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Implications for Climate Scenario Design

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Summary

The transition to a low-carbon economy, which is needed to mitigate climate change and meet the Paris Agreement temperature goals, has been affected by the supply chain and energy supply disruptions that originated during the COVID-19 pandemic, the Russian invasion of Ukraine, and the subsequent energy crisis and exacerbation of geopolitical tensions. These developments, and the broader context of the ongoing "polycrisis," can affect future decarbonization scenarios. This reflects three main factors: (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. In this context, the note assesses the implications of the polycrisis for hypothetical scenarios used to assess climate-related financial risks. Following an analysis of the channels through which these effects are likely to materialize over short- and long-term horizons and some policy implications, the note proposes potential adjustments to the design of the climate scenarios used by financial institutions, central banks, and financial sector supervisors and regulators within their risk management frameworks.

Introduction

The global economic recovery from the COVID-19 crisis has been marred by the joint occurrence of several subsequent shocks that are partly interrelated. Supply chain disruptions originated during the pandemic as a consequence of lockdowns and their impact on cross-border production and distribution processes. While they have largely subsided since, they have contributed to a resurgence of inflation across the world to levels not seen for decades (IMF 2023a). Russia's invasion of Ukraine in February 2022 and the associated weaponization of energy supply for geopolitical ends led to a renewed prioritization of energy security,[1] with mixed effects on climate change mitigation policies across and within regions[2]. For example, the European Commission's REPowerEU plan, released in May 2022, aims to increase the share of renewable energy in final energy to 45 percent by 2030, exceeding the 40 percent target previously under negotiation,

[1] According to LaBelle (2023), weaponizing energy involves interdependence, energy security, and sovereignty. The energy transition requires a new energy security arrangement to defuse the energy weapon.

[2] While the drafting of this note predates the outbreak of conflict in the Middle East in October 2023, a preliminary assessment of its main implications tends to confirm our findings. For example, the conflict itself – and even more so its potential escalation to a regional war – could cause oil prices to surge, which could raise the relative price of high- versus low-carbon energy. While this could be seen as tilting the balance in favor of low-carbon energy sources, historically oil shocks have been followed by oil counter-shocks, which have had the opposite effect. As emphasized by Fressoz (2022), in the wake of the oil shocks of the 1970s the oil counter-shock starting in the mid-1980s (see also Basosi and others, eds., 2019) led to major technological advances and production increases in the oil sector. These developments included exploitation of North Sea oil, deep offshore drilling in the Gulf of Mexico, and the development of oil shales in Alberta. Fressoz stresses that energy shocks have historically tended to boost polluting energy sources.

while at the same time Europe's liquefied natural gas (LNG) import capacity is expected to grow by 34 percent between 2022 and 2024 (Zaretskaya 2022). Rising geopolitical tensions are linked to the Russian invasion of Ukraine but also fueled by preexisting strains in international relations. The joint occurrence of these shocks—what some observers have called a "polycrisis," a situation in which "crises in multiple global systems become causally entangled in ways that significantly degrade humanity's prospects"[3]—has potentially profound implications for the transition to a low-carbon economy and raises questions about both plausible decarbonization paths and the design of short- and long-term decarbonization scenarios:

- Given the long-term nature of the energy transition, what are the structural implications of this "polycrisis" for energy and climate policies?
- Against this background, how should the design of scenarios for climate risk assessment accommodate this new reality?
- To what extent are the hypothetical transition scenarios (such as those published by the Network for Greening the Financial System [NGFS]) used mainly by central banks, financial regulators, and financial institutions in their climate risk analyses being questioned considering the current geopolitical situation, and the growing prominence of energy security over climate mitigation goals?

This note provides a synthesis of the implications of the polycrisis for climate policies and decarbonization, and preliminary suggestions to improve the design and implementation of climate scenarios.[4] Climate scenarios typically used for climate risk analysis by financial institutions and financial sector authorities depict potentially severe but plausible pathways for the evolution of the world under alternative socioeconomic, technological, and policy conditions. While there are multiple use cases for climate scenarios, this note focuses on the implications for climate scenarios used by financial institutions and authorities in their climate risk analyses (see Box 1), especially how those scenarios can better capture the structural change caused by the polycrisis and affect climate-related financial risks.

Box 1. Climate Scenarios to Assess Climate-Related Financial Risks

Climate scenarios depict plausible pathways of transitions in the human and Earth systems. They are used to explore how the future would evolve under a range of alternative socioeconomic, technological, and policy conditions and the implications for greenhouse gas and aerosol emissions and climate (Moss and others 2010; O'Neill and others 2020). Work on climate scenarios has grown significantly over the past few decades (Guivarch and others 2022). For example, the scenarios database for the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report released in 2014 comprises 31 models and 1,184 scenarios, and the scenarios database for the IPCC Sixth Assessment Report released in 2022 includes 3,131 scenarios derived from 188 models (IIASA 2014; Byers and others 2022). Along with the IPCC process, there are several model intercomparison exercises and efforts, such as the Energy Modeling Forum and the Integrated Assessment Modeling Consortium, that coordinate the efforts on scenario development, modeling, and reporting, and build the foundation for future scenario development (for example, Network for Greening the Financial System [NGFS] scenarios use the reporting template and database that were originally developed by the Integrated Assessment Modeling Consortium).

Along with the expansion of climate scenarios, new user groups and scenarios needs are emerging. In addition to the traditional use case of informing climate policies, climate scenarios have been

[3] A definition of the term "polycrisis" proposed in the literature is the following: "a global polycrisis occurs when crises in multiple global systems become causally entangled in ways that significantly degrade humanity's prospects. These interacting crises produce harms greater than the sum of those the crises would produce in isolation, were their host systems not so deeply interconnected" (Lawrence, Janzwood, and Homer-Dixon 2022). According to these authors, "established concepts, such as 'systemic risk' …, 'catastrophic risk' …, or 'existential risk' … do not adequately highlight these crisis interactions, even though they do capture essential aspects of the phenomenon."

[4] The note does not reach conclusions or provide recommendations on climate-related and other policies, which are analyzed exclusively from the perspective of their impact on decarbonization paths and climate scenario design.

increasingly used to assess the alignment of government policies and private sector strategies with emissions and temperature targets (Krabbe and others 2015; Weber and others 2018; Guivarch and others 2022). There are also growing needs from central banks, supervisors, financial institutions, and companies to use climate scenarios to assess climate-related financial risks and opportunities (FSB and NGFS 2022; NGFS 2023a).

Climate scenarios need to be tailored and adapted to specific use cases. For example, climate scenarios used by the IPCC usually run in a 5- to- 10-year time step through the end of the century and focus on energy system transition and emissions pathways, whereas climate scenarios used to assess climate-related financial risks need to be aligned with business and investment cycles (usually one to five years) and require further details over a short-term horizon (Weber and others 2018). To tailor climate scenarios to specific use cases, some key features need to be considered when developing the scenarios. These include time horizon; geographical and sectoral resolution; modeling structure and variables; economic, energy, and climate policies; and the speed and form of the transition.

Source: IMF staff.

The polycrisis entails both immediate and longer-term consequences for the transition to a low-carbon economy, with implications for the plausibility of the energy transition paths adopted in climate scenario design. In particular: (1) the consequences of carbon lock-in in infrastructure and policy, as well as the increased likelihood of a disorderly transition; (2) the decreasing likelihood of a continuous cost reduction of low-carbon versus carbon-intensive energy, as experienced in the past decade; and (3) other impacts stemming from the interaction of a more fragmented geoeconomic landscape with a likely intensification of macroeconomic shocks and the policy response those will trigger.

While some of the currently available scenarios envisage the possibility of a disorderly transition,[5] the NGFS and the climate finance community at large should consider designing scenarios that better reflect current sources of uncertainty, notably by:

- capturing carbon lock-in through an increase in near-term greenhouse gas (GHG) emissions, an increase in fossil fuel investment, and a delay in climate policy development and implementation;
- making downward adjustments to renewable energy technology deployment and diffusion as a result of high policy rates and supply chain constraints on critical minerals;
- incorporating macroeconomic impacts into short-term scenarios by considering higher-for-longer policy rates, tightening credit standards, high inflation, and reduced fiscal space; and
- developing new long-term scenarios that reflect the emerging geoeconomic fragmentation and constraints to trade multilateralism.

In sum, the objective of this note is to focus on:

- the implications of the polycrisis for the evolution of climate-relevant variables in different (potentially extreme) scenarios—as opposed to (central scenario) projections;[6] and

[5] For example, two NGFS Phase III scenarios, Delayed Transition and Divergent Net-Zero, envisage the possibility of a disorderly transition to 2 degrees Celsius and 1.5 degrees Celsius.

[6] It is important to emphasize that the note adopts a risk-management perspective: it focuses on future pathways that belong to non-central portions of the distribution of possible future outcomes (as opposed to central forecasts) –, i.e., those most likely representing heightened transition risks. They do not reflect the IMF's expectations about possible future outcomes but are considered hypothetical.

- the channels through which the polycrisis affects the likely paths of those variables (that is, we focus on the *differential* impact [between before and after the crisis]).[7]

The note is structured as follows: the first section elaborates on the main consequences of the polycrisis for the transition to a low-carbon economy, as indicated earlier. The second section provides suggestions for the evolution of climate scenario design, based on the analysis in the first section. The final section reports the authors' conclusions and discusses areas for future research.

Impact of the Polycrisis on the Global Transition to a Low-Carbon Economy

Disorderly Transition and Carbon Lock-in

The polycrisis will have both immediate and far-reaching consequences for the global transition to a low-carbon economy, primarily as a result of the major disruptions to the supply of commodities. In 2022–23, it was anticipated that the energy transition would suffer a setback and possibly also a partial reversal, because of the regained prominence of energy security over other policy objectives, such as climate change mitigation.[8] This change of priorities was spurred by the turbulence in commodity markets throughout 2022, which initially took the form of a spike in prices for energy, agriculture products, metals' extraction, and refining (which fed into global headline inflation).[9] While the first half of 2023 saw a price reversal for several commodities (including coal), prices of all major commodity groups remain above their 2015–19 average levels. This situation is likely to persist given the limited scope of commodity substitution to alleviate price pressure and the potential exacerbation of price hikes resulting from the increase in energy demand following tax cuts and subsidies across the world.

All this has both direct and indirect implications for the transition to a low-carbon economy. A direct implication is that in the medium to long term—even assuming full complementarity between the policy objectives of climate change mitigation and moderation of energy supply vulnerabilities—resuming the path to net zero will most likely require an even more intense effort than before the crisis (to compensate for the time lost). Moreover, net-zero pledges are generally formulated in terms of objectives for the very long term (typically up to 2050 or 2060)[10] and not always accompanied by concrete commitments to reduce emissions in the nearer term. Consequently, even with a domestic net zero objective, domestic emissions can continue to increase (or decrease at a slow pace). The resulting concave emission reduction curve implies much higher cumulative emissions than a steadily declining one.[11] This will raise the probability of a less gradual and/or more "disorderly" transition. At the same time, a more fragmented and less cooperative international environment would increase the likelihood of uncoordinated and possibly noncooperative climate mitigation strategies across

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[7] For example, as elaborated upon in the subsection "Prospects for Renewable Energy", while the cost of renewable energy is still declining, we find that, as a consequence of the polycrisis, the likelihood of such decline slowing down (and, possibly, even reversing) has increased.

[8] Energy security and climate change mitigation may not be conflicting objectives in the medium term (Kim and others 2023), depending on the substitutability of critical minerals across regions and flexibility options in renewable-based electricity systems. However, the promotion of energy independence amid renewable energy deployment, market concentration resulting from the exit of marginal cost energy suppliers, and the effects of inter-fossil-fuel substitution are channels through which energy sector decarbonization may impact energy security. Therefore, in a risk scenario, a series of considerations—most of which are studied in this note—may impede the positive connection between energy security and climate change mitigation.

[9] The war in Ukraine impacts the commodity markets through two main channels: (1) the physical impact of blockades and the destruction of productive capacity and (2) the impact on trade and production following sanctions (World Bank 2022).

[10] Net zero targets by 2050 have been set by the European Union, Japan, South Korea, the United Kingdom, and the United States; by 2060 by China; no later than 2060 by Russia; and by 2070 for India.

[11] If this pattern were generalized across large emitters, global emissions would increase significantly even *within* a net zero policy framework. Such concavity of global emissions (that is, a humped curve rather than a gradual or steep decline) would imply significantly greater physical risks—notably by raising the likelihood of crossing climate tipping points.

countries, for example with export blocks for countries implementing anti-carbon-leakage measures (as with the European Union's Carbon Border Adjustment Mechanism).[12]

An important indirect implication for the transition is the amount of carbon lock-in generated by the current response to the energy crisis.[13] While efforts are being made in some regions to address the energy crisis without jeopardizing the decarbonization objective (Box 2), certain decisions are likely to increase the degree of carbon lock-in in both infrastructure and policy despite an increase in renewable energy investment (Box 3).

In particular, the overall picture of energy investment, while mixed, points to a decisive increase in carbon lock-in. At the aggregate level, there has been a significant boost to renewable energy investment as a response to the global energy crisis and the recovery from the pandemic and as a result of an alignment between climate change policy ambition, energy security goals, and industrial strategies (IEA 2023a).[14] In parallel, however, investment in unabated fossil fuel supply[15] is set to rise by more than 6 percent in 2023, reaching an estimated $950 billion (IEA 2023a). Capital expenditure forecasts for new oil and gas fields remain high, especially in emerging market and developing economies (EMDEs), accounting for roughly 75 percent and 95 percent of energy industry investments by 2030 and 2050, respectively (IMF 2023b). Continued strong investment in fossil fuels, even as investment in renewables grows, is consistent with the fact that, globally, energies have a "symbiotic"—as opposed to competitive—relationship with each other.[16] This is a constraint for global decarbonization that remains largely ignored by current scenarios.

