NATIONAL INTELLIGENCE COUNCIL

NATIONAL INTELLIGENCE ESTIMATE

Climate Change and International Responses Increasing Challenges to US National Security Through 2040

NIC-NIE-2021-10030-A

Climate Change and International Responses Increasing Risks to US Interests Through 2040

Risks to US national security interests through 2040 will increase as countries respond to the intensifying physical effects of climate change. Global temperatures most likely will surpass the Paris Agreement goal of 1.5°C by around 2030, and the physical effects are projected to continue intensifying.

None Low Medium High

Risk		2021	2030	2040
Geopolitical Tensions Over Climate Responses	Perception of Insufficient Contributions to Reduce Emissions	Low	Medium	High
	Carbon Dioxide Removal not at Scale for Countries' Net-Zero Pledges	None	Low	Medium
	Developing Country Demands for Financing and Technology Assistance	Medium	High	High
	Petro States Resisting Clean Energy Transition Away From Fossil Fuels	Low	Medium	High
	Competition With China Over Key Minerals and Clean Energy Technologies	Low	Medium	High
	Contention Over Use of Economic Tools To Advance Climate Interests	None	Low	Medium
Climate Exacerbated Geopolitical Flashpoints	Miscalculation Over Strategic Competition in the Arctic Leading to Conflict	None	Low	Medium
	Cross-Border Water Tension and Conflict	Low	Medium	High
	Cross-Border Migration Attributed to Climate Impacts	Medium	High	High
	Ungoverned Unilateral Geoengineering	None	Low	Medium
Climate Effects Impacting Country-Level Instability	Strain on Energy and Food Systems	Low	Medium	High
	Negative Health Consequences	Low	Medium	Medium
	Internal Insecurity and Conflict	Low	Low	Medium
	Greater Demand for Aid and Humanitarian Relief	Medium	High	High
	Strain on Military Readiness	None	Low	Medium

Note: This graphic does not project government and non-government actions that might mitigate risks. The IC defines the level of risk as the probability of the issue occuring multiplied by its assessed impact to US interests.

Climate Change and International Responses Increasing Challenges to US National Security Through 2040

Key Takeaway

We assess that climate change will increasingly exacerbate risks to US national security interests as the physical impacts increase and geopolitical tensions mount about how to respond to the challenge. Global momentum is growing for more ambitious greenhouse gas emissions reductions, but current policies and pledges are insufficient to meet the Paris Agreement goals. Countries are arguing about who should act sooner and competing to control the growing clean energy transition. Intensifying physical effects will exacerbate geopolitical flashpoints, particularly after 2030, and key countries and regions will face increasing risks of instability and need for humanitarian assistance.

- As a baseline, the IC uses the US Federal Scientific community's high confidence in global projections of temperature increase and moderate confidence in regional projections of the intensity of extreme weather and other effects during the next two decades. Global temperatures have increased 1.1˚C since pre-industrial times and most likely will add 0.4˚C to reach 1.5˚C around 2030.

- The IC has moderate confidence in the pace of decarbonization and low to moderate confidence in how physical climate impacts will affect US national security interests and the nature of geopolitical conflict, given the complex dimensions of human and state decisionmaking.

Key Judgment 1: **Geopolitical tensions are likely to grow as countries increasingly argue about how to accelerate the reductions in net greenhouse gas emissions that will be needed to meet the Paris Agreement goals. Debate will center on who bears more responsibility to act and to pay—and how quickly—and countries will compete to control resources and dominate new technologies needed for the clean energy transition.** Most countries will face difficult economic choices and probably will count on technological breakthroughs to rapidly reduce their net emissions later. China and India will play critical roles in determining the trajectory of temperature rise.

Key Judgment 2: **The increasing physical effects of climate change are likely to exacerbate cross-border geopolitical flashpoints as states take steps to secure their interests.** The reduction in sea ice already is amplifying strategic competition in the Arctic over access to its natural resources. Elsewhere, as temperatures rise and more extreme effects manifest, there is a growing risk of conflict over water and migration, particularly after 2030, and an increasing chance that countries will unilaterally test and deploy large-scale solar geoengineering—creating a new area of disputes.

