impacted industrial sectors.	14 sectors: general tradable, general non-trade, coal mining, gas extraction, oil extraction, 5 types of electricity generation, electricity grid, ICE transportation, EV transportation, EV charging stations
Country coverage	160 countries & regional groups	200 countries, alongside country groups by region/development level	Standard aggregation is 4 regions USA, EUA, China and RoW is common. Can disaggregate to any country in GLORIA database
Time horizon	Up to 2050 and is determined by the requirements of the project	To 2035 by default (extendable to 2050).	Best suited to analysis up to 2035, but can be simulated for longer time horizons
Set-up costs	High. Requires expert support.	Low. Excel-based and possible for new users to run own analysis independent of CPAT team.	High. Requires expert support.
Sensitivity analysis/accessibility	Standard analysis available for dynamic CGE models with sensitivity analysis embedded in scenarios	All results explained in terms of familiar concepts (e.g., income and fuel price responsiveness). Readily accommodates sensitivity analysis.	Standard analysis available for dynamic CGE models with sensitivity analysis embedded in scenarios
Sectoral linkages and spillovers	Yes	Work in progress to link electrification of other sectors to electricity demand.	Yes
International policy spillovers	Yes	Supplementary trade model calculates competitiveness impacts and emissions leakage.	Yes
Modelling of multiple policies in a sector or region	Policy packages are assessed simultaneously.	Policy packages are assessed sequentially.	Policy packages are assessed simultaneously.
Frictions in factor reallocation	Yes, capital is modelled with vintages which makes relocation of old capital costly.	No	Yes, real and nominal frictions including capital adjustment, labor markets, and prices.

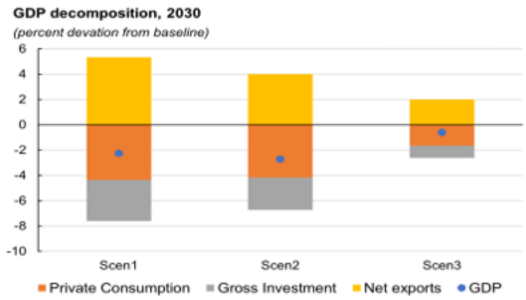
Key sectors & structure			
Energy industries	Coverage: Coal, oil, and natural gas Structure: Modeled as sectors with nested CES functions and inter-fuel substitution elasticities	Coverage: Coal, oil, natural gas, gasoline, diesel, kerosene, jet fuel, other oil products, biomass. Structure: Elasticity-based.	Coverage: Coal, oil, and natural gas Structure: Modeled as sectors with nested CES functions and inter-fuel substitution elasticities.
Power sector	Coverage: Coal, oil, natural gas, solar, wind, hydropower, nuclear, other renewables, biomass Structure: Modeled as sectors with nested CES functions and substitution possibilities between different generation technologies.	Coverage: Coal, oil, natural gas, nuclear, wind, solar, hydro, other renewables, biomass. Structure: Techno-economic model with both dispatch and investment decisions incorporating detailed data and projections on generation costs.	Coverage: Coal, oil, natural gas, solar & wind, and hydropower & nuclear. Structure: Modeled as sectors with nested CES functions and substitution possibilities between different generation technologies capturing renewable intermittency via renewable-plus-backup generation.
Transport sectors	Coverage: Land, water and air transport sectors. Structure: Modeled as sector within dynamic CGE framework.	Core model: Road, rail, aviation, maritime (elasticity-based). Complementary model: technoeconomic model with fleet turnover and detailed breakdown of road transport (EVs, ICEs, heavy- and light duty, new and used vehicles).	Coverage: Land transport sector directly modelled (other transport and associated emissions included in services/non-tradables sector). Structure: Modeled as sector with separate capital stock for ICE, EV and charging stations and includes network externality between EV and charging stations.
LULUCF	Yes, forestry	Yes	Not explicitly, emissions included in tradables sector.
Energy-intensive industries	Yes, iron and steel, cement, pulp and paper, chemicals, non-metallic minerals, and non-ferrous metals.	Yes	Not explicitly, activity and emissions included in tradables sector.
Agriculture	Yes, crops, livestock and fisheries	Yes	Not explicitly, activity and emissions included in tradables sector.
Extractives	Yes, coal, natural gas, crude oil and mining.	Yes	Yes, coal, natural gas, and oil.
Waste	Yes	Yes	No, emissions included in non-tradables sector.
Non-energy intensive sectors	Yes, public and private services, agriculture and other manufacturing	Yes, through input-output tables	Not explicitly, activity and emissions included in non-tradables sector

Policy coverage			
Carbon pricing (carbon taxes and ETSs)	Yes	Yes	Yes
Fossil fuel subsidy reform	Yes	Yes	Yes
Individual fuel excises	Yes	Yes	Yes
VAT reform	Yes	Yes	Yes
Electricity price reform	Yes	Yes	Yes
Feebates and tradable performance standards	Yes	Yes	Yes
Energy efficiency standards	Yes	Yes	Yes
Renewable portfolio standards or subsidies	Yes	Yes	Yes
Methane taxes	Yes	Yes	Yes (would require out of model calibration)
Border carbon adjustments	Yes	Yes	Yes, not on individual imports, only aggregate imports
Tariff measures	Yes	No	Yes, not on individual imports, only aggregate imports
Non-tariff measures	Yes, import quotas, rules of origin, subsidies and technical barriers via iceberg costs.	No	Yes, not on individual imports, import quotas, rules of origin, subsidies and technical barriers via iceberg costs.
Impacts coverage			
Emissions: GHGs	CO_2, CH_4, N_2O, Fgas	CO_2, CH_4, N_2O	Calibrated to total CO2e
Emissions: other local air pollutants & climate forcers	Yes: As needed for BC, CO, NH3, NMVOCs, NOx, OC, PM10, PM2.5 and SO2.	HFCs, PFCs, SF_6, NF_3, $PM_{2.5}$, NO_x, SO_2, BC, NMVOCs.	No
Economic efficiency costs	Yes	Yes, based on standard formulas, including revenue recycling	Yes
GDP effects	Endogenous, assuming equilibrium in all markets and consistency in macroeconomic balances.	Based on fiscal multipliers from WB's main macro model (MFMOD) and empirical estimates	Endogenous, assuming equilibrium in all markets and consistency in macroeconomic balances.

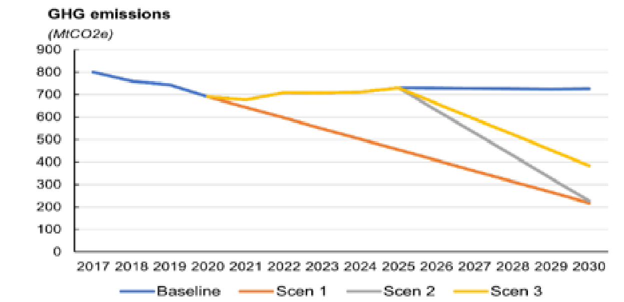
GDP effects interpretable within 5-10 years	Yes	Yes (simplified)	Yes
Broader impact on macro variables (inflation, output/investment for non-energy intensive sectors, employment)	Yes, for real variables (including changes in prices and real exchange rates relative to the baseline)	No	Yes
Competitiveness/ emissions leakage	Yes, the multi-country coverage of the model provides extensive results on competitiveness effects and carbon leakage for all major energy and non-energy sectors including the energy-intensive and trade exposed activities.	Supplementary trade model calculates changes in production costs by key industry for the domestic economy and its main trading partners from unilateral and multilateral mitigation policies for the purposes of calculating competitiveness and emissions leakage impacts. It does not calculate second round effects (e.g. on adjustments in exchange rates, etc.).	Yes, the multi-country coverage of the model provides results on competitiveness effects and carbon leakage for both fossil fuel exports and other tradeable goods. The model accounts for nominal exchange rate adjustments in line with monetary policy responses and price stickiness.
Changes in global demand for fossil fuels	Fully consistent global general equilibrium model, capable of simulating simultaneously decarbonization policies of all countries.	Exogeneous demand changes can be assessed but does not explicitly model downward pressure on international energy prices from mitigation policies causing significant reductions in global fuel demand.	Fully consistent global general equilibrium model, capable of simulating simultaneously decarbonization policies of all countries.
Fiscal	Yes	Yes, accounting for base erosion for pre-existing fuel taxes/subsidies	Yes
Distributional impacts on households	Yes, when linked with a microsimulation model.	Yes: detailed impacts at the household level for ~100 countries, including impacts on 8 energy goods &14 non-energy goods on welfare across income deciles and urban vs. rural households.	Yes, 2 types of households, higher income overlapping generations and lower income hand-to-mouth households.
Distributional impacts on industries	Yes (GTAP sectors), for both domestic and cross-border impacts transmitted via trade linkages.	Core model: Yes (GTAP sectors). Complementary model: effects relative to trading partners for key industries.	Yes, mining sector, electricity generation sectors, and trade and non-tradable.
Co-benefits: local air pollution and human health	No, but can be included when country-specific data is available.	Yes. Quantifying impacts on premature mortality, morbidity, and productivity by risk factor, fuel, sector, and age groups for all countries.	No, but can be included when country-specific data is available.
Co-benefits: transportation	No, but can be included when country-specific data is available.	Impacts on road accidents, congestion (peak/non-peak), vehicle km travelled, and road maintenance costs.	No, but can be included when country-specific data is available.
Climate damages	Yes. Can be included by activity, production factor and at the macroeconomic level when country-specific data is available.	Yes. Monetized via social cost of carbon (SCC) estimates and includes estimated impacts on global temperatures.	No, but can be included via out of model calculation and input productivity changes. Nearer-term focus of model limits value of this.