These developments are inconsistent with the ambitious decarbonization paths announced by many jurisdictions. According to the International Energy Agency's (IEA's) Net Zero by 2050 Roadmap (IEA 2021a, 2023c), beyond projects already committed as of 2021, no new oil and gas fields can be approved for development, and no new coal mines or mine extensions are required in order to achieve net zero carbon dioxide (CO_2) emissions by 2050.[17] Despite the consequences of Russia's invasion of Ukraine, new conventional oil and gas field approvals in the short term would not be helpful to meet immediate needs with meaningful volumes, given the long lead times for large new supply projects. This is why the IEA has insisted on the need to focus investments on projects with shorter lead times and quicker payback periods (IEA 2022a).

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[12] Aiyar and others (2023) identify multiple channels through which the costs of geoeconomic fragmentation are likely to materialize, including trade, migration, capital flows, technology diffusion, and the provision of global public goods.

[13] Carbon lock-in can be defined as inertia in the energy system that prevents or delays transitions toward low-carbon systems (Fisch-Romito and others 2021), and as "the degree to which the configuration of the energy system in 2030 is less than optimal, thus increasing the difficulty of emission reductions achieved post-2030" (Bertram and others 2015).

[14] Key low-emission power policies introduced and proposals announced in 2022–23 include the US Inflation Reduction Act (including tax credit extensions for solar photovoltaics and wind, investment tax credit for battery storage and zero-emission nuclear, and financial support for grids and manufacturing clean power equipment), the 14th Five-Year Plan in China (which raises the renewable energy target to 33 percent of power consumption by 2025), and the REPower EU Plan and the Net-Zero Industry Act in the European Union, in addition to individual member states' efforts to boost offshore wind capacity by 2030.

[15] See Bataille (2023) for a discussion on reliance on carbon capture and storage technologies to achieve the Paris agreement temperature goals.

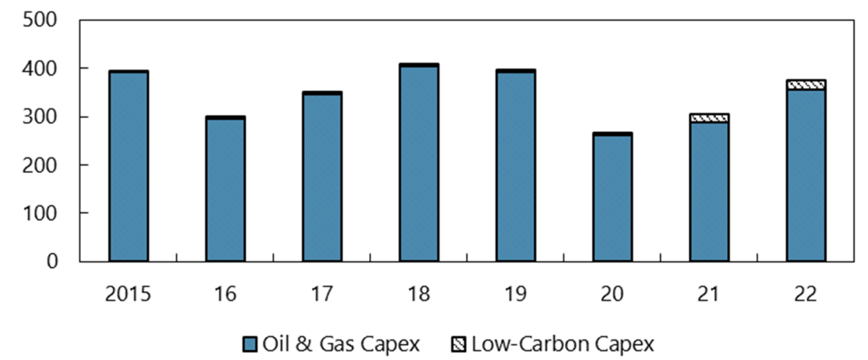
[16] As noted by Fressoz (forthcoming), the history of energy is one of "energy symbioses": the world economy has never experienced an energy transition in the sense of a *substitution* of energy sources in *absolute* terms, which is what matters from a climate perspective. This reflects the fact that, at the level of the world's energy system, energies do not substitute for one another but rather reinforce each other. For instance, while the conventional narrative that a transition from wood to coal occurred in the 19th century is accurate in relative terms, it is inaccurate in absolute terms: the world has never consumed as much wood and coal as it does today. A key reason is that, globally, coal has not replaced wood but has instead helped to boost its consumption. In 2022, Europe consumed three times more wood than in 1900. The need intensively to deploy existing energies to develop new forms of energy supply is also stressed by Smil (2017, p. 230). He notes that "today's solar photovoltaic cells and wind turbines are embodiments of fossil energies." Relatedly, Zhang (2023) estimates that 35–40 percent of wind and solar power capacity built in China over the last five years has been bundled with coal power.

[17] The trajectory of falling demand for fossil fuels is expected to match the declines in supply that would be seen with continued investment in existing sources of supply, without any need for the approval of new upstream conventional projects.

The likelihood of oil and gas companies transitioning to low-carbon activities is also further reduced. Investment by oil and gas companies is increasingly anticipated to take place in the decarbonization of their operations, including in carbon capture, utilization, and storage technologies, rather than toward a diversification into power generation (IEA 2023b). Low-carbon investment accounts for an extremely limited share of the oil and gas industry's overall capital expenditures (IMF 2023b; Figure 1), despite high profitability in 2022. This is the consequence of the highly different nature of power generation compared to the core business area of oil and gas production (Christophers 2022). It is also the result of inertia in shifting away from fossil fuels given the capital-intensive nature of the energy business (Alova 2022) and of an employment bottleneck (IEA 2023b).[18]

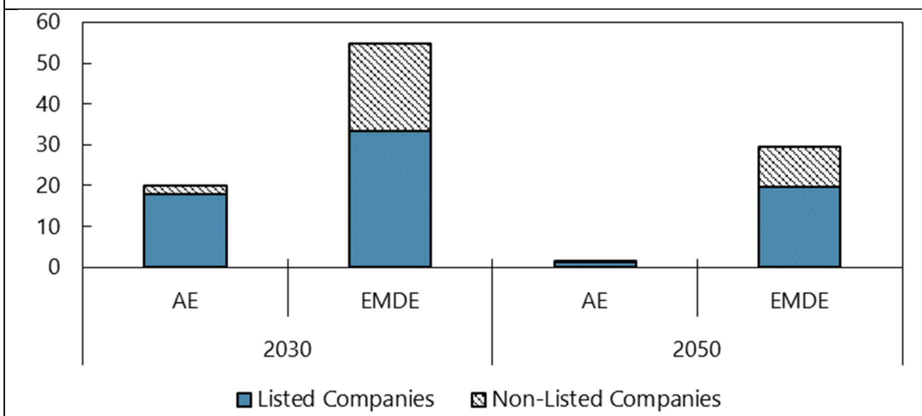
Figure 1. Capital Expenditure in the Oil and Gas Industry

1. Total Oil and Gas versus Low-Carbon Capital Expenditure (Billions of US dollars)



Sources: International Energy Agency 2023a; Rystad; and IMF staff calculations.
Note: Data only includes production capital expenditure. "Low-carbon capex" refers to capital expenditure in renewable power; grids; storage; carbon capture, usage, and storage; and energy efficiency.

2. Capital Expenditure in New Oil and Gas Fields



Sources: Rystad; and IMF staff calculations.
Note: AE = advanced economies; EMDE = emerging market and developing economies.

[18] More specifically, the IEA (2023b) notes that "Companies cannot respond to these market and policy signals without the skilled workforce needed to deliver these projects in the regions where they are being developed. Shortages of skilled labor across energy supply chains are already translating into project delays and impacting investment decisions in some sectors, such as oil, gas, and offshore wind." This is also true in the coal industry (Rutkowski and others 2022).

Carbon lock-in sets the stage for further hurdles, over time, on the path to a low-carbon economy.[19] Apart from representing a major resource misallocation and diverting funds from the objective of decarbonizing the economy, carbon lock-in also has political economy implications: dominant industries and coalitions (such as fossil fuel and other carbon-intensive sectors) have powerful incentives to intensify their efforts to protect the value of their assets (for example, via lobbying) against measures perceived as—partially or fully—"stranding" them. In turn, such action further delays or weakens climate mitigation policies.

Box 2. An Overview of Heterogeneous Short-Term Impact of the Polycrisis on Energy Transition Policies across Different Regions

- In the **European Union**, the REPowerEU initiative (European Commission 2022) was adopted in May 2022 to reduce dependence on Russian natural gas and other commodities, suggesting that the transition remains a primary policy objective. Building on the Fit for 55 package (European Commission 2023), the REPowerEU initiative puts forward an additional set of actions. These aim to increase energy efficiency, ensure diversification of fuel supply (with a focus on liquified natural gas, biomethane, and renewable hydrogen), substitute fossil fuels by accelerating the energy transition, and increasing renewable energy supplies to 45 percent by 2030 (higher solar and wind electricity production targets, addressing EU-wide infrastructure gaps and needs for gas, electricity, and hydrogen, etc.). Reaching net zero goals in the European Union now seems to entail novel challenges compared to the situation that prevailed in the years following the Paris Agreement,[1] including supply security concerns, a slower deceleration in demand for fossil fuels, the search for greater cost efficiency for renewable energy infrastructure and storage, and greater flexibility in energy systems (Eyl-Mazzega, Mathieu, and Urbasos 2022).
- In the **United States**, the adoption of the Inflation Reduction Act in August 2022 has spurred the climate policy agenda, aiming at increasing investments to reduce greenhouse gas emissions by 40 percent by 2030, notably by disbursing around $370 billion for measures dedicated to improving energy security and accelerating clean energy transitions, including funding for carbon capture, utilization, and storage projects. The Inflation Reduction Act also encompasses a Methane Emissions Reduction Program.
- In **Asia**, the polycrisis has driven up crude oil and natural gas prices, but also food inflation and manufacturing production prices (United Nations, ADB, and UNDP 2023). Yet increasing electricity output while cutting coal and oil requires significant growth in renewable energy infrastructure, paired with energy storage. The energy crisis and increased commodity price volatility may complexify the transition agenda (S&P Global 2022), especially as the polycrisis appears to have derailed development progress in Asia and the Pacific including for access to affordable and clean energy, with setbacks in access to affordable, reliable, and modern energy services (United Nations, ADB, and UNDP 2023).
- In **Central and Latin America**, the current impacts of the polycrisis have been uneven across economies, depending on whether they are oil exporters (for example, Brazil, Colombia, Ecuador, and Venezuela) or agricultural exporters (for example, Argentina, Brazil, and Uruguay) benefiting from the point of view of their external accounts, or net food and fuel importers (Central American and Caribbean countries) facing increased vulnerabilities. Fuel pricing policy is likely to become a delaying factor in the current political context, especially if not targeted toward the most vulnerable social groups. Increasing competition for US liquified natural gas imports will likely

[19] See Bertram and others (2015); Seto and others (2016); and Fisch-Romito and others (2021). It should be noted that decarbonization poses different challenges to countries depending on their level of income. For industrialized economies, decarbonization requires transforming the productive structure of the economy and changing patterns of production and consumption, including by reducing energy demand (Bhattacharya and others 2021). By contrast, low-income countries are low GHG emitters and face the challenge of achieving low-carbon forms of economic development. This matters for climate scenarios, as it creates a potential trade-off in some EMDEs and low-income countries between short-term binding constraints (in particular, exploiting natural resources to maintain external sustainability to finance investments needed to raise the level of income per capita)—which increases both physical and transition risks—and achieving low-carbon economic development over the long term (Valdecantos 2023; Prasad and others 2022).

negatively impact Central and Latin America as well, even more so given recurrent droughts have been hampering hydroelectricity production (that is, the backbone of Latin America's energy grid) (Cárdenas and others 2022). Oil exploration and increased oil production to address fiscal and external pressures point to a very large increase in oil production in the region (notably in Brazil, Guyana, and Suriname) (see IEA 2023e, p. 132; Flicking 2023).

- In **Africa**, the polycrisis is likely to have stark implications for the energy transition, as it (1) exacerbates the continent's chronic energy poverty problem, (2) is likely to enhance the lack of financial support for Africa's energy transition, (3) harms African electricity markets and renewable projects as a result of rising commodity prices and interest rates, and (4) spurs investment in Africa's mining industry as a result of supply chain diversification (IMF 2023c; Auth and Moss 2022; Tollefson 2022; Wroughton 2022).

[1] This situation was characterized by a policy focus on ensuring competitiveness through electricity market reforms and integration, and free allowances; on the decarbonization of the electricity sector; and on ensuring energy security through the expansion of EU market rules abroad.

Box 3. Recent Trends Are Likely to Increase the Degree of Carbon Lock-in in Infrastructure and Policy

Although investments in renewable energy have increased and now represent a 1.5-to-1 ratio with fossil fuels, there is a large gap between current trends and the investment required to get on track for the Net Zero Emissions by 2050 Scenario, in renewable energy deployment, energy efficiency, and electrification (IEA 2023e). In addition, investments in renewable energy remain heavily concentrated in a handful of countries (China, European Union, Japan, and the United States). Consequently, lock-in risks have increased:

- Coal-fired power generation is experiencing an intense rebound, after an all-time high in 2022 that is expected to persist in 2023. Despite high coal prices (in nominal terms), national decisions have been made to slow down decommissioning of coal-fired power plants and/or reopening shuttered coal mines (including in China, Germany, Italy, and the United States), amid a rebound in global coal demand in 2022–23.
- The role of natural gas remains significant, with final investment decisions for unabated gas-fired power generation rising in 2022 (primarily in China, the Middle East-Northern Africa region, Southeast Asia, and the United States) (see Annex 1 for additional discussion on natural gas lock-in).
- Challenges are anticipated in the implementation of the structural reforms for reduction in natural gas use, methane leakage, and renewable energy deployment adopted in the spring of 2022, especially in the European Union. For instance, the launch of the joint EU-U.S. Task Force on Energy Security in April 2022 (EU-U.S. Task Force on Energy Security 2023) to diversity gas supply via higher liquified natural gas and pipeline investment raises climate-related challenges, especially because of the carbon content of liquified natural gas and the buildup of import infrastructure. More broadly, the European Union's plans also lack guardrails on additional natural gas production by non-Russian countries to limit greenhouse gas emissions and modify incentives for the deployment of low-carbon hydrogen capacity and effective scaling up of renewable energy (Blanton and Mosis 2021; Eyl-Mazzega, Mathieu, and Urbasos 2022).
- Because of the global nature of the oil market and the short-term supply inelasticity of fossil fuel production, the European Union's rush to secure supplies may push other jurisdictions to do the same. It may trigger a sort of worldwide zero-sum resource-grabbing. Even in the natural gas market—which, before the Russian invasion of Ukraine, was usually more regional than the oil market, but is becoming increasingly global—the hoarding of liquified natural gas by Europe has been crowding out certain countries (including in South and Southeast Asia), pushing them back toward coal and causing blackouts. These developments could further spread the lock-in effect.