Key Judgment 3: **Scientific forecasts indicate that intensifying physical effects of climate change out to 2040 and beyond will be most acutely felt in developing countries, which we assess are also the least able to adapt to such changes. These physical effects will increase the potential for instability and possibly internal conflict in these countries, in some cases creating additional demands on US diplomatic, economic, humanitarian, and military resources.** Despite geographic and financial resource advantages, the United States and partners face costly challenges that will become more difficult to manage without concerted effort to reduce emissions and cap warming.

Scope Note

This National Intelligence Estimate (NIE) is in response to a Presidential tasking to assess the national security impacts of climate change. While climate change effects are forecast to intensify in the latter half of the 21st century and continue well beyond 2100, based on current emissions trends and technologies, this NIE assesses the near- (5–10 years) and medium-term (10–20 years) geopolitical implications abroad—we do not assess impacts to the homeland or DOD facilities. We assume the following during the next 20 years:

- No precipitating world event that would devastate industrial activity will occur that sharply and permanently reduces greenhouse gas emissions.

The scientific content of this NIE, both the observed climate effects to date and the modeled future impacts, were reviewed by the US Federal science agencies on the Climate Security Advisory Council (CSAC). The CSAC is a partnership between the IC and the Federal science community established by Congress to better understand and anticipate the ways climate change affects US national security interests. It includes the Environmental Protection Agency, the Department of Energy, the Department of the Interior/US Geological Survey, the Office of Naval Research, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and the National Science Foundation.

The IC relies on the broad consensus of scientific studies, modeling, and forecasts from the Intergovernmental Panel on Climate Change, the US National Climate Assessment, and US Federal science agencies as the baseline to assess the geopolitical implications of climate change. We are aware of, but in this estimate do not rely on, the small minority scientific perspectives on climate change ranging from those who consider it nonexistent to those who view it as a near-term existential threat to humanity.

Confidence Levels

The IC uses as a baseline the US Federal scientific community's high confidence in global projections of temperature increase and moderate confidence in regional projections of the intensity of extreme weather and other effects during the next two decades.

The IC has moderate confidence in the pace of decarbonizing the energy sector, given how historically entrenched and slow moving energy systems have been to change and the difficulty of predicting technological breakthroughs. Our confidence decreases after 2030 because government and private sector policies and investments have the potential to drive a more rapid transition.

The IC has low to moderate confidence in assessing how climate change effects could cascade in ways that affect US national security interests as well as the timing and location of potential geopolitical tension, given the complex dimensions of human and state decisionmaking and the challenge of connecting climate, weather, and sociopolitical models.

Climate Change and International Responses Increasing Challenges to US National Security Through 2040

Discussion

Reports from US Federal science agencies and the Intergovernmental Panel on Climate Change (IPCC) indicate that the burning of fossil fuels has increased the concentration of greenhouse gases in the atmosphere and raised global average surface temperatures about 1.1 degrees Celsius (°C) over pre-industrial levels. Temperature rise has accelerated, and every decade since the 1960s has been hotter than the previous one, according to the National Aeronautics and Space Administration.

International diplomatic efforts since the late 1980s have centered on understanding and mitigating the effects a changing climate poses to human security. The 2015 Paris Agreement for the first time established a global goal of limiting temperature rise to "well below 2˚C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5˚C" by 2100, concluding that this would "significantly reduce the risks and impacts of climate change." US Government and other scientists argue that the risks grow as the temperature rises and could be catastrophic and nonlinear after 2˚C if there are tipping points in the Earth's system. (*See Annex B.*)

- In the Paris Agreement, more than 190 countries agreed to submit updated plans—known as Nationally Determined Contributions (NDC)—every five years that should outline increased commitments to peak and reduce their emissions. NDCs are voluntary and have no enforcement mechanism for non-compliance.

- Developing countries—which have long argued that they should not have to limit emissions because they were late in industrializing, need to use fossil fuels to grow economically, and have historically emitted fewer greenhouse gases—signed on to the Paris Agreement in part because it did not require country-specific emissions reduction targets. In addition, developed countries pledged to mobilize $100 billion a year by 2020 to help developing countries mitigate and adapt to climate change.