Illustrations of IMF-ENV Results

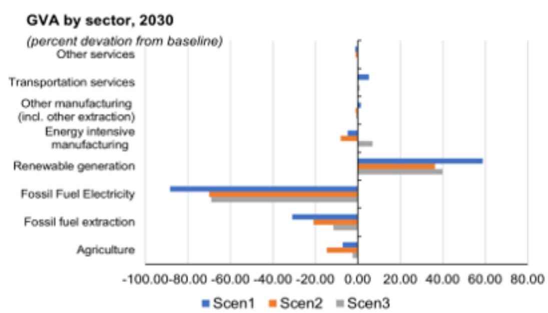
GDP impacts and decomposition



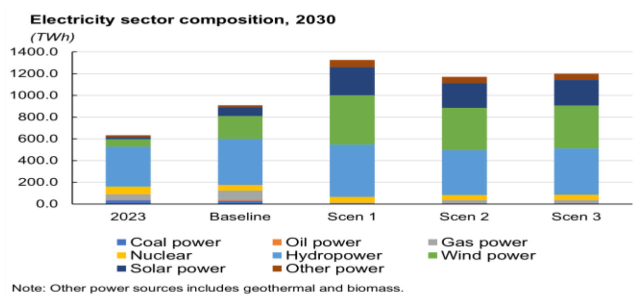
Emission impacts



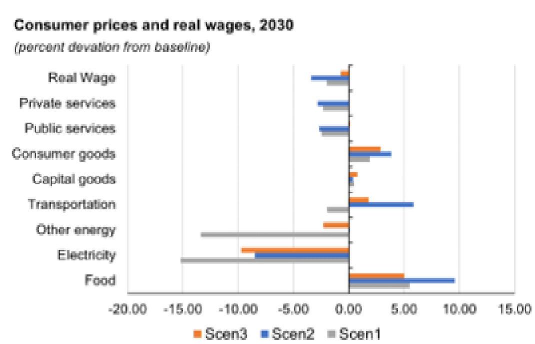
Gross value added of key sectors



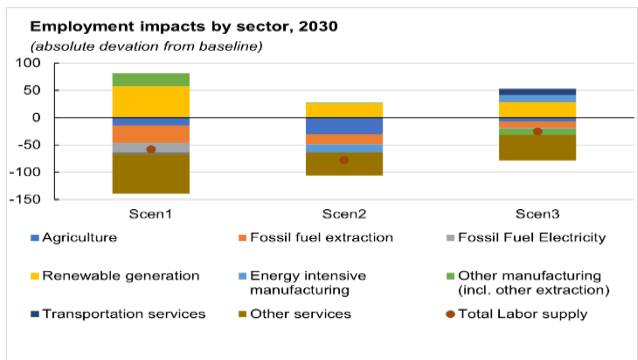
Electricity generation and composition



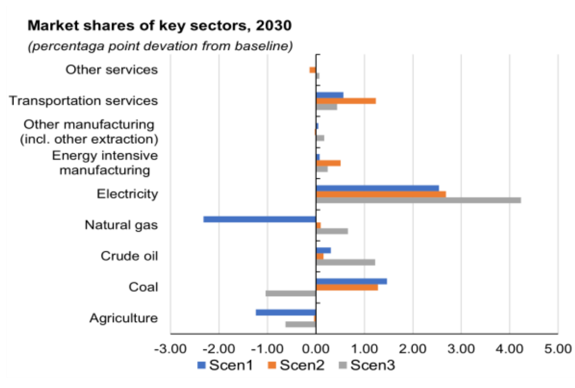
Consumer prices and real wages



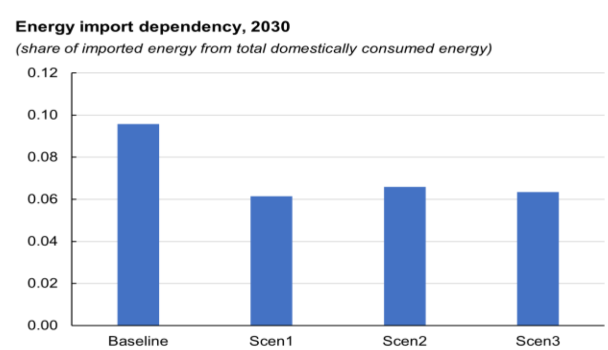
Employment effects by sector



International market shares by key sectors

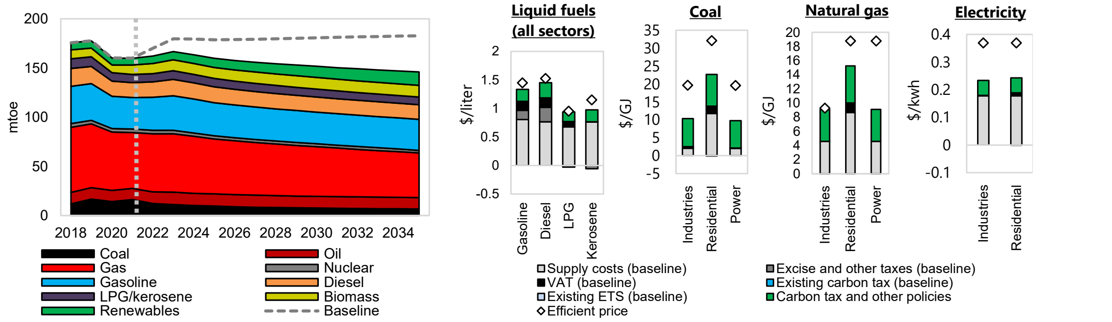


Energy security (import dependency)

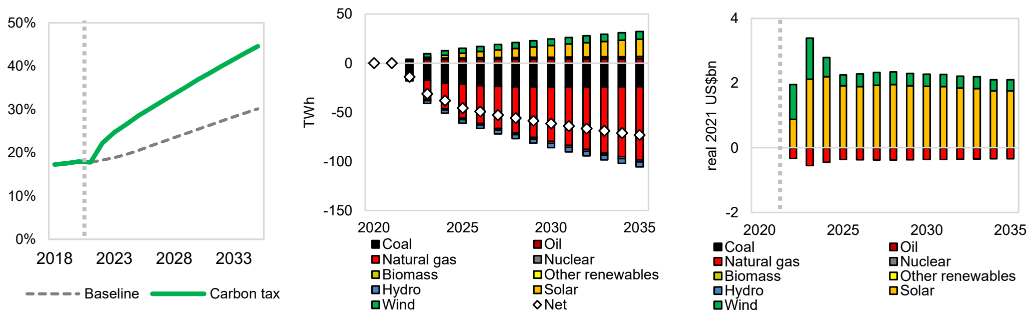


Example Outputs from CPAT Mitigation Module (for US$50 Carbon Price/ton CO_2e by 2030, Unspecified Country)

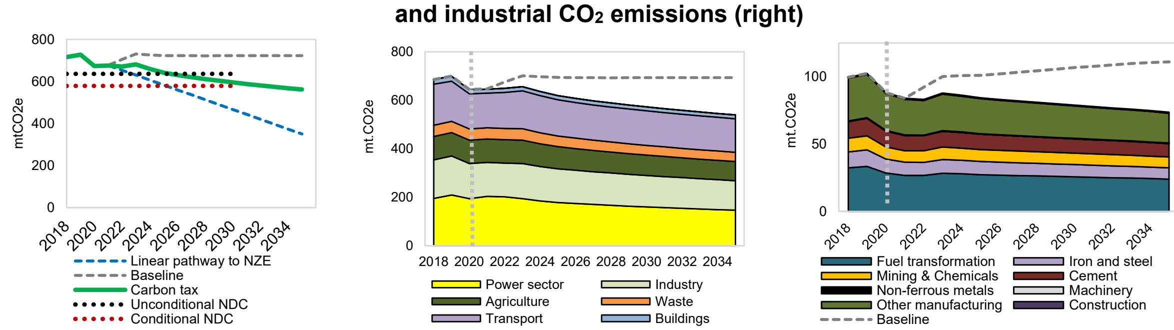
Panel A. Energy – Modelled total energy demand by fuel (left) and impacts on 2030 energy prices (right)