Prospects for Renewable Energy

The likelihood of a continuous cost reduction of low-carbon versus carbon-intensive energy, as experienced in the past decade, is decreasing. Prices have decreased rapidly for several key energy system mitigation options between 2015 and 2020 (for example, –56 percent for solar, –45 percent for wind, and –64 percent for batteries) amid an increase in capacity (+170 percent for solar and +70 percent for wind). Meanwhile, there are signs that the room for further cost reductions in solar and wind technologies might be shrinking, at least with respect to the recent past. Specifically, the IEA has found that, following multiple years of cost declines, the prices for several major low-carbon energy technologies rose in 2021 and 2022 because of higher input prices for critical minerals, semiconductors, and bulk materials like steel and cement (IEA 2023a).

The polycrisis might reinforce this trend, in a context where wind and solar technologies have reached a relative stage of maturity and critical mineral prices[20] have recently risen (IEA 2021a; Espagne and others 2023). First, the increase in energy prices since 2021 led to increased inflation and real interest rates, which is anticipated to have a stronger impact on renewable energy infrastructure (see later discussion). It is hence likely to impact the affordability of low-carbon energy sources relatively more than carbon-intensive ones, because of their higher elasticity with respect to interest rates. Second, the heightened sensitivity of the energy sector to geostrategic factors may lead to friend-shoring practices (White House 2021)[21] for fundamental inputs to renewable energy infrastructure (for example, lithium), leading to reduced supply, higher costs, and larger investment needs. This relative cost-competitiveness could be further affected if renewable energy projects start to be perceived by financial market participants as riskier than previously assumed. It may stem from heightened uncertainty about the direction and time consistency of policies supporting the energy transition, thus commanding a higher credit spread. In the Renewable Energy Market Update published in June 2023, IEA (2023f) stated that the financial health of the renewable energy industries, while showing overall resilience, varies significantly across sectors and countries. Moreover, solar and wind manufacturers could face financial challenges as a result of supply gluts, declining profit margins, high commodity prices, and changing financing environment.

Low-carbon technologies could be affected more heavily than carbon-intensive ones by the current high-rate environment. The Russian invasion of Ukraine drove up inflation in Europe by generating a surge in energy prices (Arce, Koester, and Nickel 2023). The policy response to the combination of pandemic-related supply disruptions, the war-related energy price surge, and broader price pressures consisted in massive and synchronized tightening of monetary policy by most central banks (Gourinchas 2023a).[22] The business model of low-carbon technologies—and mining investments—is intensive in capital expenditure and entails high upfront capital costs. By contrast, the cost structure of high-carbon technologies is tilted toward operational expenditure, and firms can use current revenues to pay for fuel. This makes the low-carbon technologies relatively more sensitive to increases in the cost of capital—and to interest rates, in particular: for example, there is evidence that the levelized cost of energy (LCOE) of solar photovoltaics and onshore wind would increase by 11 percent and 25 percent, respectively, with interest rates in the 4 to 4.5 percent range, rather than close to zero (Schmidt and others 2019), and that the LCOE of a gas-fired power plant would rise by around 4 percent if interest rates were to rise from 3 percent to 7 percent, whereas the LCOE of offshore wind and solar photovoltaic

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[20] As noted by Hache and Louvet (2023), the criticality of metals can be determined based on different dimensions: geological, environmental, and economic. A metal can be deemed critical by a country's authorities because of its increased use in industrial production, its high and rising price, the absence of identified substitutes, production located in fragile and conflict-affected states or whose production processes have large negative environmental impacts, etc.

[21] The report underlines: "Methods of guarding against single-source risk in the critical minerals supply chain, for example, is limited in part by where natural resources exist. *Tools including ally and friend-shoring, and stockpiling, along with investments in sustainable domestic production and processing will all be necessary to strengthen resilience*. Sectors where we seek to advance our technological competitiveness—like high-capacity batteries—will require an ecosystem-building approach that includes supporting domestic demand, investing in domestic production, recycling, and R&D, and targeting support of the U.S. automotive workforce" (White House 2021, p. 8).

[22] Ongoing monetary and fiscal policy tightening is consistent with the IMF's policy recommendations (IMF 2023a).

technologies would rise by more than 30 percent.[23] Moreover, higher funding costs could be particularly detrimental because, according to the IEA, decarbonization in EMDEs requires a significant amount of debt financing (IEA 2021b).

The current environment of high policy rates could hamper the cost reduction path of energy renewables—or even reverse it. A lack of investment in renewables or in expanding mining investment could exacerbate the underlying drivers of inflation, notably vulnerability to fossil energy supply-demand imbalances, without addressing other drivers of inflation such as rising corporate profit margins.[24]The current resurgence of industrial policies more or less directly aimed at supporting the low-carbon transition does not substantially alter the overall picture. While the U.S. Inflation Reduction Act, for example, could help lower the cost of renewable energy technologies (see, for example, Bistline and others 2023), several factors go in the opposite direction. As discussed further below, factors that put upward pressure on the cost of renewable energy technologies include higher interest rates, supply chain disruptions, permitting lags, transmission capacity and grid stability. Moreover, current and expected profitability of renewable energy technologies is hampered by both the aforementioned factors and the removal of subsidies for renewables in many countries.[25] Finally, the LCOE of power from renewables masks potentially large costs, including those related to transmission, distribution, wholesale price volatility and market competition, which collectively dampen profitability and therefore investment incentives (Christophers 2022).

Supply being insufficient to meet the requirements of orderly decarbonization may impact the "resilience of transitions" (IEA 2023a). Expansion in the supply of multiple critical minerals for the transition (lithium, cobalt, copper, zinc, iron ore, aluminum, nickel, silicon, silver, platinum, palladium, manganese, graphite, rare earths) could well be insufficient to meet demand (Miller and others 2023). The scale that the supply of certain minerals should reach to feed the energy transition requires a multifold expansion of production, straining the existing supply chains (McKinsey & Company 2022). At the same time, IMF (2023e) notes that geoeconomic fragmentation has led to a sharp rise in the dispersion in commodity prices across regions, including critical minerals, and finds that intensifying geoeconomic fragmentation could disrupt the commodity flows across markets, inducing further price volatility and hindering the low-carbon transition.[26] According to Boer and others (2021), copper, nickel, cobalt, and lithium are potential bottlenecks for the energy transition. They are currently absent from transition scenarios, despite their critical role as inputs into the production of renewable energies and batteries. In addition, the bottlenecks and insufficient supply of commodities already observed before the start of the Russian invasion of Ukraine could in fact persist and even worsen: the surge in material prices (on a sustained upward trend since the start of 2021 and accelerated since the start of the invasion) "threatens a decades-long trend of falling costs for clean energy technologies" (Boer, Pescatori, and Stuermer 2021; Kim 2022). The necessary expansion of these minerals could be slowed down

[23] See IEA (2020). See also Schnabel (2023). Anecdotal evidence suggests that profitability for renewables and batteries has been significantly reduced by monetary policy tightening, including in the United States. On the impact of higher interest rates on the viability of offshore wind projects, see Millard and Pitel (2023).

[24] According to Pisani-Ferry and Mahfouz (2023), climate action will increase inflationary risks because of a slowdown in productivity and the costs of building a more resilient economy. They argue that climate action therefore requires that central banks adopt a longer-term perspective than what they are used to and include in their thinking considerations they are not used to factoring in. Furthermore, the report argues that excessive monetary policy tightening risks slowing climate action and delaying efforts to build a low-carbon economy, thus amplifying risks of a disorderly transition. The report calls for central banks to conduct monetary policy with dexterity and even temporarily raise their inflation targets. Consistent with this view, Bandera and others (2023) argue that addressing risks to energy supply requires prioritizing measures to ensure sufficient levels of inventory or technological diversification in production or in trading partners' supplies so as to prevent or attenuate the impact of shocks on the economy. On the role of corporate profit margins in recent high levels of inflation, see Weber and Wasner (2023); Arce, Hahn, and Koerster (2023); Gourinchas (2023b); and Hansen, Toscani, and Zhou (2023).

[25] See IEA (2023a), which notes that following the removal of subsidies for onshore wind in China in 2020, investment appetite declined. Other countries that have removed subsidies to renewable energy technologies or renewables operations in recent years include France, Italy, Norway, Spain, Sweden, and the UK.

[26] The report underscores the vulnerability of commodity markets—including critical minerals markets—to geopolitical tensions by simulating a stylized risk scenario in which commodity trade between two geopolitical blocs is persistently disrupted. It is important to note the illustrative nature of the scenarios assessed in IMF (2023d), and the uncertainty around the results.

also by the permit processes needed to mitigate the projects' environmental and social impacts and, in some cases, by local protests or forms of "NIMBY-ism."[27]

The outlook looks complex also from a geostrategic perspective. Relevant reserves of certain transition minerals are present in Russia (nickel, platinum, palladium), while others are concentrated in fragile states (for example, cobalt in the Republic of Congo) (IRENA 2023). Should the world's economy fragment in competing blocks, this effect could be further exacerbated, given the relative concentration of other minerals' extraction and processing in a few countries.[28] For countries intent on "friend-shoring" their supply of transition minerals, such a strategy could come at the cost of less cheap and/or less abundant sourcing of such minerals.

Geoeconomic Fragmentation, Macroeconomic Shocks, and Policy Responses

Monetary policy reactions to macroeconomic impacts of geopolitical confrontations and geoeconomic fragmentation could have implications for short-term scenarios. The current environment is characterized by high geopolitical and geoeconomic uncertainty (IMF 2023a) and growing climate impacts on prices (Schnabel 2022). Moreover, while under the IMF's baseline scenario (IMF 2023a), inflation continues to decline, some analysts argue that the world economy has entered a new high-inflation regime (BIS 2022). Furthermore, the interdependence of global productive structures makes them vulnerable to shocks to prices and output (Espagne and others 2023). A case can be made, therefore, that inflationary pressures and associated monetary policy tightening will grow over the medium term. These factors would make "higher-for-longer" interest rates more likely (see also Adrian 2023a). Apart from the impact on the economic viability of renewable energy projects (see earlier discussion), higher policy interest rates could reduce expected demand and thereby productive investment, and trigger or amplify capital outflows, especially in EMDEs, thus hindering the channeling of the resources needed to support the transition (Prasad and others 2022).

Monetary policy reactions could also affect short-term scenarios by indirectly contributing to a credit crunch. In the wake of historic monetary tightening (Figure 2), there are signs of considerable strains in the global financial system, with higher interest rates undermining trust in several large financial institutions (Adrian 2023b). In addition, the pace of net tightening in credit standards in the euro area in the last quarter of 2022 and the first quarter of 2023 is the largest seen since the euro area debt crisis, with demand for loans to firms falling in the four largest euro area economies (ECB 2023). The significant decline in credit growth and tightening lending conditions (IMF 2023b), which may spread to other large economies, could have adverse implications for decarbonization by dampening productive investment, notably for innovation spending and patenting (Ma and Zimmermann 2023).

Higher interest rates also favor oil majors and national oil companies because of market structure, as these firms have accumulated large cash equivalents that benefit from higher rates and long-duration fixed-rate debt at relatively low interest rates, increasing the differential between their assets and liabilities (see Blas 2023).

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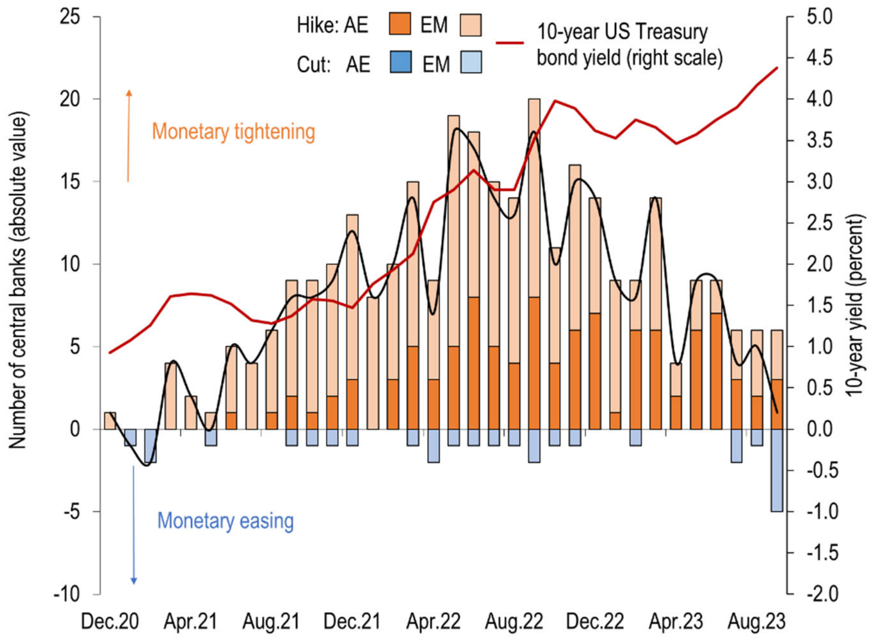
[27] "Not in my backyard."