Trajectory of Climate Change

The current trajectory of growing global CO_2 emissions would cause global temperatures—at 1.1˚C over pre-industrial levels now—to add 0.4˚C and cross the 1.5˚C threshold by about 2030, according to modeling from the National Oceanic and Atmospheric Administration (NOAA), and surpass 2˚C by around mid-century. Many of the physical effects are projected to increase in intensity, frequency, and speed.

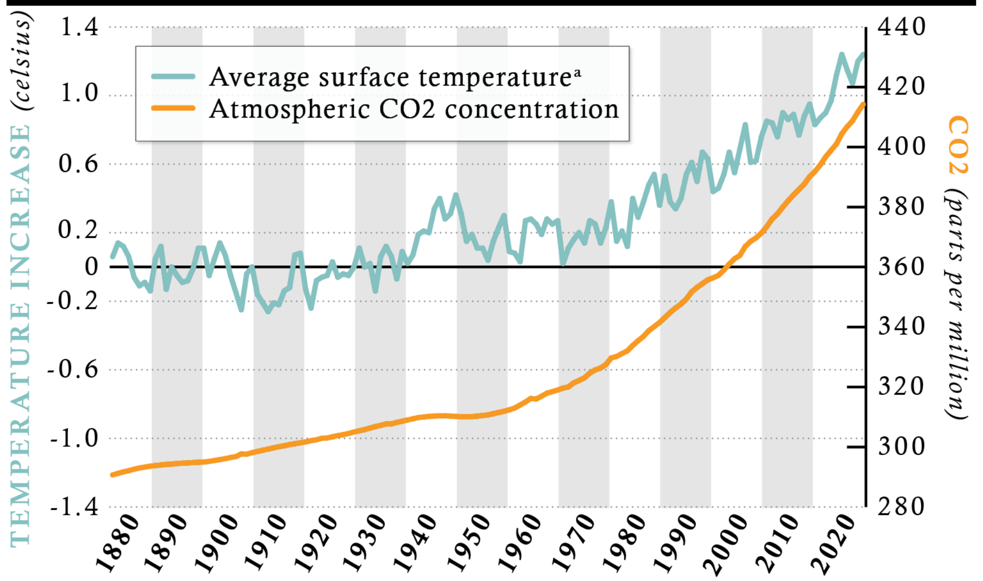
To change that trajectory, the IPCC estimates that global emissions would have to drop sharply in the next decade and reach net zero by around 2050 to limit warming to 1.5˚C, or reach net zero by about 2070 to limit warming to 2˚C.

Pressure To Decarbonize Will Increase Geopolitical Tensions

Key Judgment 1: **Geopolitical tensions are likely to grow as countries increasingly argue about how to accelerate the reductions in net greenhouse gas emissions needed to meet Paris Agreement goals. Debate will center on who bears more responsibility to act and to pay—and how quickly—and countries will compete to control resources and dominate new technologies required for the clean energy transition.** Most countries will face difficult economic choices and

Climate Change Effects and Impacts Intensifying as Greenhouse Gas Emissions and Temperatures Increase

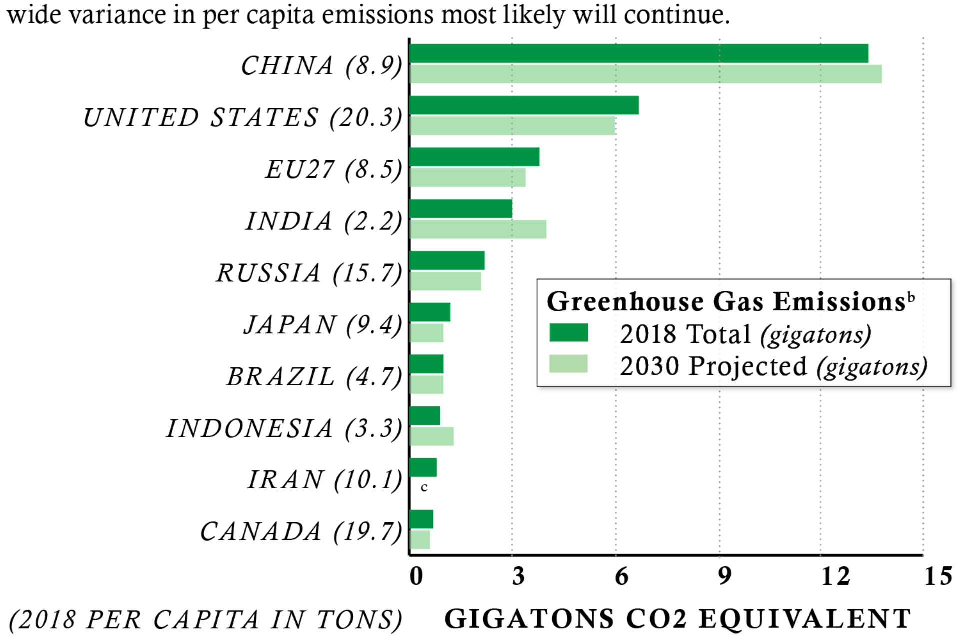
Global Rise in Carbon Dioxide and Average Surface Temperature