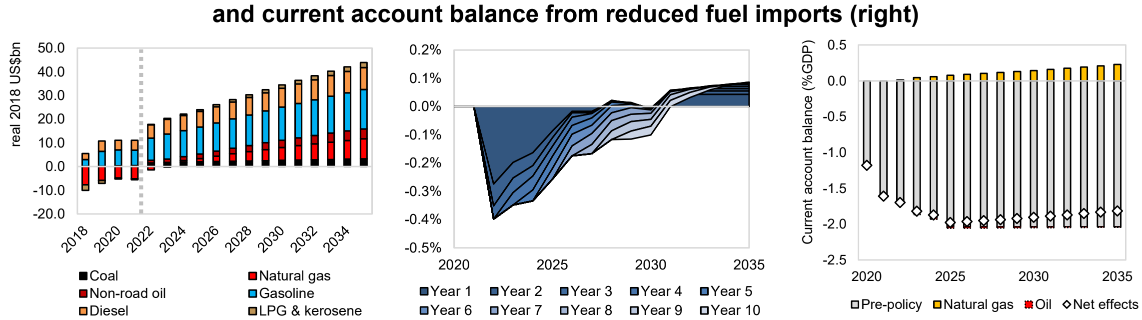
Panel B. Electricity – renewable shares of power generation (left), changes in generation by source (middle), and changes in annual investment in power capacity (right)



Panel C. Emissions – GHGs vs. targets (left), GHG by sector (middle), and industrial CO_2 emissions (right)



Panel D. Economic – revenues raised by fuel (left), net impacts on GDP levels by reform year (middle) and current account balance from reduced fuel imports (right)



Source: IMF staff using CPAT.

Annex 2. Climate Change, Inflation, and Monetary Policy

The impact of climate change on inflation and monetary policy is multi-faceted. First, physical climate risks affect inflation and other macroeconomic variables (e.g., productivity and economic growth) that are key to the conduct of monetary policy. Second, climate change can impact monetary policy transmission channels. Third, mitigation and adaptation policies have inflationary effects. Fourth, climate change may complicate the trade-offs facing monetary policy by increasing the frequency and intensity of climate-related supply shocks. These shocks pose greater risks to EMDEs with weaker institutional frameworks and less well-anchored inflation expectations.

Physical Climate Risks, Inflation, and Challenges for Monetary Policy

Climate change can lead to increased relative prices through supply shortages from extreme weather events and to volatility in domestic and imported inflation. Supply shortages from damaged agricultural and industrial production, as well as trade disruptions can increase relative prices. Beirne et al. (2024) show that weather-related disasters have a positive, non-persistent effect on inflation owing to the prevalence of negative (positive) supply (demand) shocks. Extreme weather events could also cause persistent price changes, and measures to mitigate climate-related energy supply shocks (such as inventory build-up, technological diversification in production or trading partners) could affect inflation (Bandera et al. 2023). Factoring in the expected rise in the frequency and intensity of extreme weather events, inflationary pressures are likely to become increasingly relevant for monetary policy (Schnabel 2022). Moreover, domestic and imported inflation volatility could rise as a result of the impact of extreme weather events and gradual warming on agricultural crops, housing, and energy prices (Espagne et al. 2023).

The impacts of physical climate risks on prices of goods and services depend on three factors. To analyze these effects, three key distinctions should be made. First, between *slow-moving long-term shifts in climate* (e.g., gradual temperature increases,[43] sea level rises, and changing precipitation patterns) and *extreme weather events*. Second, between the *realization* of specific extreme weather events and changes in their *distribution*. Regarding the latter, increases in intensity and/or frequency of extreme weather events can lead to larger anticipated damages and higher precautionary savings, and thereby, lower aggregate demand and output—independently of their realization. Moreover, the impacts of extreme weather events on key macroeconomic variables (consumption, savings, investment) depend on their characteristics. Storms mainly affect the economy through the capital stock, amplified by macrofinancial feedback loops such as credit contraction and lower investment. By contrast, heatwaves work mainly through a decline in labor and agricultural productivity (NGFS 2024b). Third, between *direct* and *knock-on* effects. The impact of climate change may be larger if system failures (agriculture, energy, industrial, transport) cascade up (Kemp et al. 2022).

[43] Kotz et al. (2023) show that higher average temperatures are associated with persistent inflationary pressures.

Climate change can also affect the monetary policy transmission channels. For instance, physical climate risks can affect bank balance sheets—potentially impairing the transmission of monetary policy via stranded assets and increased credit risk.

The monetary policy response to physical climate risks depends on the type of the shock. Monetary authorities need to evaluate the size, nature, and effects of the shock on the balance of supply and demand—and their persistence— to decide if a policy response is needed. Central banks may also need to develop new modeling approaches to distinguish climate shocks from other inflation drivers. Given the variety of potential climate shocks, it may be useful to create region-specific climate models to improve inflation forecasts. To address heightened uncertainty around future inflation, central banks could complement baseline forecasts with alternative scenarios. For those central banks that have the capacity, conducting in-depth analyses of the cyclical and structural factors shaping inflation will be increasingly important as climate change worsens, and if more wide-spread climate policies are implemented across countries.

Climate change poses challenges to monetary policy decision-making through two mechanisms: (i) by making the distribution of shocks fatter tailed (for instance, in the event of a succession of extreme weather events with inflationary effects, the central bank may only be able to control inflation by reducing output); and (ii) by increasing the risks of monetary policy mistakes by making it more difficult to infer underlying inflation pressures. In effect, the signal-to-noise ratio becomes more cloudy given high volatility in headline inflation and may precipitate monetary tightening when it is not needed and vice versa (Coeuré 2018).

Implications of Climate Policies for Inflation

Measures undertaken to mitigate and adapt to climate change could impact inflation. Climate policies can affect the real, fiscal, external, and financial sectors as well as the price of goods and services and financial assets. For example, the introduction of carbon pricing or raising its ambition can lead to transitory inflationary effects (Moessner 2022, Känzig 2023) and increased inflation volatility (Santabárbara and Suárez-Varela 2022).

'Greenflation' could arise from heightened demand for metals and minerals necessary for decarbonization against supply constraints (Schnabel 2022). These supply-demand imbalances could generate significant and persistent price pressures. The resulting increase in critical material costs could lead to a reversal in the trend decline in the costs of low-carbon technologies (IEA 2021). Furthermore, there could be physical limits to material substitution possibilities needed to overcome such supply constraints (Ayres 2007). Decarbonization policies may also lead to higher inflation volatility; increased electricity costs from intermittency in renewable energy sources; oil and gas price volatility; and changes in relative prices across key sectors (energy, transport, agriculture).

Climate policies could impact various measures of domestic inflation. An example is EVs, which could generate disinflation if they enter price indexes as distinct from internal combustion engine vehicles and see their price decline. More broadly, and in view of the challenges climate changes poses for central banks to assess the underlying inflation trends, there may also be some scope for central banks to augment their "dashboards" with new, complementary measures of inflation in order to continue delivering on their price stability mandates.

Annex 3. Climate Change Panel Charts

This annex describes the standardized climate change charts that are often applied in Fund country reports (i.e., staff reports). The charts allow for a consistent and evenhanded presentation of climate issues across countries—facilitating comparisons within a country over time and across countries—while recognizing the nuances of country-specific challenges and resource constraints. The charts are not aimed at providing a diagnostic, but are rather an overview of the leading climate challenges and opportunities.

There are generally three sets of panel charts targeted at (i) most countries —called "most countries" (largely focused on LICs and EMDEs) (ii) largest fossil fuel exporters and (iii) largest emitters. Each set of panel charts covers mitigation- and adaptation-related issues and policies—with commonalities across countries—while also encompassing specific challenges faced by each country group. Each country group's panel charts consist of two panels: (i) panel 1 focuses on climate risks, extreme weather events, and adaptation, while also covering emissions, energy mix, and mitigation and (ii) panel 2 is discretionary, with chart selection depending on country-specific challenges. For each country group, charts A1, A2, M1, M2 establish relevant climate challenges and the remaining two charts in the panel support the direction of the authorities' policies and/or Fund recommendations.

For the "most countries" category, the panels emphasize adaptation challenges for the country while also clarifying that these countries are not large emitters.

- The first column of panel 1 focuses on mitigation. In chart M1, three emissions metrics are shown: total emissions—which are generally modest for these countries— emissions per capita, and emissions intensity. Chart M2 provides an overview of the sectoral structure of emissions, how it has evolved, and how it compares to other countries. Chart M3 describes production and net energy exports, indicating whether there is energy import dependence.
- The second column of panel 1 emphasizes adaptation issues. Chart A1 presents climate risks and readiness. Countries that have both high vulnerability and low readiness are most susceptible. However, even countries with modest vulnerability may face strong consequences if their climate readiness is low. Chart A2 identifies the main types of hazards the country has historically faced, while providing a metric of intensity. Chart A3 gauges the capacity of countries to adapt to climate risks that may threaten food security.
- Panel 2 delves deeper into adaptation and mitigation-related topics, for example, access to electricity and its reliability, the electricity mix, water scarcity, fossil fuel subsidies, and NDC targets. For Small Developing States (SDS), Panel 2 delves deeper into adaptation-related topics.