[28] This element of vigilance lies in the "dependency switch" for the European Union, primarily from Russia to China, as increased volumes of metal, inert gases, and other raw materials will be needed for renewable production and deployment. Despite the 2020 Communication on Critical Raw Materials that had announced the launch of a dedicated industrial alliance to securing a sustainable supply of raw materials in Europe, short-term needs may be prioritized by resourcing to external supply. See also the European Commission's Critical Raw Materials webpage (https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en, last consulted on September 7, 2023) and European Raw Materials Alliance (https://eitrawmaterials.eu/european-raw-materials-alliance-contributes-to-europes-industrial-resilience/, last consulted on September 7, 2023).

Figure 2. Monetary Policy Tightening

(Number of central banks hiking/cutting rates, 2020–23)



Sources: Bloomberg, and IMF staff calculations.
Note: AE = advanced economies; EM = emerging markets.

The ability of capital flows to finance the transition is affected by the geopolitical tensions, while inadequate bank policies pose additional risks. Capital flows may not enable the financing of transition investments given the lack of alignment of climate policies and commitments of major banks and insurance companies with net-zero-emission targets (IMF 2023b). Yet the concept of alignment is embedded into the Paris Agreement. Climate policies and commitments should therefore not merely lead to a redistribution of emissions among financial market participants, thereby contributing to greenwashing risks, but to capital flows supporting real-world decarbonization (World Bank, IMF, and OECD 2023). Moreover, reduced capital flows because of geopolitical tensions could limit the access of many countries to financing needed for the transition. There is evidence that greater geopolitical tensions between an investing and a recipient country could reduce bilateral cross-border portfolio and bank allocation, cause a sudden reversal of cross-border capital flows, especially in EMDEs, and raise banks' borrowing costs (more so when the banking system has smaller capital or reserve buffers) (IMF 2023e). These hurdles can reduce affected countries' capacity to finance investments in low-carbon energy sources.

Fiscal policy reactions to high public debt and fiscal deficits, as well as support to household to deal with "fossilflation," could also affect short-term scenarios. Public debt has expanded globally as a result of large fiscal deficits incurred by many countries initially in response to the COVID-19 crisis (public support measures), and subsequently the Russian invasion of Ukraine (increased subsidies to counter the spike in energy prices). The increase in military spending caused by the new geopolitical context could also critically reduce fiscal space. The fiscal policy reaction, by depressing expected demand, could lower productive investment and therefore investment in low-carbon technologies.[29] In addition, windfall taxes in some EU countries on renewable electric power producers (for example, 90 percent in Germany, although set to be temporary) could disincentivize investment in renewables. A global recession, partly resulting from tighter macroeconomic policies in response to high inflation and fiscal deficits, would lower expected demand and

[29] For instance, in the European Commission Spring package, public debt paths imply significant fiscal policy tightening in several large EU economies. In the context of monetary and fiscal tightening, private investment is slowing down sharply (UNCTAD 2023).

investment, potentially delaying decarbonization of the economy by several years, including through path-dependency effects.

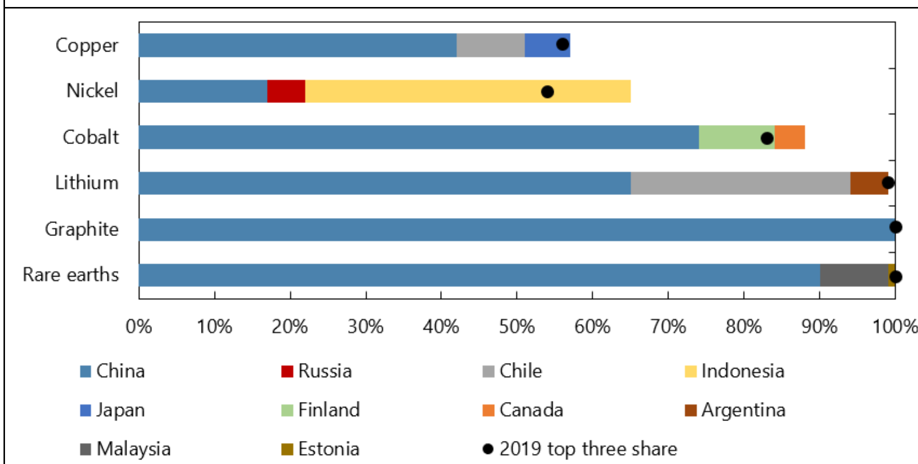
Geoeconomic fragmentation and the risk of a reversal of trade multilateralism could have ramifications for short-term scenarios (see Aiyar and others 2023). A decline in economic and technological cooperation stemming from geopolitical tensions could have adverse consequences for global decarbonization. This applies especially to the intensifying trade war between the United States and China.

- First, costly trade-offs could arise. For instance, reports indicate that Korean auto firms that have made large investments in the United States will eventually not be eligible for tax credits under the US Inflation Reduction Act if their electric vehicles continue to contain battery components or critical minerals from China (Chea 2023; Sahay and Mackenzie 2023). Similarly, Japanese companies' plans to expand investments in the United States have come under increased scrutiny for their business activities in China, pointing to a trade-off for Japanese firms.
- Second, lack of cooperation on transition-critical minerals could hinder decarbonization throughout the global economy. One example would be by constraining access to supplies and raising prices. Figure 3 shows that the processing of critical minerals is highly concentrated in a small number of countries.
- Third, the cross-border spillovers of domestic fiscal policies could affect short-term scenarios. These include incentivization of electric vehicle supply chain creation outside of key manufacturing hubs for geopolitical rather than economic reasons, the response of trading partners to international spillovers resulting from large climate-related subsidies (notably the US Inflation Reduction Act), the displacement of legitimate market access expectations of trading partners leading to retaliation (in turn imposing costs on the US economy), and subsidies leading trading partners to change their climate policies because of concerns about lower industrial competitiveness (Brown 2023).
- Fourth, a relative lack of decarbonization—or the decision not to participate in global policy initiatives—by large emitters could discourage action by other countries because of concerns about (cost) burden sharing across countries.

These issues come in addition to the idiosyncratic features of renewable energy geopolitics, including strong market competition and multiscale governance (Criqui and Hache 2023).

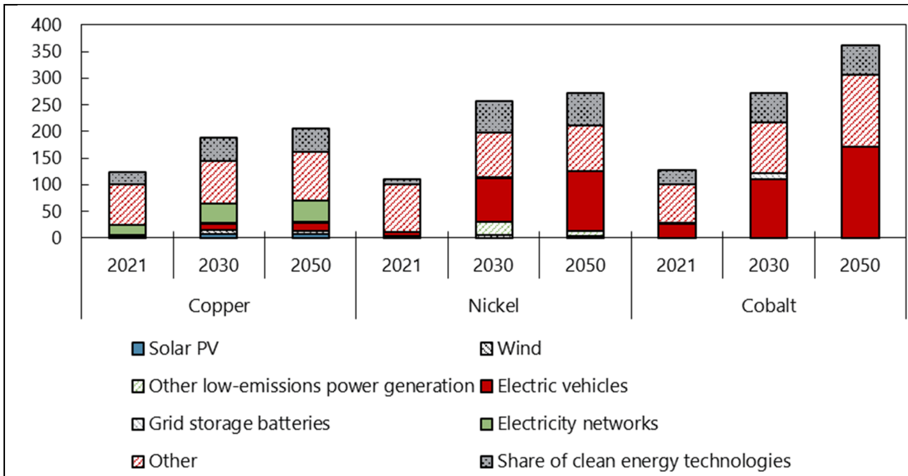
Figure 3. Concentration of Critical Resources Production

1. Share of Top Three Producing Countries in Processing of Selected Minerals in 2022 (Percent)



Sources: Benchmark Mineral Intelligence; IEA analysis based on S&P Global; USGS 2023; and Wood Mackenzie.

2. Total Demand for Selected Minerals by End Use in the Net Zero Scenario, 2021–50 (Index, 100 = 2021)



Source: IEA 2023d.
Note: PV = photovoltaic.

Ultimately, more frequent global shocks may lead to structurally lower global growth, a possibility that few climate scenarios take into account. The polycrisis entails interacting crises that "produce harms greater than the sum of those the crises would produce in isolation" (Lawrence, Janzwood, and Homer-Dixon 2022).[30] The macroeconomic consequences could be significant: if the root causes of the polycrisis are not addressed, it is plausible that global growth will continue to be buffeted over the medium term. The IMF's steadily falling global medium-term growth forecast between 2008 and 2023, from around 5 percent to 3 percent, suggests such forces may be at play (Figure 4). Growing climate and other interrelated environmental impacts could also increasingly disrupt economic activity, amplifying downward structural forces on growth independently of their contribution to polycrisis dynamics.[31] These considerations highlight a potentially significant weakness of widely used climate scenarios, such as those of the Intergovernmental Panel on Climate Change (IPCC): their growth assumptions are optimistic by construction and ignore possible large-scale disruptions.[32] Indeed, growth projections based on shared socioeconomic pathways (SSPs), such as those used for climate change mitigation scenarios, do not incorporate specific economic shocks or the economic impacts of climate change.[33] The use of low- or negative-growth assumptions would obviously have major implications for climate scenarios.[34] It would also raise questions about the relevance of measuring economic impacts relative to a hypothetical forecast that represents prior trends, as done in widely used scenarios.

[30] Likewise, IMF (2023a) notes that "forces that hindered growth in 2022 persist."

[31] On the economic impacts of climate change, see the IPCC Working Group II's overview (IPCC 2022, chapter 16). On other environmental impacts on the economy, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019) finds that with increasing global connections local impacts of biodiversity loss can be felt across long distances, Dasgupta (2021) warns that "biodiversity loss could give rise to 'existential risks' for humanity," while Richardson and others (2023), focusing on so-called planetary boundaries, find that "Earth is now well outside of the safe operating space for humanity."

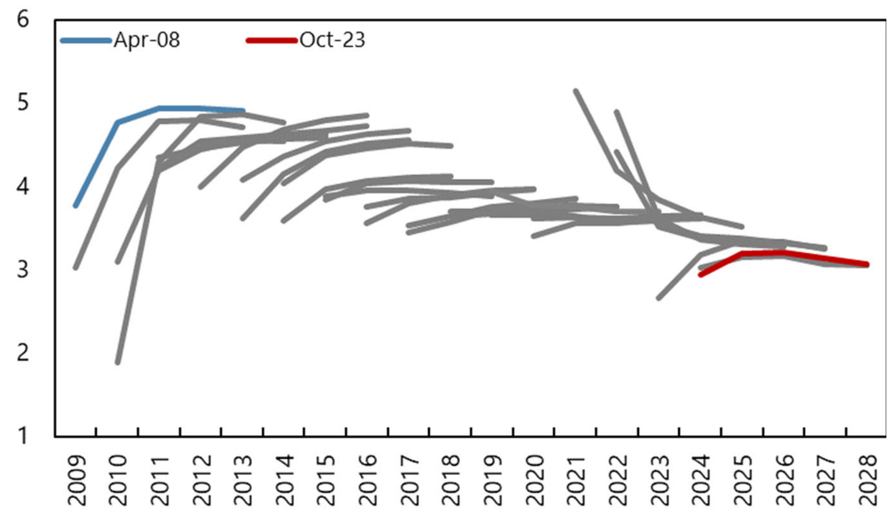
[32] Buhaug and Vestby (2019) find that extrapolating past trends generates results that are at the lower end of growth projections used to construct shared socioeconomic pathways (SSPs). Similarly, Burgess and others (2023) find that extrapolations based on past data suggest that the world is closest to the SSP4 trajectory, characterized by low growth.

[33] While lower economic activity is also generally associated with lower GHG emissions, shocks to growth and structurally lower growth would also tend to reduce productive investment, which would hinder the transformation of the different systems needed to enable the decarbonization of the global economy over the longer term.

[34] There is ongoing work to develop so-called post-growth scenarios. See Keyßer and Lenzen (2021) and Chapter 5 of IPCC (2023), which focuses on energy demand reductions.

Figure 4. Five-Year Global Economic Projections

(Percent, year-over-year, 2009–28)



Source: IMF, World Economic Outlook database.

Finally, an understudied feedback effect lies in the impact of the financial system on the climate system, which is part and parcel of a robust risk management strategy (Bhattacharya and others 2021). While most studies to date analyze the implications of climate change for the financial system, the endogeneity of climate risks (Battiston 2019) calls for a comprehensive approach to climate-related financial risks: the fact that climate change can affect financial institutions, and the fact that financial institutions impact the climate system and therefore contribute to the risks they aim to measure (Oman and Svartzman 2021). According to Stiroh (2022), the double materiality perspective gains in importance in a broader framework with macroprudential objectives that incorporate financial sector externalities.

Avenues to Accommodate the Design of Climate Scenarios to the New Reality[35]

Climate scenario analysis is an emerging tool used by financial institutions and financial sector authorities to evaluate climate-related financial risks and assess the resilience of the financial system. By considering socioeconomic development, technological change, behavioral change, and policy actions, climate scenarios depict plausible pathways to which the economy and society would transition in response to climate change and mitigation actions. The past two decades have seen the expansion of climate scenarios and exercises as well as community-building efforts (Guivarch and others 2022). Along with the rapid expansion of climate scenarios, new user groups with new needs have emerged. This note focuses on climate scenarios used by the financial sector, which require more realistic characterization of polices, better temporal and sectoral granularity, and better reflection of tail risks.

NGFS scenarios are among the climate scenarios that are most widely used by the financial community. The NGFS has developed long-term scenarios to assess climate risks to the economy and financial system throughout the century and recently published a conceptual note on short-term scenarios (NGFS 2021, 2022a, 2023b; Richters and others 2022) (see Annex 2 for more information). Many jurisdictions have used NGFS scenarios or built upon NGFS scenarios to assess climate risks (BNM 2022; BOE 2022; ECB 2022; Board of Governors of the Federal Reserve System 2023; IMF 2022a, 2022b).