a. Compared to 1880-1900 average

Top 10 Current and Projected Greenhouse Gas Emitters

The top 10 emitters in 2018 accounted for about 70 percent of global emissions. The wide variance in per capita emissions most likely will continue.



b. Excluding land use change emissions.
c. We lack a 2030 projection for Iran.

Current and Projected Climate Change Effects and Impacts

Climate Change Effect	Current (at 1.1°C average warming)	1.5°C Warming	2°C Warming	Impacts to Human Security
Heat	5 percent of global population exposed to severe heat waves once in 20 years	14 percent of global population exposed to severe heat waves once in five years	37 percent of global population exposed to severe heat waves once in five years	More intense and frequent heat waves will reduce labor productivity, increase frequency and intensity of wildfires, undermine human health, and lead to loss of life
Heavy Precipitation and Flooding	25 percent of land with significant increase in once-in-a-century floods	17 percent increased frequency of precipitation extremes over land	37 percent increased frequency of precipitation extremes over land	Increased flooding will lead to economic losses, increased calls for humanitarian assistance, and loss of life
Drought	Observed increase in frequency and intensity of droughts in southern Europe, northern Africa, and Near East	Around 132 million more people exposed to severe droughts	Around 194 million more people exposed to severe droughts	More frequent, intense, and longer droughts will undermine food security in developing countries, cause more extreme wildfires, increase political instability, and drive migration
Sea Level Rise	8 to 9 inches higher with the rate of increase doubling in the last 30 years compared to the 20th century	Total projected rise of between 11 and 32 inches, with a median of 19 inches	Total projected rise of between 11 and 38 inches, with a median of 22 inches	Rising sea levels will increasingly imperil coastal cities and exacerbate storm surges that damage infrastructure and inundate water systems
Arctic Ice Melt	13 percent decline per decade of sea ice extent since 1979 90 percent decline of at least five year old thick ice	Probability of an ice-free summer—defined as less than 15 percent ice concentration—is one every 42 years	Probability of an ice-free summer—defined as less than 15 percent ice concentration—is one every five years	Accelerated melting of Arctic ice sheets will affect ocean circulation and salinity, threaten local ecosystems, and increase competition over resources and transit route access
Tropical Cyclones	Global annual average has remained level since 1980 but geographic distribution has shifted, with more cyclones in the North Atlantic and northern Indian Oceans	Additional 2.1 category-4 hurricanes per year, compared to 2018 Additional 1.2 category-5 hurricanes per year, compared to 2018	Additional 1.4 category-4 hurricanes per year, compared to 2018 Additional 1.2 category-5 hurricanes per year, compared to 2018	More frequent, destructive, and shifting tracks of cyclones will lead to trillions of dollars in economic losses in tropical zones, increase calls for humanitarian assistance, drive population displacement and migration, and lead to loss of life
Coral Reefs	33 percent threatened with loss	Projected long-term degradation of 70-90 percent	Projected long-term degradation of more than 99 percent	The disappearance of coral reefs will eliminate an ecosystem that serves 500 million people, impacting economic and food security
Biodiversity	50 percent of terrestrial mammals and 25 percent of birds already under threat are affected by climate change	8 percent of plants, 6 percent of insects, and 4 percent of vertebrates will lose at least half of their geographic range	16 percent of plants, 18 percent of insects, and 8 percent of vertebrates will lose at least half of their geographic range	Loss of species will increase human health risks and threaten food security

probably will count on technological breakthroughs to rapidly reduce their net emissions later. China and India will play critical roles in determining the trajectory of temperature rise.