The large fossil-fuel exporters panels emphasize issues surrounding these exports and emissions. Panel 1 contains the same charts as described for the "most countries" category (above), with the addition of Chart T1 covering explicit fuel subsidies. While the choice of charts is similar, country teams are encouraged to accentuate the distinct features of this group in the captions for each chart. For instance, more emphasis can be placed on the role of total emissions in Chart M1, in higher readiness observed in Chart A1 (highly correlated with income levels), and the relevance, intensity, and type of historic natural hazard types in Chart A2. Chart M2 can emphasize fugitive emissions from resource extraction while Chart T1 illustrates how large and prevalent fossil fuel subsidies are across different fuels and sectors—where many fossil fuel exporters heavily subsidize fossil fuel consumption. Panel 2 delves deeper into the Kaya Identity,[44] mitigation targets, oil dependency, diversification, economic complexity, and the electricity mix.

The largest emitters' panels center around domestic GHG emissions and mitigation issues, with an overview of emissions, mitigation targets, and the energy mix.

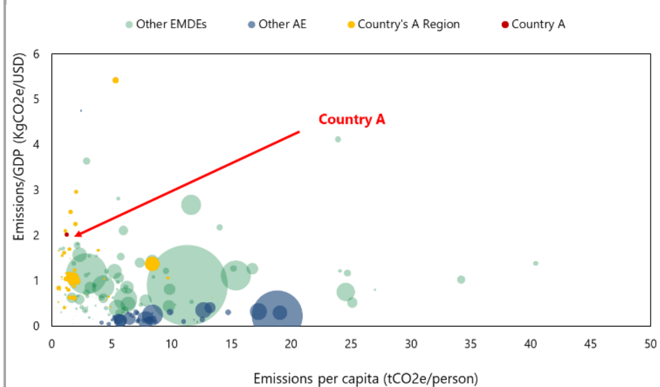
- Panel 1 Chart M1 emphasizes total emissions in comparison to other advanced economies and the country group. Total emissions can also be contrasted against emissions per capita and emissions intensity. Chart M2 highlights mitigation gaps (i.e., deviations of emissions under a business as usual (BAU) scenario from the country's NDC target) and historic emissions, followed by Fund-estimated (and, sometimes, the country's own) estimated baseline. Chart M3 turns to the role of renewables in the energy mix and illustrates energy import dependence. Chart M4 can help compare dynamics in the structure of sectoral emissions and highlight differences with other top emitters and the country's region.
- Panel 1 Chart A1 illustrates that most countries in this group are expected to face low vulnerability and high readiness.
- Panel 2 covers mitigation related policies including fuel subsidies and carbon pricing.

[44] The Kaya identity derives a country's CO_2 emissions as the product of population, GDP per capita, energy intensity and intensity. The identity helps policymakers identify the drivers of emissions growth and targeted interventions for reducing emissions. However, it has limitations, including that it assumes that its components are independent, e.g., improvements in income per capita can lead to increased energy consumption, and carbon intensity.

Most Countries Panel 1 – Country A

M1. GHG Emissions Intensity Vs. Total Emissions, 2023

Despite accounting for only 0.08% of global GHG emissions, Country A's emissions intensity (Emissions/GDP) is high globally, within its region and compared to EMDEs.

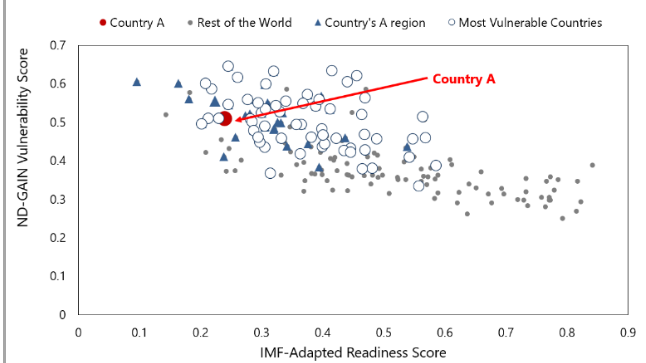


Note: Bubble size indicates total GHG emissions excluding land-use, land-use change, and forestry. Outliers are excluded.

Sources: IMF Climate Change Dashboard (2021) and IMF World Economic Outlook (WEO).

A1. Climate risks and readiness (NDGAIN, 2022)

Country A's vulnerability to climate is near the global median, but its readiness to address these risks is significantly lacking.

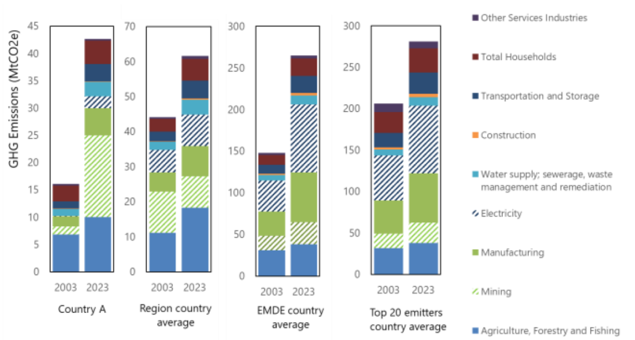


Sources: IMF Climate Change Indicators Dashboard (2021)

Note: The Vulnerability Score assesses a country's current vulnerability to climate reflecting exposure, sensitivity, and adaptive capacity. The Readiness Score assesses a country's readiness to leverage public and private sector investment for adaptative actions.

M2. Emissions by Sector

Country A's agriculture, manufacturing and power emissions have increased, reflecting the trend seen in other countries in the region.

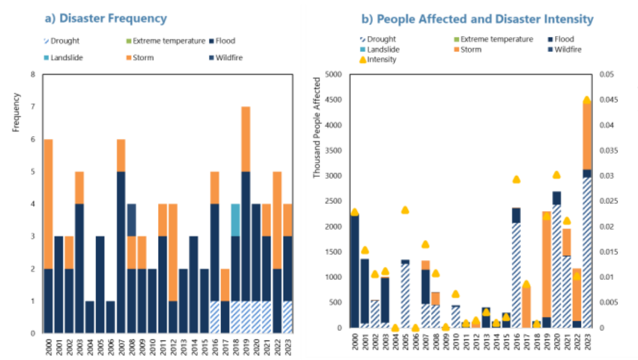


Note: GHG emissions excluding land-use and land-use change and forestry are shown.

Source: OECD Air Emission Accounts; UNFCCC; EDGAR; IMF staff calculations.

A2. Key Natural Hazard Statistics

Country A is primarily vulnerable to floods and storms, often facing multiple natural hazards in a single year.

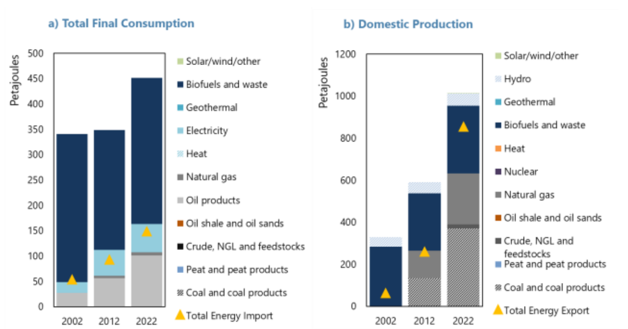


Note: Intensity is defined as (Total death+30% Total Affected)/Total population.

Sources: EMDAT and Staff calculations using Pondi and others (2022).

M3. Energy Mix

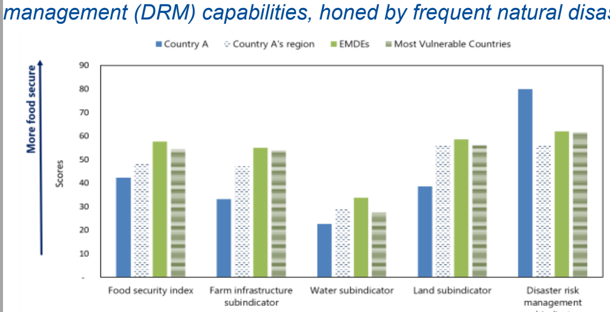
Country A is a net exporter of coal and natural gas. Renewable energies make up only a small share of the domestic energy mix.



Source: World Energy Balances (2022).

A3. Food Security and Adaptation

While the country faces food insecurity due to challenges in farming infrastructure and water risks, it benefits from strong disaster risk management (DRM) capabilities, honed by frequent natural disasters.



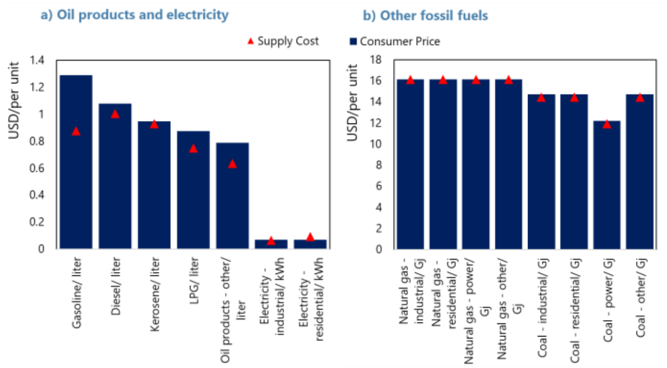
Source: Global Food Security Index 2022 from the Economist and Corteva.