[35] While the recommendations apply to all climate scenarios, most considerations are developed with specific reference to the suite of scenarios developed by the NGFS (see the NGFS scenario portal: https://www.ngfs.net/ngfs-scenarios-portal/).

While some of the current NGFS scenarios envisage the possibility of a disorderly transition, the next phase of NGFS scenarios[36] and climate scenarios in general could more closely reflect the structural changes since the COVID-19 pandemic and the Russian invasion of Ukraine. This section presents some initial proposals that can be used to improve NGFS scenarios and better represent the current state of uncertainties caused by the polycrisis (Table 1). While some of these proposals can be addressed in the current modeling framework and prioritized for near-term implementation (for example, most scenario implications of carbon lock-in and renewable energy prospects), others require more technical work to develop modeling capabilities and scenarios (for example, critical mineral supply and scenario implications of geoeconomic fragmentation, macroeconomic shocks, and policy responses)

This section is organized as follows. The subsequent two subsections focus on the evolution of the energy system and emissions trajectories in NGFS long-term scenarios and implications for the integrated assessment models (IAMs) used to generate these scenarios, but these recommendations also apply to short-term scenarios that contain similar features and assumptions. The third subsection discusses the implications of geoeconomic fragmentation and macroeconomic shocks for short-term and long-term scenarios and sheds light on the next phase of NGFS scenario development. The proposals discussed in this section also apply to other climate scenarios developed using a similar framework, for example transition scenarios developed by the Bank of Canada using the Economic Projection and Policy Analysis model (Chen and others 2022a). Finally, discussions in the following subsections are interlinked; geoeconomic fragmentation and macroeconomic shocks can affect energy system transition and GHG emissions and vice versa. Annex 2 further illustrates how these interconnected factors can be incorporated into NGFS scenarios.

Table 1. Consequences of the Polycrisis Discussed in the First Section and Implications for Climate Scenarios

Consequences of Polycrisis	Scenario Implications
Disorderly Transition and Carbon Lock-in	Increase in near-term greenhouse gas emissions, implying higher peaking temperature and more disorderly transition to align with the Paris Agreement temperature goals Increase in near-term fossil energy investment and delay in fossil energy phase down and phase out Delay in climate policy development and implementation
Prospects for Renewable Energy	Slower improvement in technology cost and efficiency Constrained deployment due to limited critical minerals supply Slowdown in investment due to higher policy rates
Geoeconomic Fragmentation, Macroeconomic Shocks, and Policy Responses	*Short-term scenarios* Higher inflation and policy rates Tightening in credit standards High public debts and fiscal deficits Constraints to trade multilateralism *Long-term scenarios* New scenario narratives that include geopolitical fragmentation and new trade dynamics

Source: IMF staff.

Capturing Carbon Lock-in in Climate Scenarios

As discussed in the first section, risks of carbon lock-in stemming from the geoeconomic and energy trends, combined with delays in developing and implementing climate policies, will have long-lasting impacts on future emissions trajectories and associated transition and physical risks (UNFCCC Secretariat 2023).

More rapid emissions growth (which started with the post-COVID-19 recovery) needs to be considered when developing both short-term and long-term scenarios. Global GHG emissions hit a record level in 2022, implying a more accelerated and disorderly transition (to make up for the recent recarbonization) and

[36] NGFS scenarios are updated on a regular basis to reflect the evolution of socioeconomic conditions, technologies, and policies. This note was prepared prior to the release of NGFS Phase IV scenarios. Some of the issues listed here (for example, emissions and energy prices) have been at least partially addressed in Phase IV scenarios, while others (for example, fossil fuel consumption and energy trade) remain topics for future research and scenario development.

potentially higher peaking temperature. Models, such as IAMs used by NGFS and computable general equilibrium models[37] used to assess climate-related financial risks, need to update and calibrate the base-year on a regular basis. In particular, they need to update the near-term emissions trajectories to capture recent deviations from the original decarbonization plans and the increased likelihood of a disorderly transition.

Climate scenarios need to capture the increase in fossil energy investment since 2020 to reflect increasing disorderliness in energy system investment. Results from the NGFS Phase III show that all models across scenarios significantly underestimate coal power capacity expansion since 2020 (Figure 5). Model-projected annual coal-fired power capacity additions between 2021 and 2025 range from 0–44 gigawatts across six NGFS Phase III scenarios (Richters and others 2022b), whereas the actual annual coal-fired power capacity additions between 2021–23 are between 46–52 gigawatts.[38] In addition to the increase in coal power investment, as noted in the first section of this note, there is also an expansion in LNG terminals in Europe in response to the Russian invasion of Ukraine and the subsequent energy crisis; LNG import capacity in the European Union and the United Kingdom will expand by 34 percent between 2021 and 2024 (see Annex 1 for additional discussions on natural gas lock-in). Models should consider carbon lock-in risk, driven by the increased capital stock of fossil fuel–based assets. New investments made in coal and gas infrastructure need to be reflected in the historical periods (especially if the model base year is older than 2022) as well as current policy assumptions. This may take the form of integrating an exogeneous path of investment toward fossil-fuel based assets.[39] These fossil fuel–based assets also need to be properly vintaged,[40] in order to fully account for the cost of transitioning to clean energy technologies.[41]

Models should attempt to incorporate economic and financial strategies of fossil fuel producers for the price of oil and the quantity of oil produced. Fossil fuel producers' strategies can have a material impact by contributing to determine the share of decarbonization that will occur under the impact of high fossil fuel prices. For instance, Organization of the Petroleum Exporting Countries members could attempt to extract the full oil rent before oil demand is phased out, or they could attempt to disincentivize decarbonization by selling oil at a loss. An adverse scenario could be one in which oil producers wait for advanced economies to fail to develop low-carbon energies, slowing down their oil exploration in the meantime while supplying EMDEs with oil. This could allow them to wait for oil prices to surge and to obtain the oil rent. While oil prices could rise because of a slowdown in exploration, thereby incentivizing fossil fuel importers to consume less oil, the low price elasticity of demand for oil limits the extent to which such incentives can reduce oil consumption (Golding 2022). To our

[37] Computable general equilibrium models provide the aggregate representation of the entire economy in equilibrium. Some computable general equilibrium models have developed energy and environmental components, allowing them to capture the interaction between the economy, energy, and environmental systems. Computable general equilibrium models have been used by central banks and supervisors to assess climate risks. For example, the Bank of Canada uses a computable general equilibrium model, Economic Projection and Policy Analysis, to examine transition risks (Chen and others 2022a). NGFS uses a computable general equilibrium model, G-cubed, to replicate its long-term scenarios with improved sectoral granularity (NGFS 2022b).

[38] Data on actual coal capacity additions between 2021 and 2023 are from Global Coal Plant Tracker, Global Energy Monitor, July 2023 release. IAMs used in NGFS Phase III run in a five-year time step. The reported values of coal capacity additions per year in the 2025 time period for the GCAM 5.3+ NGFS, MESSAGEix-GLOBIOM 1.1-M-R12, REMIND-MAgPIE 3.0-4.4 models represent the time period 2021–2025, 2021–2025, and 2023–2027, respectively. The reported coal capacity additions per year in 2020 for the REMIND-MAgPIE 3.0-4.4 model represent the time period 2018–2022.

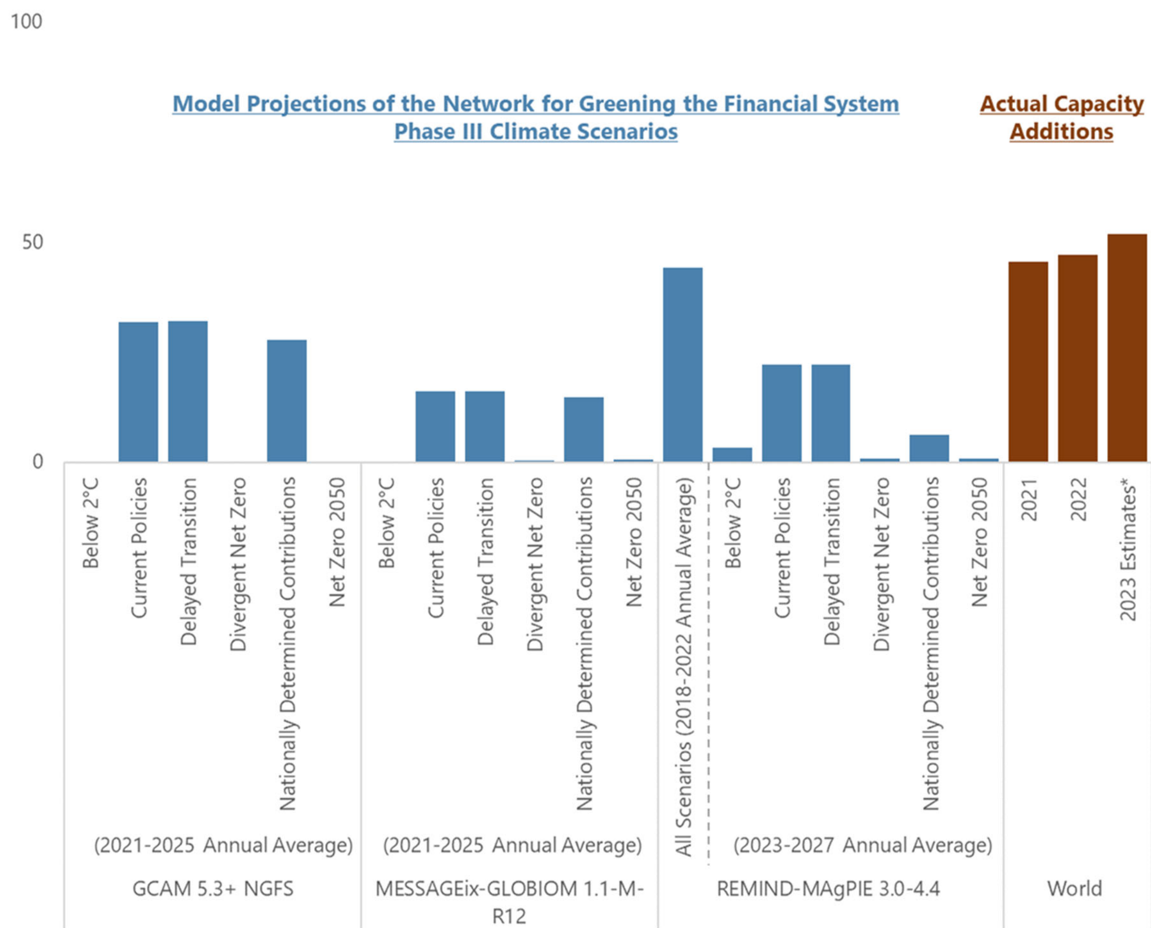
[39] In view of the recent trends, and despite previous lower fossil fuel demand that has likely reduced capital expenditures in oil and gas globally since 2019—especially for publicly traded companies—reducing their investment by about 20 percent. See IMF 2022b.

[40] To estimate technology and capital stock turnover, IAMs and energy models need to include several parameters (for example, lifetime, retirement curves, capital expenditures, operating expenditures, etc.) to track the development and retirement of different energy technologies and infrastructure.

[41] In a low-carbon transition, fossil fuel technologies need to be replaced by clean energy technologies with low or no GHG emissions. For example, coal, oil, and gas power plants can be replaced by renewable power plants (that is, solar, wind, hydro, and biomass) and nuclear power plants, or equipped with carbon capture and storage technologies. Blast furnaces that use coke to produce steel can be replaced by hydrogen direct reduced iron combined with electric arc furnaces.

knowledge, no technical work (including in IAMs) has been conducted so far on incorporating the possible strategies of fossil fuel producers into climate scenarios.[42]

Figure 5. Coal Power Generation Capacity Additions: Comparison Between Model Projections and Actual Additions



Sources: Global Coal Plant Tracker (2023) and NGFS Climate Scenarios Data Set Version 3.0.
* For 2023, data on coal power generation additions are only available for the first half of 2023. 2023 estimates shown in Figure 5 are calculated as twice the power generation capacity additions reported in the first half of 2023.

Climate scenarios, both short-term and long-term scenarios, need to consider the potential delay in climate policy implementation. Although countries have put forward nationally determined contributions

[42] For an example of work that seeks to disentangle interactions among oil production profiles, the dynamics of oil prices, and growth trends, see Waisman and others (2012). These authors find that it could be in the interest of oil producers to trade off short-term export revenues for higher long-term revenues in the "post–peak oil" period; however, they would do so only if they prioritize long-term macroeconomic objectives over maximizing discounted oil revenues.

(NDCs), long-term strategies, and net zero pledges,[43] they may not meet all these pledges as a result of reduced fiscal space and increased carbon lock-in. Moreover, the distribution of NDC ambition across income groups (Black, Parry, and Zhunussova, forthcoming) shows that increased ambition is tilted toward high-income countries. Still, Group of Twenty countries collectively are expected to fall short of their 2030 pledges without strengthened actions (UNEP 2022). Climate modelers could contemplate the design of a scenario with the delayed implementation of NDCs in some jurisdictions in the short to medium term (for example, by 2025 or later), and a resumption of the decarbonization path to meet NDC and/or net zero pledges afterward, but not necessarily by all jurisdictions.