Policies Not Driving Decarbonization Fast Enough

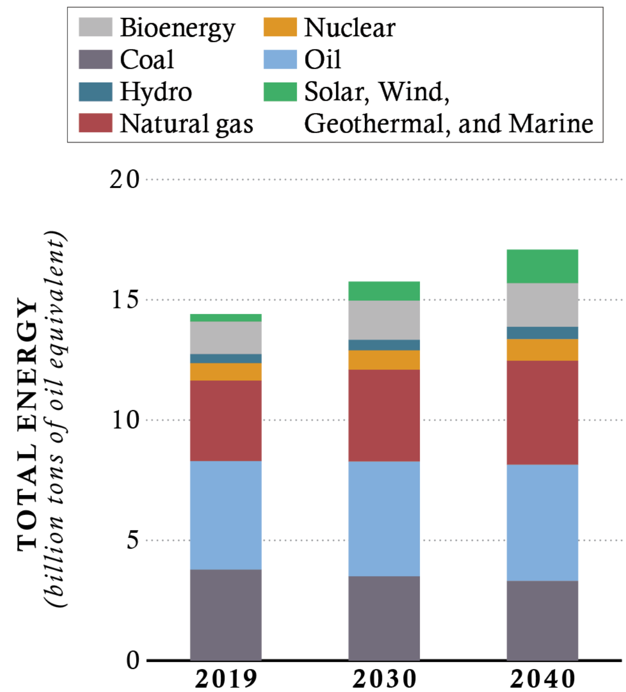
Given current government policies and trends in technology development, we judge that collectively countries are unlikely to meet the Paris goals because high-emitting countries would have to make rapid progress toward decarbonizing their energy systems by transitioning away from fossil fuels within the next decade, whereas developing countries would need to rely on low-carbon energy sources for their economic development. Quickening the pace and trajectory of the energy transition will depend on reducing key countries' continued dependence on fossil fuels; investing in research, development, and deployment of low-carbon technologies for specific sectors that are hard to decarbonize; and enacting policies to incentivize renewable energy sources.

The current pace of transition to low- or zero-emission clean energy sources is not fast enough to avoid temperatures rising above the Paris goal of 1.5˚C. Global energy demand is expected to increase by more than 18 percent by 2040, according to the International Energy Agency's (IEA) modeling of current policies, with fossil fuel use also growing and continuing to account for only a modestly smaller share of supply even though solar, wind, and other clean sources will grow more quickly, particularly after 2030.

- To achieve the 1.5˚C goal through shifts in energy, coal use would need to decline, oil use would need to fall immediately rather than plateau in the 2030s, and natural gas consumption would have to peak this decade, according to IEA data and modeling.

- Fossil fuels will be difficult to replace because the large sunk costs of established production systems make them competitively priced, existing distribution networks offer advantages of flexibility and reach, and scaling alternatives to the level necessary to replace them is difficult. Industrial and transportation sectors will struggle to reduce their reliance on fossil fuels because these sectors are the most dependent on the high energy density that fossil fuels provide.

Current and Projected Energy Demand by Source Based on Current Policies



The IC assesses that increased government and private-sector investment will reduce the share of energy produced by fossil fuels by more than what the International Energy Agency (IEA) estimated in 2020.

- Solar photovoltaic and wind generation almost certainly will increase worldwide because they are on average the cheapest form of energy to add to an electricity grid in many countries—particularly when factoring in installation and lifetime operating expenses. Accelerating the speed and scale of their deployment would require new manufacturing capacity, changes to electricity grids and markets, and development of more advanced batteries to provide power when there is no sun or wind.

- Nuclear and hydropower are forecast to maintain, at most, their current modest shares of energy supply. Some countries are planning to expand nuclear power generation, but others plan to reduce it because of safety concerns and high costs. The development of small modular nuclear reactors may lead to renewed expansion; given long lead times in production, any notable increase in capacity would occur during the latter part of the period of this estimate.