Notes: M=Mitigation, T=Transition, A=Adaptation.

Most Countries Panel 2 – Country A

M4. Explicit Consumer Fuel Subsidies

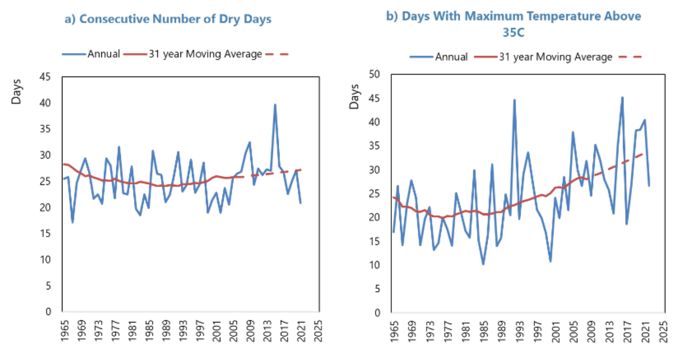
Fuel pricing is well above the supply costs for most fuels, i.e., there are no explicit consumer fuel subsidies.



Sources: IMF Climate Change Dashboard (2022) and IMF Fossil Fuel Subsidies database.

A4. Extreme Weather: Dry and Heat Days

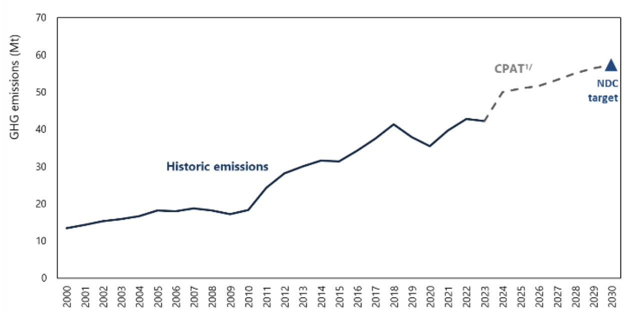
Over the past two decades, the average number of heat days per year has shown an upward trend.



Sources: FADCP Climate Dataset (Massetti and Tagklis, 2024), using CMIP6 data (Copernicus Climate Change Service, Climate Data Store, 2021).

M5. GHG Emissions vs. NDC targets

Country A can achieve its NDC targets without additional mitigation efforts.



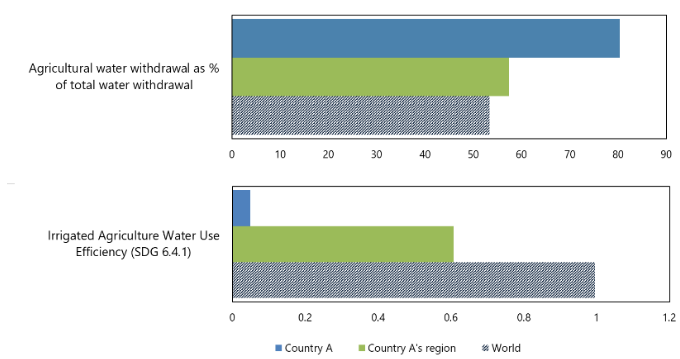
Sources: IMF Climate Change Dashboard with data from the UNFCCC, EDGAR, FAO and IMF Staff-calculations.

Note: GHG emissions exclude Land Use, Land-Use Change and Forestry.

1/ CPAT estimations are indicative as they are based on uniform assumptions across all countries across the globe (i.e., no new mitigation policies, 50% reduction in explicit subsidies if applicable, energy prices based on average IMF-WB forecasts, and macroeconomic projections from the latest WEO).

A5. Water use efficiency

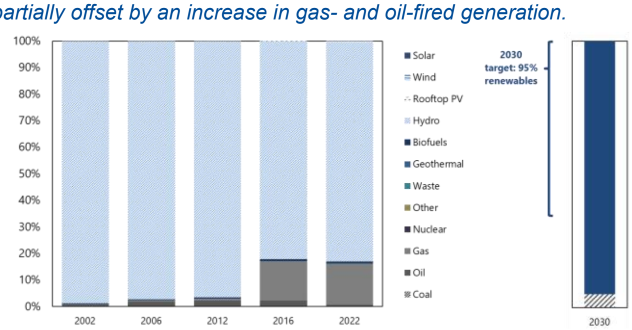
High agricultural water withdrawal and low water use efficiency compared to the regional average is expected to be further exacerbated by climate change.



Source: IMF staff estimates based on FAO Aquastat.

M6. Electricity Mix

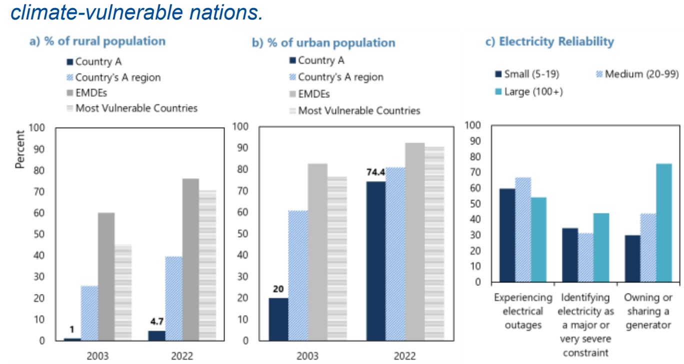
Hydropower constitutes more than 80% of the total electricity supply. However, the share of hydropower has declined over time, being partially offset by an increase in gas- and oil-fired generation.



Sources: International Energy Agency, Electricity Mix.

A6. Access to Electricity

Rural electrification is lagging in the country, where merely 4.7% of households are electrified, well below the regional average and other climate-vulnerable nations.



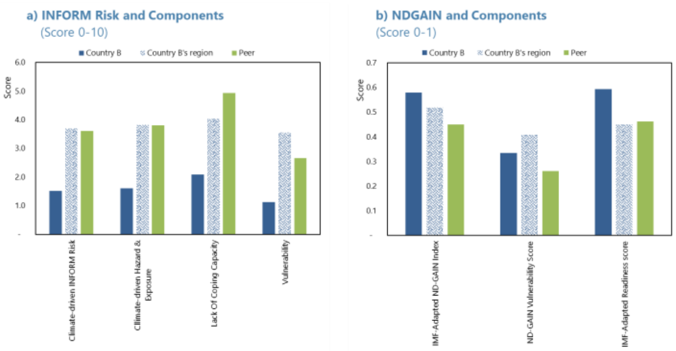
Source: World Development Indicators (2021)

Notes: M=Mitigation, T=Transition, A=Adaptation.

Small Developing States Panel 2 – Country B

A4. Vulnerability: NDGAIN Vs. INFORM Risk in 2022

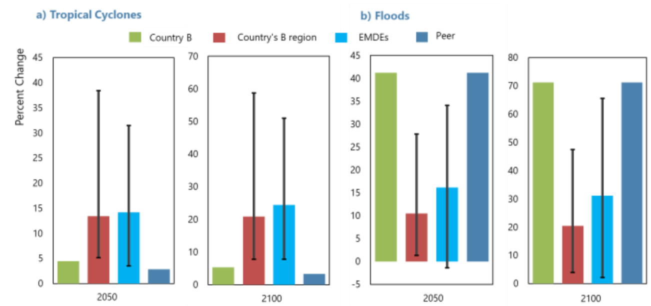
Vulnerability is lower than that of peers, while the country is better placed than peers in terms of readiness and coping capacity.



Sources: IMF Climate Change Indicators Dashboard (2021)

A5. Projected Damages from Floods and Tropical Cyclones

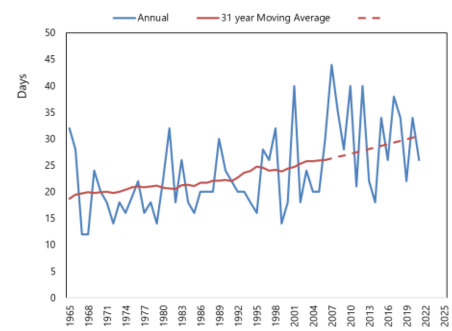
Under the SSP2-4.5 scenario, economic damage from tropical cyclones and floods are projected to increase by 5% and 40% respectively by 2050 relative to the historical baseline.



Sources: Fornino, M., Kutlukaya, M., Lepore, C. and Urunuela Lopez, J. 2024. A Multi-Country Study of Forward-Looking Economic Losses from Floods and Tropical Cyclones. IMF Working Paper.