Implications for Renewable Energy Development and Deployment

As discussed in the first section "Impact of the Polycrisis on the Global Transition to a Low-Carbon Economy," the deployment of renewable energy may slow down owing to the negative impact of the polycrisis on renewable energy cost, policy rates, and the supply chain of critical minerals. The likelihood of a rapid cost reduction of renewable energy is decreasing as the technologies approach a relative stage of maturity and material prices rise. The current high policy rates may discourage investors from taking on renewable energy projects with high upfront costs. Moreover, the deployment of renewable energy is complicated and further constrained by the supply chain of critical minerals, which are concentrated and may not be sufficient to meet the demand for the low-carbon transition.

Models need to consider a plausible slowdown in renewable energy technology diffusion, as a result of longer inertia in the energy system and an evolving and negatively impacted market structure. These effects may be exacerbated by the polycrisis, considering that learning of renewable energy technologies with interregional spillovers could be impaired by lack of business dynamism, the resistance to the energy transition by fossil fuel–based incumbents, lock-in in carbon-intensive technologies, heightened trade fragmentation, etc. (as described in "Prospects for Renewable Energy"). The assumption of continued efficiency improvements in renewable energy in models could be challenged with a more pessimistic outlook as part of a scenario with fragmentation and tight monetary policies, to account for the recent rise in capital costs. In addition, the increased difficulty in expanding renewable production and storage, based on the diagnosis made in the first section (that is, persistent bottlenecks, impacts of protracted interest rates, concentration of reserves, rise in "NIMBY-ism," etc.), should be included by tracking flows and stocks of critical raw materials (whose availability is poorly accounted for in current modeling approaches).

Climate scenarios should also consider the potential slowdown in renewable deployment owing to the current high policy rate environment. As discussed in the first section, compared to carbon-intensive technologies, renewable energy technologies have higher upfront cost and are more sensitive to interest rates. Recent research has shown that the LCOE of renewable energy technologies rises with interest rate increase (Schmidt and others 2019). Cost assumptions in IAMs need upward adjustments if tightening monetary policy and higher-for-longer interest rates are considered.

The supply of critical minerals could be a bottleneck for renewable energy technology deployment and needs to be more explicitly modeled and considered in climate scenarios. Critical minerals, such as copper, lithium, nickel, and cobalt, are critical to the low-carbon transition. Demand for certain critical minerals

[43] NDCs and long-term strategies are countries' commitments to tackle climate change under the Paris Agreement Framework. A total of 177 Parties, representing 177 countries, have submitted their NDCs (for more information, see https://www.climatewatchdata.org/ndcs-explore). NDCs, setting climate targets through 2030, can be in different forms, such as absolute GHG or CO_2 emissions reduction, decrease in emissions intensity, renewable energy targets, or sectoral policies. Countries are also invited to communicate "mid-century long-term low greenhouse gas emissions development strategies" (long-term strategies) under the Paris Agreement, and only 65 Parties submitted their long-term strategies (for more information, see https://www.climatewatchdata.org/lts-explore). Net zero pledges are countries' pledges to achieve net zero GHG or CO_2 emissions; they can be part of long-term strategies or independent of long-term strategies. A total of 93 Parties, representing 97 countries, have communicated a net zero target (for more information, see https://www.climatewatchdata.org/net-zero-tracker), but the robustness of these targets varies (for example, target year, legal status, gas and sector coverage, path to net zero). Countries' NDCs do not necessarily align with their long-term strategies and net zero pledges, which could increase the risk of carbon lock-in.

rose sharply in the past few years as countries started to accelerate the deployment of renewable and clean energy technologies. For example, lithium, cobalt, and nickel demand has increased by 300 percent, 70 percent, and 40 percent between 2017 and 2022, respectively (IEA 2023b). The supply of critical minerals, however, is concentrated in a few countries—the top three countries accounted for almost 90 percent of rare earths, graphite, and lithium supplies, and more than 60 percent of cobalt and nickel supplies in 2022. With limited diversification in critical minerals supply, geopolitical fragmentation can create potential trade barriers and slow down the deployment of renewable energy technologies. Models can consider adding critical mineral supply curves and mineral trade, developing material sectors, and explicitly linking critical mineral supply and demand sectors. In addition, in the current modeling framework, even if critical minerals are not explicitly modeled, models can still apply postprocessing methods to ensure the current level of technology deployment is unlikely to be constrained by the availability of critical minerals.

Impact of Geoeconomic Fragmentation and Macroeconomic Shocks on Climate Scenarios

In addition to the impact on the energy system and emissions discussed in previous sections, the polycrisis also has implications for the economic and financial systems that need to be considered in climate scenarios. The following subsections discuss policy implications that are more relevant for short-term scenarios but can also have implications in the long term and potential new scenario narratives that can be applied to long-term scenarios.

Implications for Short-Term Scenarios

Short-term scenarios should consider monetary policy implications of geoeconomic fragmentation and macroeconomic shocks, particularly high inflation, high policy rates, and a potential credit crunch. As discussed in the section titled "Geoeconomic Fragmentation, Macroeconomic Shocks, and Policy Responses," the inflationary pressures and associated monetary policy tightening could persist over the medium term, which could trigger capital outflows, especially in EMDEs, constrain resources needed for a low-carbon transition, and further discourage green technology innovation and investment. Models producing short-term scenarios should consider adjusting the assumptions on financial variables (for example, short-term rates, risk premiums, lending conditions, etc.) as well as macro and technological variables that drive these changes (for example, limited supply/capacity of production means, higher cost of capital resulting from tightening monetary policies, and potential changes in agents' expectations).

The impact on fiscal policies should also be explicitly considered in short-term scenarios. The polycrisis increases fiscal deficits, which need to be reflected in macro variables (for example, fiscal balance, subsidies, taxes). Moreover, the reduced fiscal space has implications for technology development and investment, which can be represented by decreasing investment in low-carbon technologies, lower rate of improvement in the cost and efficiency of less mature low-carbon technologies, or slower rate of technology diffusion.

The impact of trade and industrial policy reactions to rising geopolitical tensions should also be considered in short-term scenarios. For instance, scenarios could attempt to reflect a decline in economic and technological cooperation, through adjusting sectoral and bilateral trade flows, increasing technology costs, delays in clean technology development and deployment in both advanced economies (because of supply chain bottlenecks) and EMDEs (reflecting limitations on technology transfers and supply chain bottlenecks), and explicitly accounting for trade-related policies (such as the Carbon Border Adjustment Mechanism in the

European Union’s Fit-for-55 packages and the domestic content requirement in the US Inflation Reduction Act).[44]

Implications for Long-Term Scenarios

The structural changes brought to the fore by the Russian invasion of Ukraine may increase the relevance of other Shared Socioeconomic Pathways (SSPs), in addition to SSP2[45] (*middle of the road*) used in the NGFS scenarios. SSPs depict how the world might evolve throughout the century. There are five SSPs developed along two dimensions: mitigation challenges and adaptation challenges (O’Neill and others 2016). SSP2 (“middle of the road”) assumes that social, economic, and technological trends follow historical patterns. Other SSPs might be better suited to the current context: SSP3 *(“Regional Rivalry”*—highly challenging for climate change mitigation and adaptation), for example, envisages “resurgent nationalism, concerns about competitiveness and security, and regional conflicts [that] push countries to increasingly focus on domestic or, at most, regional issues. Policies shift over time to become increasingly oriented toward national and regional security issues. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development.” Under this scenario, IAMs are not able to achieve the 1.5 degrees Celsius targets—nor even the 2 degrees Celsius one—as a result of “regional rivalry and resurgent nationalism limiting the ability of the world to cooperate on reducing emissions over the next few decades” (Figure 6) (Hausfather 2018).

A slightly less pessimistic alternative could be SSP4 (*“A Road Divided”*—low challenges to mitigation, high challenges to adaptation), characterized by “increasing inequalities and stratification across and within countries,” but also by “investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources.” A more rapid technological development in SSP4 allows IAMs to achieve the 2 degrees Celsius target in at least some of the simulations.

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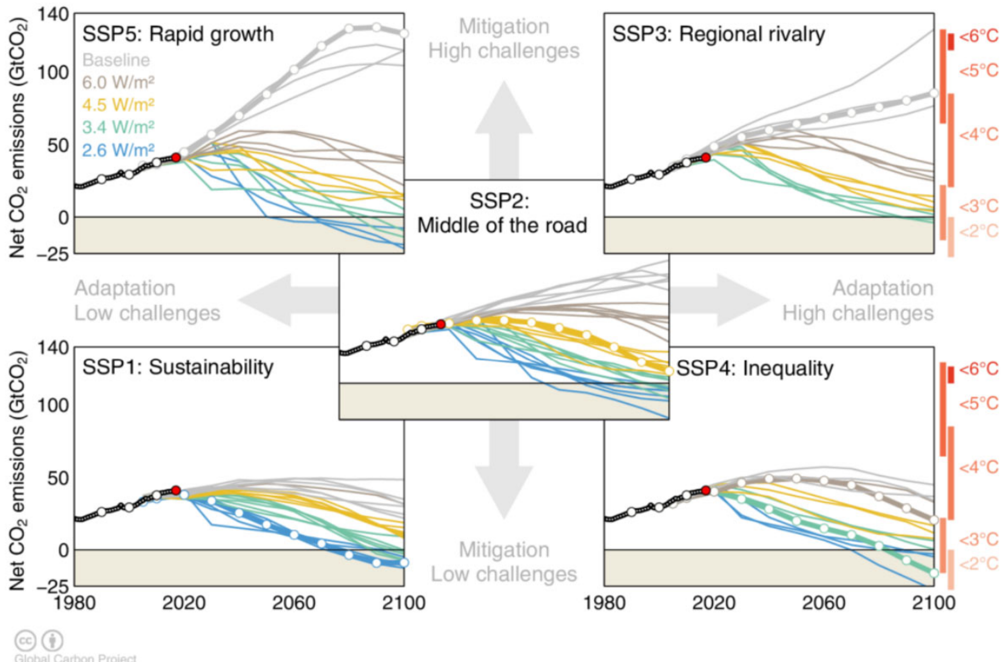
[44] Implications for trade apply to both short-term and long-term scenarios. Several countries and supranational entities, including the European Union, have sought to rapidly reduce their dependence on Russian oil and gas, and to restrict energy imports from Russia. Meanwhile, new LNG terminals are planned in Europe to diversify energy supply and new pipelines have been proposed between Russia and China to divert gas supply. These changes in energy trade and infrastructure can be captured by models generating long-term scenarios by restricting energy supply, revising energy supply cost curves, or modifying energy trade patterns. In addition, the construction of new fossil energy infrastructure (for example, LNG terminals and pipelines) will itself entail a significant amount of GHG emissions.

[45] NGFS Phase II and Phase III scenarios are based on SSP2 growth rates, with updated policy and baseline GDP trajectories in the near term. SSP2 assumes that society evolves broadly in line with past trends. Given the current geoeconomic fragmentation, SSP2 assumptions used by models might be more optimistic than the current trends of socioeconomic and technological development.

Figure 6. Net CO_2 Emissions from IAMs across SSPs and Temperature Implications

(Percent, year-over-year, 2009–28)



Global CO2 emissions (GtCO2) for all IAM runs in the SSP database separated out by SSP. Chart via Glen Peters and Robbie Andrews and the Global Carbon Project.

Source: Hausfather 2018.
Note: CO_2 = carbon dioxide; Gt = gigatons; IAM = integrated assessment model; SSP = shared socioeconomic pathway

Conclusions

Achieving the climate mitigation goals of the Paris Agreement requires a decisive transition of the economic system toward low-carbon energy sources. The limited progress recorded in the years following the Agreement came to a halt after the COVID-19 pandemic in 2020–21: while GHG emissions temporarily dropped as a consequence of lockdowns in most countries, the post-COVID-19 recovery in many economies was accompanied by reduced attention to the compatibility with emission reduction objectives. The weaponization of energy triggered by the Russian invasion of Ukraine, in 2022, further dented the determination of policymakers—now primarily concerned with energy security—in pursuing the decarbonization policies to which they had originally committed. This happened against a backdrop of increasing geopolitical fragmentation, leading to a combination of multiple, simultaneous crises.

This note analyzed the main impacts of this "polycrisis" on the path to a low-carbon economy, starting from the increase in emissions and the related carbon lock-in. It highlighted how the pullback on climate mitigation policies, though not universal, is material enough to drive a significant deviation of global GHG emissions not only from the path necessary to keep the increase in global average surface temperature by the end of the century below the "safe" level of 1.5 degrees Celsius above preindustrial times (as called for by the Paris Agreement), but also from the path implicit in the sum of all countries' own commitments. Moreover, the scramble to ensure the provision of fossil fuels (to replace the partial removal of Russian supply from the markets) leads to policy decisions that represent a significant carbon lock-in—that is, an increase in the inertia of energy systems (still largely based on fossil fuels) and a heightened resistance to the more widespread introduction of alternative forms of energy.

Renewable energy also faces other headwinds. There are signs that the renewable energy sector is approaching a stage of relative maturity and the relentless, often surprising reduction in production costs of the past decades (especially for solar and wind) might slow down significantly, if not be reversed. Apart from a possibly natural deceleration (as for other technologies), the deployment of renewable energy might face specific challenges: in particular, its structurally higher upfront capital intensity with respect to other forms of energy (because of the concentration of expenses at inception) entails a higher sensitivity of projects to currently high interest rates, while geoeconomic fragmentation and other factors (such as the complexity of permit processes and "NIMBY-ism") weigh on the availability and cost of the critical minerals used in its production.

Combined with the probable intensification of macroeconomic shocks and a context of increasing geoeconomic fragmentation, these factors are likely to make the low-carbon transition more disorderly. Inflation might prove harder to subdue and interest rates could remain at higher levels for longer; the spike in fiscal deficits and public debt could lead to a downsizing of policies in support of decarbonization; trade disruptions could extend beyond the energy sector and further limit the diffusion of technology; and global growth could be permanently lower, with a depressing impact on investments, including those needed (especially in EMDEs) for the low-carbon transition (IMF 2023b).