World leaders are increasingly concerned that a window is closing on the opportunity to reduce emissions before irreversible damage to the climate occurs, and many are responding to public and global pressure to act more ambitiously. A growing number of countries are imposing or increasing carbon taxes to discourage emissions and increase the cost competitiveness of clean energy sources and carbon dioxide removal. In addition, private and public investment in these areas is rapidly increasing.

- By summer 2021 more than 90 countries—covering more than 40 percent of global emissions—had submitted updated NDCs. Several had pledged to reach net zero emissions, including Brazil, Chile, the EU, Japan, South Korea, New Zealand, and the United Kingdom by 2050, and China by 2060.

- In March, the European Central Bank announced plans for new capital requirements for banks that have high levels of climate risks on their accounts, and in April, the United Kingdom passed legislation codifying its emissions target. In July, the EU unveiled its emissions reduction roadmap.

- However, few other countries have enshrined these targets into law or have detailed plans on how to get there. For example, industry analysts estimate a carbon price as high as $100 per ton would be needed to accelerate a shift to clean energy. In addition, we assess that some countries are using a pledge to mask a lack of seriousness.

Carbon Dioxide Removal Key to Meeting Paris Goals

Most countries are delaying major emissions cuts until closer to their net-zero target year, which means that breakthroughs, commercialization, and incentives related to carbon dioxide removal (CDR) technologies will be critically important for meeting their goals. Australia, China, the EU, Japan, the United Kingdom, and the United States are leading R&D efforts and pilot projects, according to the Global Carbon Capture Sequestration Institute, but deployment sufficient to meet the goals of the Paris Agreement is contingent on either technological breakthroughs that sharply reduce costs or government support through subsidies and taxes that raise the costs of fossil fuels. Currently, there is no large-scale market use for CO_2.

- Major hydrocarbon producing countries in Europe, led by Norway and the United Kingdom, probably are best positioned for large-scale CDR deployment during the next decade because of government policy and regulatory regimes to support its growth, including carbon-pricing schemes.

- The United States has several advantages that position it to become a leader in CDR. US companies are investing heavily and have experience using CDR to enhance oil and gas yields. In addition, the United States is home to almost half the world's operating carbon capture facilities and has large geologic storage capacity, including natural gas reservoirs and saline aquifers, according to the US Geological Survey (USGS).

- More countries probably will invest in and tout CDR as key to offsetting their emissions and prolonging fossil fuel production and consumption. Oil and gas companies are increasing their R&D in CDR for similar reasons.

Select Carbon Dioxide Removal Technologies Under Consideration

TECHNOLOGY	POTENTIAL BENEFITS	CURRENT LIMITATIONS
Direct Air Capture *Various methods of sucking CO2 out of the air*	Can be used anywhere with access to geological storage potential . . . unlimited scale	Very high energy usage and cost per ton of CO2 removed
Forestation *Protecting trees or planting new ones*	Co-benefits to biodiversity, protecting soil and preventing against landslides	Trade off with land-usage for agriculture . . . very difficult to measure compliance . . . risk of CO2 released when tree dies or wildfire occurs . . . modest scale
Bioenergy with Carbon Capture & Storage (BECCS) *Growing bio-energy via CO2 and capturing CO2 upon burning it as a fuel*	Could be a ‘negative emissions technology’	Opportunity-cost in using land for BECCS instead of agriculture . . . modest scale

China and India will play critical roles in determining the trajectory of temperature rise. They are the first- and fourth-largest emitters, respectively, and both are growing their total and per capita emissions, whereas the United States and EU—as the second- and third-largest—are declining. Both China and India are incorporating more renewable and low-carbon energy sources, but several factors will limit their displacement of coal. They need to modernize their grids, have sunk costs that make it relatively cheaper to use coal compared with other energy sources, want to minimize reliance on fuel imports for national security reasons, and are trying to appease domestic constituencies who rely on the coal industry for jobs.

- China accounts for about 30 percent of global emissions and has pledged to peak before 2030, but modest emissions reduction targets in its 14th Five Year Plan (2021–2025) in 2021 put that into question. China has not publically articulated detailed plans for meeting its 2060 net-zero-emissions target; to do so, we assess that Beijing would need to follow through on President Xi Jinping’s pledge at the US Climate Summit in April to phase out coal consumption.