A6. Extreme Weather: Consecutive Dry Days

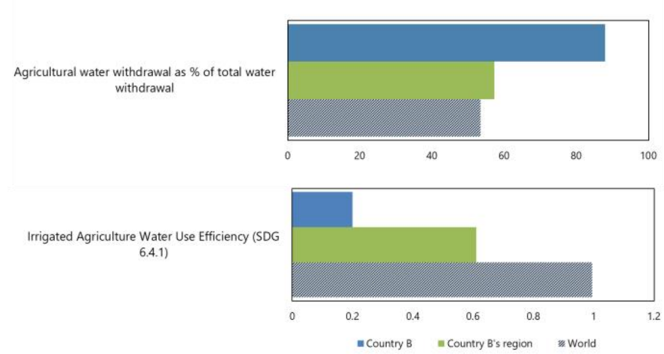
Over the past two decades, the average number of consecutive dry days per year has shown an upward trend.



Sources: FADCP Climate Dataset (Massetti and Tagklis, 2024), using CMIP6 data (Copernicus Climate Change Service, Climate Data Store, 2021).

A7. Water Use Efficiency

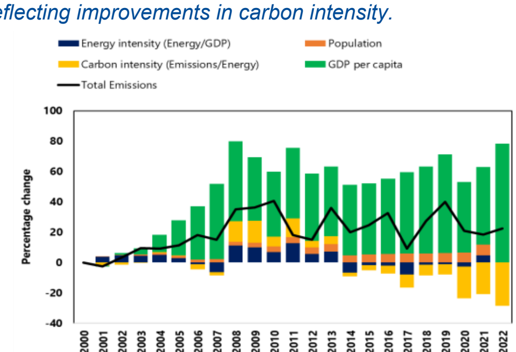
High agricultural water withdrawal and low water use efficiency compared to the regional average is expected to be further exacerbated by climate change.



Source: IMF staff estimates based on FAO Aquastat.

M4. Kaya Identity

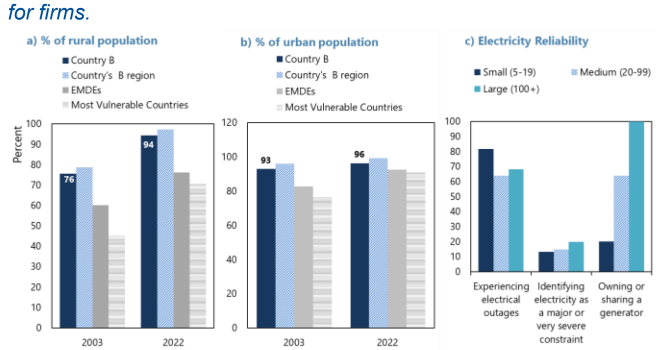
GHG emissions growth in the early 2000s was fueled by rising GDP per capita. However, it has since stagnated, paralleling GDP per capita and reflecting improvements in carbon intensity.



Sources: IMF Climate Change Dashboard with data from the UNFCCC, EDGAR, FAO, WEO, Our World in Data and IMF staff estimates. Note: The Kaya identity is a mathematical identity illustrating that total GHG emissions can be expressed as the product of population, GDP per capita, energy intensity and carbon intensity. Base year is 2000.

A8. Access to Electricity

Electrification is high and close to the regional average and other climate-vulnerable nations. However, power reliability is a challenge for firms.



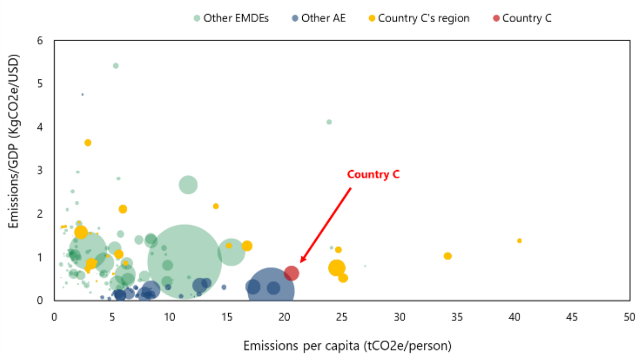
Source: World Development Indicators (2021)

Notes: M=Mitigation, T=Transition, A=Adaptation.

Largest Fossil Fuel Exporters Panel 1 – Country C

M1. GHG Emissions Intensity vs. Total Emissions, 2023

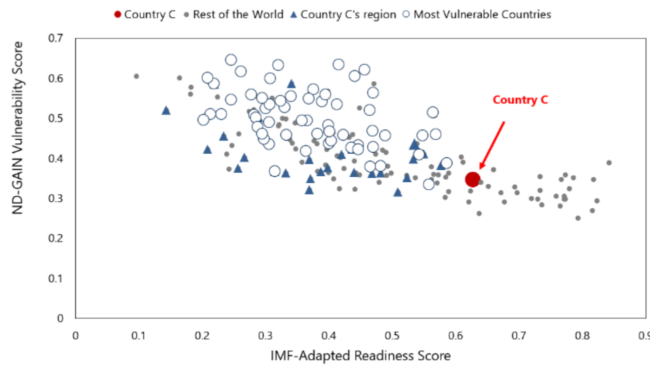
With relatively low emissions intensity (Emissions/GDP), Country C stands out as a top global emitter per capita, with substantial total emissions.



Note: Bubble size indicates total GHG emissions excluding land-use and land-use change and forestry. Outlier Palau is excluded. Sources: IMF Climate Change Dashboard (2021) and IMF World Economic Outlook (WEO).

A1. Climate risks, readiness, and income (NDGAIN, 2022)

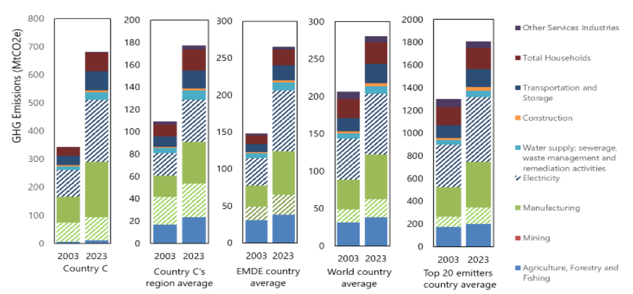
With income levels bolstering climate readiness, Country C is not significantly vulnerable to climate risks.



Sources: IMF Climate Change Indicators Dashboard (2021)
Note: The Vulnerability Score assesses a country's current vulnerability to climate reflecting exposure, sensitivity, and adaptive capacity. The Readiness Score assesses a country's readiness to leverage public and private sector investment for adaptative actions.

M21. GHG Emissions by Sector

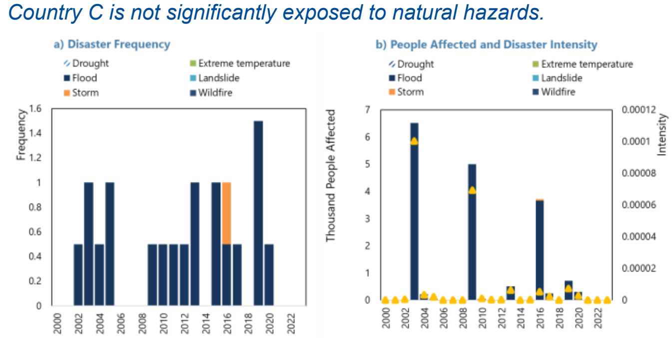
Emissions in power, transport and industry sectors make up for 70% of emissions, with substantial increases in power and transport.



Note: GHG emissions excluding land-use and land-use change and forestry are shown.
Source: OECD Air Emission Accounts; UNFCCC; EDGAR; IMF staff calculations.

A2. Key Natural Hazard Statistics

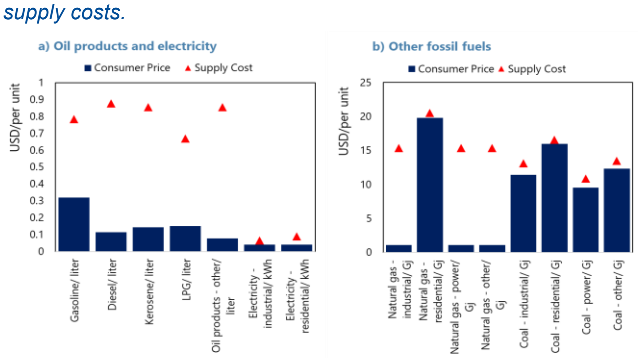
Country C is not significantly exposed to natural hazards.



Note: Intensity is defined as (Total death+30% Total Affected)/Total population.
Sources: EMDAT and Staff calculations using Pondi and others (2022).

T1. Explicit Consumer Fuel Subsidies

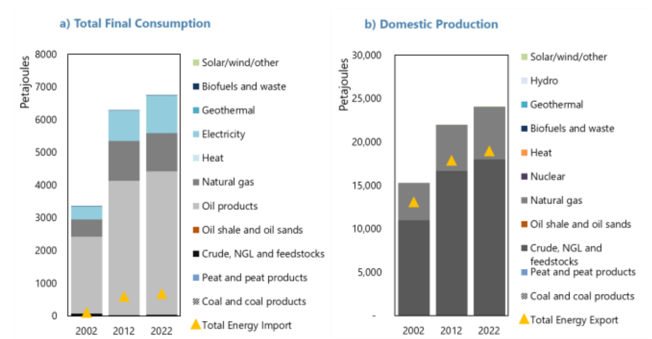
Representing 9% of GDP in 2022, fuel subsidies keep consumer prices for most oil products, electricity, and natural gas well below supply costs.