While the climate scenarios currently used in climate risk analyses already include the possibility of a "disorderly" transition, the short- and long-term implications of the current state of things have not been fully incorporated. Climate scenarios are used by financial institutions and financial sector authorities, as part of their risk measurement and management frameworks, for the evaluation of climate-related financial risks and the resilience of the financial system; those published by the NGFS stand out in terms of width, breadth, and scope of application. However, even though the possibility of a "disorderly" transition is explicitly contemplated, some of the headwinds facing the low-carbon transition discussed in this note have not been fully considered yet.

This note advances a range of proposals to upscale the capacity of climate scenarios to capture the new reality. To reflect the carbon lock-in and a potentially more disorderly transition, climate scenarios should adjust near-term emissions trajectories, build in recent fossil energy investment, and explicitly account for delay in climate policy development and implementation. Climate scenarios should also consider a less optimistic pathway on renewable energy, including downward adjustment on the improvement in cost and efficiency, incorporation of supply chain constraints, and slowdown in new renewable energy investment because of supply chain bottlenecks and the high-rate environment. The macroeconomic and macrofinancial implications of the polycrisis should also be captured in climate scenarios, especially short-term scenarios, such as high inflation and policy rates, a potential credit crunch, high public debts and fiscal deficits, and constraints to trade multilateralism. Finally, the structural changes brought to the fore by the polycrisis require new scenario narratives with increasing geopolitical fragmentation; lower global growth over the short, medium, and long term; and increasing inequalities and stratification across and within countries. While some of these proposals can be addressed in current models, more technical work is needed to advance the modeling capability (for example, modeling fragmented commodity markets) to better reflect the implications of the polycrisis.

The sources of uncertainty for the low-carbon transition analyzed in this note are not the only relevant ones for the advancement of climate scenario design: models should also attempt, in particular, to capture the interactions between physical and transition risks (Annex 3). The current disorderly transition implies higher peaking temperature, which can result in higher physical risks. Increasing physical risks, if feeding into transition risk analysis, may lead to an even more disorderly transition. For example, this may result in changing heating and cooling demand, lowering power plant efficiency, increasing water scarcity, lowering agricultural productivity, increasing supply chain disruptions and inflation, and decreasing labor productivity, which all together lead to higher damages. Moreover, given climate nonlinearities, once exceeding climate tipping points, there could be cascading effects and irreversible societal and financial losses.

Annex 1. Potential for Lock-in of Natural Gas Infrastructure and Its Implications for Climate Scenario Design: Literature Review

A bottleneck in the assumptions of current scenario analyses lies in the climate assessment of natural gas along the value chain and climate-related risks of gas expansion into global energy systems (Kemfert and others 2022).

- ***The underestimation of methane emissions is important, despite significant warming potential.*** The contribution of anthropogenic fossil fuel sources to total methane emissions has been underestimated in the range of 20–60 percent (Schwietzke and others 2016). This is primarily due to methane leakage rates that exceed previous estimates in the literature.[46] While current average rates are estimated around 2 percent, current super-emitters can lead this rate to an estimated 6–17 percent range (Kühne and others 2022). Despite its shorter atmospheric residence time, methane has much higher global warming potential than CO_2 on time horizons of a century or less. It is up to 87 times greater than that of CO_2 over the first 20 years after emission, and up to 36 times greater in the first 100 years (IPCC 2013). Given this high warming potential, the use of natural gas as a temporary substitute for coal may even lead to an additional short-term temperature increase.
- ***The characteristics of natural gas infrastructure entail significant carbon lock-in potential, delaying the critical transition to renewable energy.*** Natural gas pipelines, LNG terminals, and gas-fired power plants have a technical lifetime spanning several decades. Tong and others (2019) demonstrate that if global energy infrastructure (as of 2018) operates as it has historically, the entire remaining carbon budget to limit warming to 1.5 degrees Celsius would be exceeded. In addition to infrastructure, carbon lock-in also stems from institutional mechanisms such as the legal protection of private property. According to Serkin (2018), the decommissioning of natural gas infrastructure after only a fraction of its lifespan is very challenging.
- ***While shifting to renewable energy is an imperative, scenarios could therefore treat with caution the argument of natural gas being a "bridge technology."*** As emphasized by the IEA (2019), "beating coal is not enough to make a case for gas" when lower-emission and lower-cost alternatives exist. Scenarios should carefully frame assumptions related to coal-to-gas switching policies—especially when new gas infrastructure is required. The IEA states: "from a policy perspective, a key comparison is between the costs and feasibility of expanding the electricity grid versus the expansion of a gas grid that could eventually also deliver decarbonized gases (renewable methane or hydrogen) as well as providing important energy security benefits."
- ***In this context, natural gas should not be overlooked as part of assumptions on energy asset stranding given potential cascading effects on coupled sectors, including the financial sector (Godin, Campiglio, and Kemp-Benedict 2017).*** Kemfert and others (2022) argue that losses from stranded gas assets remain a source of great uncertainty. In addition, currently developing methane leakage regulations—and potential policy and regulatory consequences stemming from the 26th Conference of Parties (COP26) Global Methane Pledge—might be a cause for additional stranded assets.

[46] Given that methane leaks depend heavily on the individual technical characteristics and process-related factors of the gas system, the recent literature emphasizes the need to adopt large sample sizes to better characterize the heavy tail of the distribution and thereby capture low-probability, high-consequence events when estimating regional oil and gas methane emissions (Chen and others 2022b).

Annex 2. Preliminary Recommendations on NGFS Long-Term and Short-Term Scenarios

The NGFS has developed long-term scenarios to assess climate risks to the economy and the financial system. NGFS long-term scenarios are characterized by their overall level of physical and transition risks, driven by the level of policy ambition, the timing of policy implementation, the regional variation of climate policies, and the degree of technology change and deployment.[47] NGFS Phase III includes six scenarios, ranging from current policies (3+ degrees Celsius) to below 1.5 degrees Celsius.[48] NGFS Phase IV drops the Divergent Net Zero scenario and adds two new scenarios: Low Demand and Fragmented World. The Fragmented World scenario is built on the Divergent Net Zero scenario and adds divergent policy implementation across countries, in addition to heterogenous sectoral actions.

The NGFS is also in the process of developing short-term scenarios.[49] The short-term scenarios focus on the impact of climate change and climate mitigation in the next three to five years and consider a combination of climate policies and macrofinancial conditions.

Building on the current ones, the design of future NGFS scenarios could benefit from extending and deepening the characterization of emerging headwinds to the decarbonization process. NGFS scenarios are among the most widely used climate scenarios by the financial community; they stand out in terms of their scope, coverage, and relevance. Although NGFS scenarios attempt to reflect the plausibility of a disorderly transition, some additional work can be done in the next round of scenario development (both short-term and long-term scenarios) to better capture the current geoeconomic fragmentation and carbon lock-in. In particular, some recent trends can be explicitly modeled.[50] Most of the issues listed here can be addressed in the near term, as they only require limited changes to the current modeling framework.

- ***Emissions**:* Calibrating emissions between 2020 and 2023 to capture the COVID-19 impact in 2020 and emissions rebound afterward.
- ***Fossil fuel consumption:*** Adjusting fossil fuel consumption at the regional level to reflect countries' responses to the Russian invasion of Ukraine and increasing energy security concerns.
- ***Power sector investment:*** Accounting for new investment in coal, gas, and nuclear power plants[51] that may compete with renewable power generation or become stranded assets.
- ***Energy trade and infrastructure:*** Depicting changes in energy trade relationships after the Russian invasion of Ukraine and including and vintaging the newly developed energy infrastructure (for example, new LNG terminals built in Europe).
- ***Energy prices:*** Keeping energy prices up to date to reflect the trend of increasing energy prices, driven by growing demand, the Russian invasion of Ukraine, and climate conditions.

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[47] Including CO_2 removal technologies.

[48] The six scenarios are Current Policies, Nationally Determined Contributions, Delayed Transition, Below 2°C, Divergent Net Zero, and Net Zero 2050.

[49] The NGFS published a conceptual note on short-term scenarios in October 2023.

[50] This note was developed prior to the release of NGFS Phase IV scenarios. Some of the issues listed here (for example, emissions and energy prices) have been at least partially addressed in Phase IV scenarios, while others (for example, fossil fuel consumption and energy trade) remain topics for future research and scenario development.

[51] In addition to coal and gas power capacity additions that are explicitly discussed in the section titled "Capturing Carbon Lock-in in Climate Scenarios," capacity addition in nuclear power plants is underestimated. Estimates across NGFS Phase III models and scenarios on nuclear power capacity additions are 2.3–9.7 gigawatts; the actual capacity of new reactors connecting to the grid between 2020 and April 2023 is 21 gigawatts (as of May 2023, see the International Atomic Energy Agency's Database on Nuclear Power Reactors at https://pris.iaea.org/PRIS/home.aspx) and there are an additional 19 reactors, 22 gigawatts capacity in total, being announced/planned to become operational in 2023 and 2024 (as of May 2023, see Plans for New Reactors Worldwide [https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx] from the World Nuclear Association).

The regular and timely update of NGFS scenarios makes them relevant to the current needs of the financial sector. The discussion in this note sheds light on future climate scenario development and the potential areas of improvement in the next phase of NGFS scenarios to better reflect the structural changes caused by the polycrisis. In addition, the timely update of climate scenarios needs to be accompanied by a transparent modeling framework and documentation, so users understand scenario narratives and underlying assumptions, as well as the implications for their analysis. Annex Table 2.1 discusses the implications for scenario narratives, technology assumptions, and policy reactions.

Annex Table 2.1. Preliminary Recommendations on NGFS Long-Term and Short-Term Scenarios

Scenario Name	Scenario Narrative	Technology Assumption	Policy Assumption
NGFS Phase III Scenarios[1]			
Current Policies	Only currently implemented policies are preserved and delays in climate policies after the COVID-19 pandemic led to increasing fossil fuel investment in some jurisdictions (implying even higher physical risks than under the existing “Current Policies” scenario).	Continuation of the current trends of increasing fossil fuel investment in some jurisdictions.	Incorporating climate legislation passed in major countries, for example, Inflation Reduction Act, Fit for 55, and GX Green Transformation; reflecting delay in climate policy implementation in several jurisdictions.
NDCs	Countries and regions are implementing their pledged NDC targets, but some jurisdictions may reverse or delay NDC implementation.	More fossil fuel investment in the near term; lower cost reduction for renewables; higher energy prices.	Incorporating real-world climate policies at the national and sectoral levels; considering the potential reversal of NDCs or delayed NDC implementation in some jurisdictions until 2025 or later.
Delayed Transition	Annual emissions follow emissions in current policies until 2030. Strong policies are needed to limit warming to below 2 degrees Celsius. Negative emissions are limited.	Lower cost reduction for renewables and growing interest in nuclear, which may lead to a different energy structure from the current NGFS results.	The potential reversal of climate policies or delayed policy implementation in some jurisdictions until 2025 or later and a resumption of the decarbonization path to net zero afterwards (possibly steeper than under the current “Delayed Transition” scenario).
Below 2 Degrees Celsius	The stringency and implementation of climate policies gradually increases over time, giving a 67 percent chance of limiting global warming to below 2 degrees Celsius.	Growing interest in nuclear in several jurisdictions, which may lead to a different energy structure from the current NGFS results.	An immediate, but slower, transition to a low-carbon economy before 2025 or 2030.
Divergent Net Zero	Global carbon dioxide emissions reach net zero around 2050 but with higher costs due to divergent policies introduced across countries and sectors. Trade friction slows down clean energy technology diffusion and adds transition costs in jurisdictions.	Lower cost reduction of electric vehicles given critical mineral constraints. Slow clean energy technology diffusion due to trade frictions. Divergent technology deployment across regions.	Different policy trajectories across jurisdictions and sectors—countries with inconsistent near-term and long-term targets fail to achieve or delay their long-term targets, while few jurisdictions with strong near-term policies meet their climate commitments; countries without net zero targets follow current policies or reverse the implementation of NDCs. Trade policies, such as CBAM, or domestic subsidies aggravate policy divergence across countries and sectors. Less ambitious transportation sector policies due to constraints in critical minerals supply.
Net Zero 2050	Stringent climate policies and technology innovation limit global warming to 1.5 degrees Celsius, reaching global net	Limited use of biomass and carbon dioxide removal technologies.	An immediate, but slower transition to a low-carbon economy before 2025 or 2030.