Sources: IMF Climate Change Dashboard (2022) with data from the IMF Fossil Fuel Subsidies database.

T2. Energy Mix

As a net oil exporter, Country C underscores the challenges of fugitive emissions from resource extraction, with energy imports comprising a minor share of total consumption.



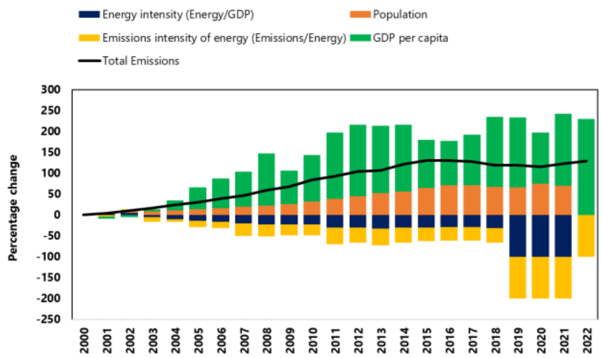
Source: World Energy Balances.

Notes: M=Mitigation, T=Transition, A=Adaptation.

Largest Fossil Fuel Exporters Panel 2 – Country C

T3. Kaya Identity

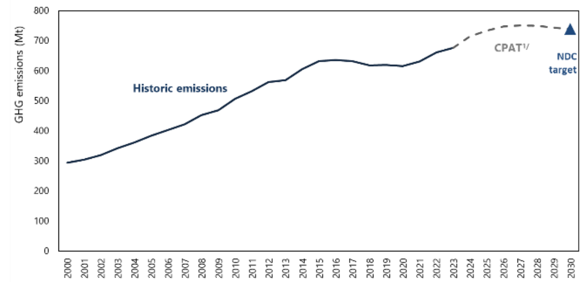
GHG emissions growth is driven by population and income growth, despite improved energy and carbon intensity.



Sources: IMF Climate Change Dashboard with data from the UNFCCC, EDGAR, FAO, WEO, Our World in Data and IMF staff estimates. Note: The Kaya identity is a mathematical identity illustrating that total GHG emissions can be expressed as the product of population, GDP per capita, energy intensity and carbon intensity. Base year is 2000.

M2. GHG Emissions vs. NDC Targets

Country C's can achieve its NDC targets without additional mitigation efforts.



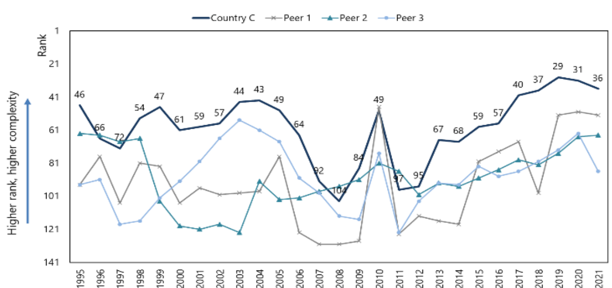
Sources: IMF Climate Change Dashboard with data from the UNFCCC, EDGAR, FAO and IMF Staff-calculations

Note: GHG emissions exclude Land Use, Land-Use Change and Forestry.

1/ CPAT estimations are indicative as they are based on uniform assumptions across all countries across the globe (i.e., no new mitigation policies, 50% reduction in explicit subsidies if applicable, energy prices based on average IMF-WB forecasts, and macroeconomic projections from the latest WEO).

T4. Oil dependency, Diversification and Economic Complexity

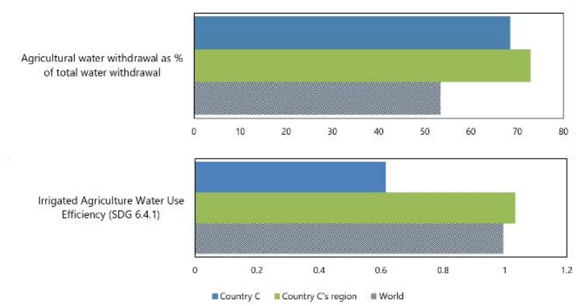
While oil dependency remains large, Country C has added 25 new export products since 2006, which have contributed to improved economic complexity.



Sources: The Growth Lab at Harvard University. The Atlas of Economic Complexity. http://www.atlas.cid.harvard.edu.

A3. Water Availability and Use Efficiency

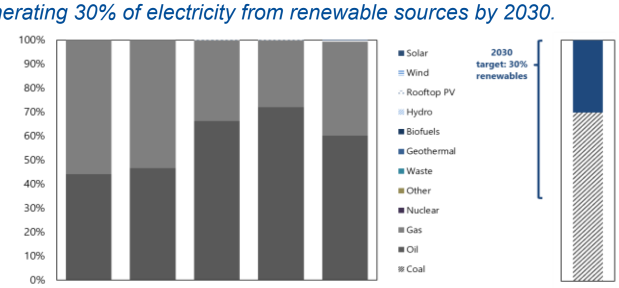
Water availability and efficiency of use are both significantly low compared to the world average and regional peers.



Source: IMF Staff estimates based on FAO Aquastat.

T5. Electricity Mix

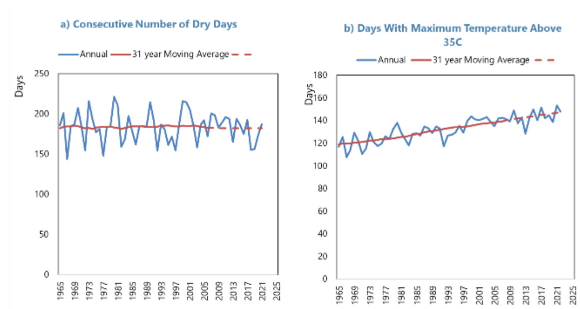
Fossil fuel-based electricity generation constitutes nearly all electricity supply. Substantial efforts will be required to achieve the goal of generating 30% of electricity from renewable sources by 2030.



Sources: International Energy Agency, Electricity Mix.

A4. Extreme Weather: Dry and Heat Days

Over the past two decades, the average number of heat days per year has shown an upward trend.



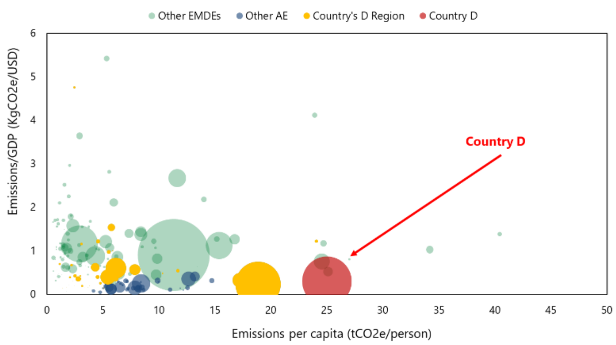
Sources: FADCP Climate Dataset (Massetti and Tagklis, 2024), using CMIP6 data (Copernicus Climate Change Service, Climate Data Store, 2021).

Notes: M=Mitigation, T=Transition, A=Adaptation.

Largest Emitters Panel 1 – Country D

M1. GHG Emissions Intensity Vs. Total Emissions, 2023

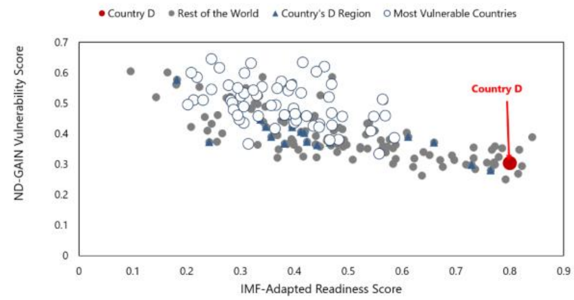
Country D is one of the top global emitters on both a per capita and absolute basis.



Note: Bubble size indicates total GHG emissions excluding land-use and land-use change and forestry. Outlier Palau is excluded.
Sources: IMF Climate Change Dashboard (2021) and World Economic Outlook.

A1. Climate Risks and Readiness (NDGAIN, 2022)

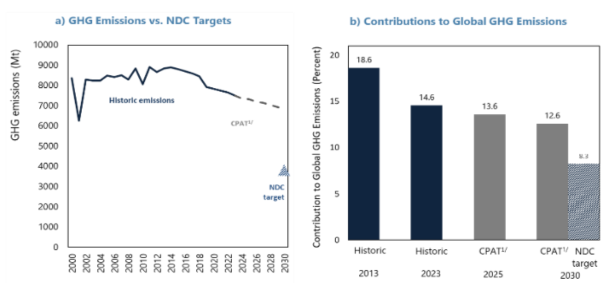
The country faces very low vulnerability and strong readiness to face climate change risks.



Sources: IMF Climate Change Indicators Dashboard (2021)
Note: The Vulnerability Score assesses a country's current vulnerability to climate reflecting exposure, sensitivity, and adaptive capacity. The Readiness Score assesses a country's readiness to leverage public and private sector investment for adaptative actions.

M2. GHG Emissions vs. NDC Targets

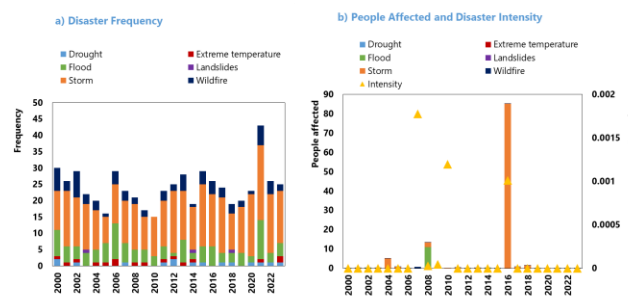
While the country significantly contributes to global GHG emissions, the country's mitigation gap, i.e., the deviation of emissions under the baseline from the country's NDC target, is somewhat pronounced.



Sources: IMF Climate Change Dashboard, UNFCCC, EDGAR, FAO and IMF Staff-calculations
Note: GHG emissions exclude Land Use, Land-Use Change and Forestry.
1/ CPAT estimations are indicative as they are based on uniform assumptions across all countries across the globe (i.e., no new mitigation policies, 50% reduction in explicit subsidies if applicable, energy prices based on average IMF-WB forecasts, and macroeconomic projections from the latest WEO).

A2. Key Natural Hazard Statistics

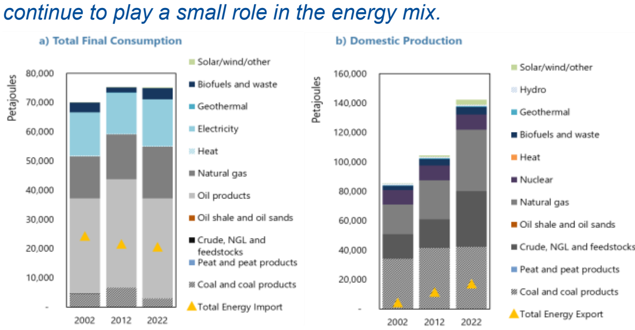
While not largely vulnerable to climate risks, recent black swan events have affected several millions of inhabitants.



Note: Intensity is defined as (Total death+30% Total Affected)/Total population.
Sources: EMDAT and Staff calculations using Pondi and others (2022).

M3. Energy Mix

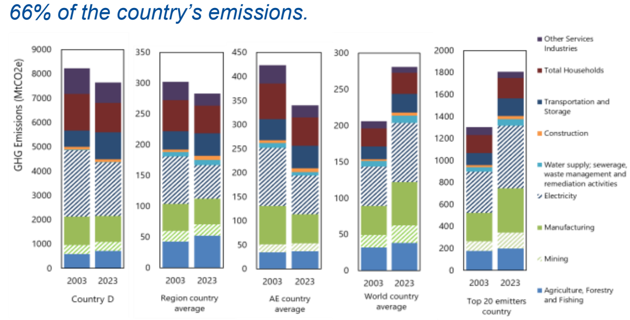
The country is a net exporter of natural gas. Renewable energies continue to play a small role in the energy mix.



Source: IEA World Energy Balances.

M4. GHG Emissions by Sector

The power, manufacturing and household emissions make for 66% of the country's emissions.



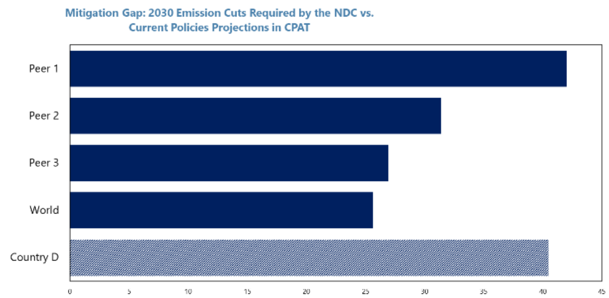
Note: GHG emissions excluding land-use and land-use change and forestry.
Source: OECD Air Emission Accounts; UNFCCC; EDGAR; IMF staff calculations.

Notes: M=Mitigation, T=Transition, A=Adaptation.

Largest Emitters Panel 2 – Country D

M5. Multilateral Component: Comparison vs. Peers

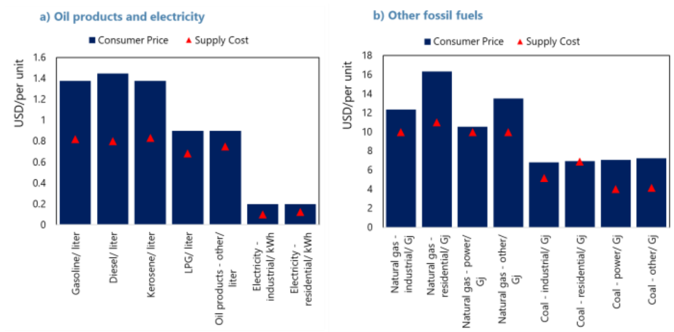
Reaching the NDC target necessitates GHG emissions reductions comparable to those of key peer countries.



Sources: Sources: [IMF Climate Change Dashboard] with data from the UNFCCC, EDGAR, FAO and IMF Staff-calculations

M6. Explicit Consumer Fuel Subsidies

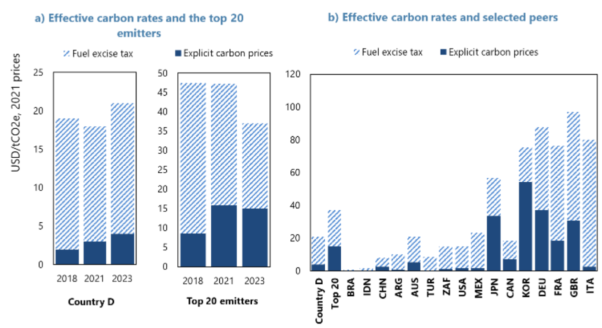
Consumer prices are well above supply costs for most fuels. The gap between supply costs and consumer prices is large in the transport sector.



Sources: [IMF Climate Change Dashboard] (2022) with data from the IMF Fossil Fuel Subsidies database.

M7. Effective Carbon Pricing

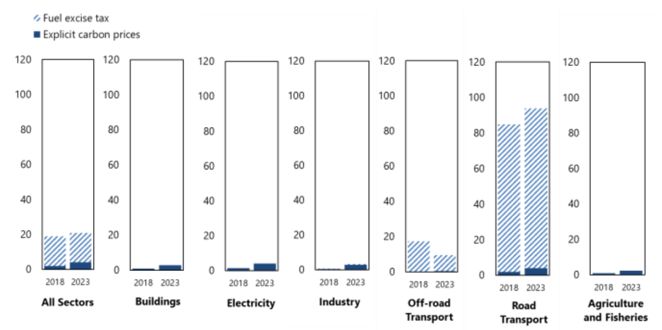
Effective carbon rates (which incorporate explicit carbon prices and fuel excise taxes) are low compared to other large emitters.



Source: OECD Effective Carbon Rates

M8. Effective Carbon Pricing by Sector

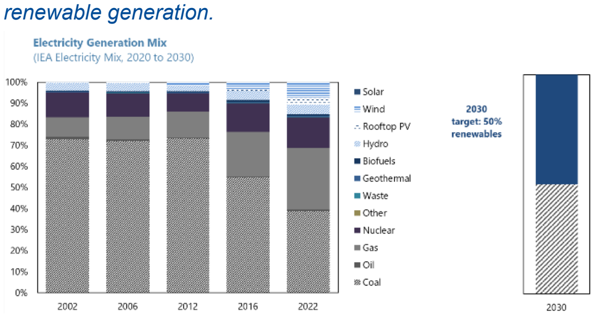
Effective carbon rates differ considerably across sectors, with the highest rates in transport.



Source: OECD Effective Carbon Rates

M9. Electricity Mix

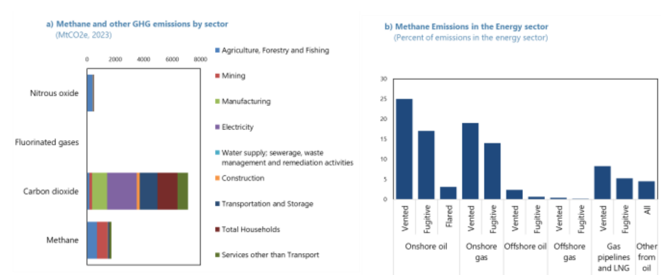
Coal and gas dominate electricity generation. Accelerating the transition will be crucial to achieve the country's 2030 target on renewable generation.



Source: International Energy Agency Electricity Mix.

M10. Methane Emissions: Significance and Drivers

Methane emissions are the country's second largest source of CO2e emissions. In the energy sector, they mainly come venting and fugitive emissions in onshore oil and gas operations.



Sources: OECD Air Emission Accounts; UNFCCC; EDGAR; IEA Methane tracker database and IMF staff calculation.

Notes: M=Mitigation, T=Transition, A=Adaptation.

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