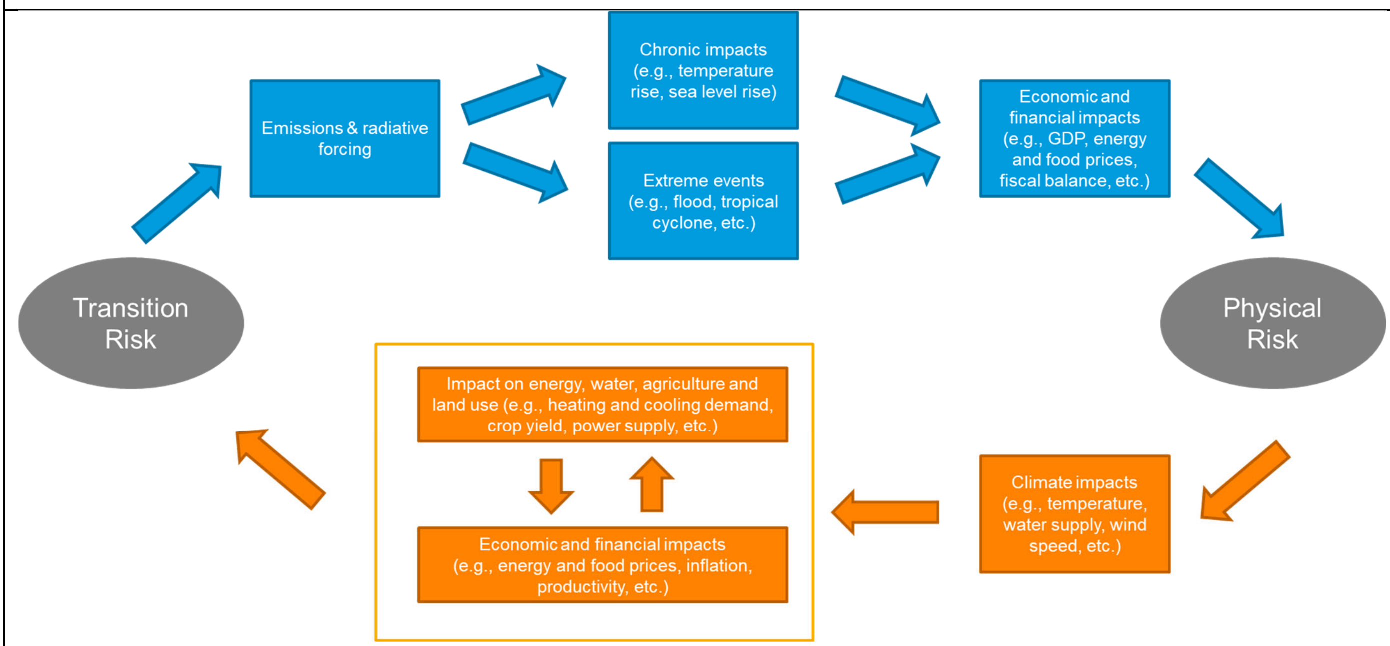
	zero carbon dioxide emissions around 2050.		
A Proposed New Scenario to Capture the Polycrisis (For both short-term and long-term scenarios)			
Carbon Lock-in and Cascading Impacts	The current increase in fossil fuel assets results in carbon lock-in, leading to higher transition and physical risks. As a result, governments' fiscal budgets tighten, and risk premiums rise. Supply chains face additional pressure, which slows down technology diffusion.	Increase in fossil fuel investment in the near term; slow deployment of clean energy technologies due to overcapacity and supply chain constraints.	Failure to achieve or delay in climate commitments in some jurisdictions due to the current increase in fossil fuel assets and implied higher mitigation cost, leading to higher peaking temperature and higher physical risks; tightening governments' fiscal budgets due to increasing physical risks and slower economic growth; high inflation due to supply chain constraints; high risk premiums due to perception of high transition and physical risks.

Source: IMF staff.
Note: CBAM = Carbon Border Adjustment Mechanism; NDCs = nationally determined contributions; NGFS = Network for Greening the Financial System.
[1] Some recommendations on NGFS Phase III scenarios have been addressed in NGFS Phase IV scenarios, while others provide ideas for future improvement.

Annex 3. Feedback Effects between Physical and Transition Risks

This annex describes the main reasons why the dynamic relationship and feedback effects between physical and transition risks are becoming increasingly relevant for climate scenarios. Transition and physical risks need to be assessed in a coherent framework.[52] Climate-related physical and transition risks differ in their direct impacts on economic sectors, therefore leading to potentially different indirect impacts and feedback effects. Because transmission channels often overlap, transition and physical risks may affect different sectors at the same time. The interplay of likely and recurring events and different sources of risk and sectors could gradually or abruptly turn into a vicious cycle, giving rise to destabilizing feedback loops that could trigger tail risks, shifting the likelihood of their occurrence (Coalition of Finance Ministers for Climate Action 2021). Annex Figure 3.1 presents a schematic view of the dynamic relationship between physical and transition risks.

Annex Figure 3.1. Feedback Effects between Physical and Transition Risks



Source: IMF staff.

Acute and chronic physical risks are increasing as a result of growing changes in the Earth system in direct relation to increasing warming: increased frequency and intensity of hot extremes, heavy precipitation, marine heatwaves, agricultural and ecological droughts, increased proportion of intense tropical cyclones, alongside chronic changes such as reductions in poles' sea ice, snow cover, and permafrost. Meanwhile, the IPCC (2021) underscores that low-likelihood outcomes (such as ice sheet collapse or abrupt ocean circulation changes) and compound extreme events (such as concurrent heatwaves and droughts on a global scale)

[52] Physical risks are typically classified as "acute" (risks arising from increased frequency and intensity of extreme weather events) and "chronic" (risks reflecting the effect of long-term changes in climate patterns, such as rising sea levels or changes to precipitation). Transition risks are those resulting from policy, technology, legal, and market changes that occur during the move to a low-carbon economy; they include assets becoming stranded, reputational damage, and financial distress of polluters. See Adrian and others (2022).

should not be overlooked and are part of physical risk assessment. Yet many of these changes are deemed irreversible for centuries to millennia, primarily those in the ocean, ice sheets, and global sea level.

Impact of Transition Scenarios on Physical Risks

Current NGFS scenarios assess the impact of transition policies on physical risks, including both acute and chronic physical risks (see the blue boxes in Annex Figure 3.1). NGFS Phase III scenarios released in October 2022 include the macroeconomic damages estimates from global mean temperature change as well as damages from some extreme climatic events (tropical cyclones and riverine floods) (Richters and others 2022a). NGFS Phase IV scenarios further enhance physical risk modeling by considering temperature and precipitation variability in chronic physical risk estimates and expanding hazard coverage (that is, adding heatwaves and droughts to tropical cyclones and riverine floods) and incorporating additional transmission channels (that is, impact of heatwaves on labor productivity, impact of droughts on crop yield).

Yet physical risks can be underestimated because of the lack of consideration of tipping points, simultaneous occurrence of different hazards, and chains of events (for example, floods made more devastating by previous droughts). Recent climate variability, in particular, needs to be incorporated, especially in short-term scenarios. The onset of El Niño will greatly increase the likelihood of extreme events (World Meteorological Organization 2023). The increase in physical risk will have implications for the economy at large (for example, food price increase and inflation because of physical risk, tightened fiscal budgets and heightened risk premiums because of the high perception of physical risks, and supply chain constraints). Exploring compounding risks from physical, macroeconomic, and sectoral drivers will be critical.

Climate scenarios also need to consider climate tipping points and nonlinearities. Continuing increase in GHG emissions risks triggering climate tipping points and irreversible impacts, such as the accelerated melting of Greenland and/or West Antarctic ice sheet, leading to significant sea level rises and large-scale impacts on the economy of coastal areas (McKay and others 2022).[53] While climate scientists have emphasized the importance of climate tipping points, climate scenarios have largely ignored them or represented them (as well as other potential nonlinearities and second-round effects) in highly stylized ways (Dietz and others 2021), leading to understated measures of exposure and vulnerability (see FSB and NGFS 2022). To properly capture climate risks, next-generation climate scenarios need to incorporate climate tipping points in scenario design and implementation.

"Upstream" effects would also be relevant, running from a failed or faltering low-carbon transition to further exacerbation of climate impacts. This is even more important given that humankind's adaptation potential is decreasing, leading to greater socioeconomic risks (IPCC 2022).[54] For instance, some observers highlight the risk of social and political responses to growing climate impacts potentially distracting societies by shifting the focus on the effects rather than the root causes of global warming, which could in turn exacerbate climate change, producing a vicious cycle (Laybourn, Throp, and Sherman 2023). Further research on scenario development should therefore explore the incorporation of climate change adaptation needs, and the heterogeneity in societies' adaptive capacities and their temporal dynamics (Andrijevic and others 2023). Moreover, the impacts of physical risks and physical transition risk interactions are heterogenous across

[53] There is scientific evidence that Antarctica is warming about twice as fast as the rest of the world and faster than climate models had predicted, with potentially major implications for sea level rise. Climate models, or general circulation models, use mathematical equations to simulate interactions between the ocean, atmosphere, and land. See Kim and others (2023).

[54] See also Andrijevic and others (2023): "Social and political unrest related to armed conflict leads to socioeconomic deterioration in terms of human capacity and lower economic growth, which in turn hinders both adaptation and mitigation action. Advances in scenario conceptualization that would account for shocks, disruptions and multiple intersecting crises (for example, war, food security, pandemics and climate extremes) would also be necessary to fully capture the socioeconomic complexity and would allow for an identification of regions and populations whose need for increased adaptive capacity is the most pressing, because they are the most vulnerable and exposed to compound and cascading risks resulting from poverty, lack of access to basic services, political instability or governance challenges."

regions. Many EMDEs could have greater exposures to physical risks than advanced economies, and the delay in the low-carbon transition could further worsen vulnerabilities in EMDEs, including lowering the capacity to adapt to climate change in these regions (IMF 2020, 2023c).

Other links between transition risks and physical risks could also be significant. For example, while climate scientists have made progress in understanding and quantifying the impact of aerosols on the weather and integrating it into Earth system models, regional estimates of climate risks generally do not sufficiently consider the effects of aerosols, a more potent factor in climate extremes than GHGs.[55] This omission implies a large underestimation of short-term climate risks in different regions, especially densely populated ones such as Southeast Asia and sub-Saharan Africa (Persad, Samset, and Wilcox 2022). Crucially, transition risks affect physical risks through aerosols since future aerosol emissions depend on technological and policy trends (for example, those that target aerosols emissions from fossil fuel plants or shipping). Policies aimed at phasing out those emissions would generate large public health benefits through reduced air pollution but could have major local or global warming effects.

Impact of Climate Change on Transition Risks

Meanwhile, the feedback loop from physical risk to transition risk is studied neither in the current vintage of NGFS scenarios nor in most climate scenarios (the orange boxes in Annex Figure 3.1). Physical risk can affect transition risk in several ways, including direct impact on the energy system and agricultural sector. For example, temperature rise can affect heating/cooling degree days and, therefore, heating/cooling energy demand. Temperature and precipitation changes can also impact electricity supply and crop yield. Physical risks also have macroeconomic and macrofinancial implications. Increasing physical risk can reduce fiscal space and slow economic growth, disrupt supply chains, and increase inflation. Moreover, the negative impact on energy and agricultural systems and on economic and financial systems can exacerbate each other, leading to a more disorderly transition.

The materialization of physical risks could further complicate the energy landscape, including energy security. It would affect both carbon-intensive sources (for example, coal-fired power plants whose efficiency drastically deteriorates because of more frequent and long-lasting heatwaves that reduce the availability of sufficiently cold water as a coolant) and low-carbon ones (for example, droughts affecting the generation of hydropower) (IEA 2022c),[56] as well as critical mineral extraction and grid efficiency.

Likewise, implications of the materialization of physical risks for carbon budgets and trade routes should be better incorporated into short-term scenarios. Currently, some large direct and indirect effects of climate change are overlooked in short-term scenarios. A direct effect of climate change that could have significant implications for carbon budgets and decarbonization is linked to extreme weather events. For instance, as of October 23, 2023, wildfires in Canada had generated about three times as many emissions as Canada’s annual fossil fuel use—with implications for the country’s carbon budget and decarbonization pathway that are overlooked in short-term scenarios.

Similarly, some indirect impacts of extreme weather events that imply potentially significant knock-on effects are typically ignored in short-term scenarios and should be incorporated. For example, in 2023 large US insurance companies announced that they would scale back homeowner policies in vulnerable areas nationally as a result of climate-related risks (floods, storms, fires), and some announced they would stop

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[55] According to Persad, Samset, and Wilcox (2022), aerosol emissions have had a major cooling effect on the planet since the 19th century by reflecting sunlight, reducing global warming by 30–50 percent.

[56] “Growing climate change is putting global energy security at risk, threatening the reliable supply of fuels and resources. Climate change directly affects every aspect of the energy system, from the extraction, processing and transport of fuels and minerals to the potential, efficiency, and reliability of power generation, to the physical resilience of energy infrastructure, as well as impacting energy demand patterns.”

accepting new applications including all business and personal lines property and casualty insurance, citing growing climate-related risks (Eaglesham 2023). This is consistent with ECB and EIOPA (2023), which warned that with insurance claims rising, premiums are likely to rise and/or coverage to fall, thereby widening the protection gap.[57] Credit risk could also be affected given the mismatch between long-term mortgages and insurance policies that must be renewed on an annual basis.

Finally, the omission of certain developments in the ongoing debate on climate change mitigation can represent a blind spot in current transition scenarios. Geoengineering, for example, is a controversial range of technological solutions presented by some as a potential alternative option to offset—at least partially—global warming. So-called solar radiation management is rapidly emerging as a prospective area of climate policy. In July 2023, an official report required by US Congress discussed research options for last resort attempts to slow global warming (Hiar 2023). In June 2023, the European Commission called for international efforts to assess "the risks and uncertainties of climate interventions, including solar radiation modification" and for research into how to regulate it globally (Hancock 2023). The use of geoengineering, even on a limited scale, could have major consequences for the climate and the Earth system, including damage to the Earth's ozone layer and unintended changes in global precipitation patterns, together with knock-on effects on the economy. It could therefore affect transition scenarios in profound ways.[58]

[57] ECB and EIOPA (2023) stress that "A crucial consideration concerning the insurance protection gap is that the public sector is currently in any case the holder of the residual risk, which makes it liable for large climate-related catastrophe losses that are likely to increase in frequency and magnitude." The paper also notes that "At such very high loss layers, the traditional model of reinsurance starts to reach its limits, causing reinsurers to either charge very high premiums or stop underwriting catastrophe risks altogether ('hard market')."

[58] Biermann and others (2022) warn that, in the absence of effective global governance, the geopolitics of unilateral deployment of solar geoengineering would be complex and dangerous.

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