- India almost certainly will increase its emissions as it develops economically. Indian officials have not committed to a net-zero target date and have instead called on countries with larger economies to reduce emissions.

Arguing About Who Bears Responsibility To Act

The cooperative breakthrough of the Paris Agreement may be short lived as countries struggle to reduce their emissions and blame others for not doing enough. The Paris Agreement allows countries to self-report emissions data, which means that increased transparency, monitoring, and consistency in reporting will be necessary to accurately measure and assess which countries are meeting their commitments.

- We assess that the longstanding diplomatic divide between expected contributions from developed versus developing countries will persist. Most developing countries almost certainly will continue to submit conditional targets, arguing that developed countries must provide substantial financial assistance—as called for in the Paris Agreement—technology transfers, and aid in capacity building for them to reach their NDC goals.

- Developing countries will continue to press for more money to mitigate and adapt to climate change, arguing that developed countries’ failure to mobilize $100 billion a year starting in 2020 has hampered their ability to take serious action.

Financial needs will grow as the physical effects intensify; the UN estimates that developing countries will need upwards of $300 billion in annual investment by 2030 just to adapt.

- In addition, countries probably will continue to present favorable data or compare their reductions against a chosen baseline year to their benefit. Russia's target is baselined to 1990 levels—at the height of the Soviet Union's economic activity and before Russia's economic collapse in the 1990s—which allows it to appear ambitious in meeting its goal. Brazil updated its NDC in 2020 by recalculating its 2005 baseline number upwards, allowing it to claim it is still on track to meet its goal.

Growing Competition Over Key Minerals and Technologies

Competition will grow to acquire and process minerals and resources used in key renewable energy technologies. China is in a strong position to compete; it currently controls more than half the global processing capacity for many of these minerals, according to the USGS and industry reporting, including rare earths for wind turbines and electric vehicle motors; polysilicon for solar panels; and cobalt, lithium, manganese, and graphite for electric vehicle batteries. China is able to process these at reduced cost mainly because of its lower environmental standards, lower labor costs, and inexpensive power.

Countries will increasingly compete over developing renewable energy technologies to become leading exporters and gain market share as the energy transition picks up speed. This competition potentially will enable technological breakthroughs that could speed up decarbonization.

- The decarbonization of the electricity sector, combined with the electrification of transportation, will require countries to upgrade and expand their grids. Under current policies, the global electric vehicle stock is projected to grow twentyfold by 2030 and account for 7 percent of the global fleet, according to the IEA.

- Deployment of utility-scale solar and wind technologies in remote areas is likely to require ultra-high-voltage transmission lines to move the power to cities. China is the world's leading supplier of advanced grid components for ultra-high-voltage systems, such as transformers, circuit breakers, and inverters, which we assess creates cyber vulnerability risks.

- Private firms and governments in China, the EU, Japan, Russia, and the United States are increasing R&D efforts on emerging energy technologies to

Select Emerging Energy Technologies

TECHNOLOGY	POTENTIAL BENEFITS	CURRENT LIMITATIONS
Green Hydrogen	Help store excess wind and solar energy . . . could help decarbonize heating, industry, and heavy transport sectors . . . probably less need for new infrastructure buildout than electrifying transport	High costs, industry still in infancy
Floating Offshore Wind	Potential to produce 3 to 15 times more electricity than fixed offshore wind installations	High costs of cables to shore
Small Modular Nuclear Reactors	Cheaper and easier to install than conventional nuclear power plants . . . could provide power to remote areas and reduce challenge of intermittency from renewables	Bureaucratic, regulatory, and safety concerns . . . high initial costs

Petrostates Fear Transition Risk in International Decarbonization Efforts

We assess that most countries that rely on fossil fuel exports to support their budgets will continue to resist a quick transition to a zero-carbon world because they fear the economic, political, and geopolitical costs of doing so. US and Western efforts to push these countries to speed up the energy transition could complicate bilateral relations and force tradeoffs with other national security priorities.

- Russian President Vladimir Putin only recently acknowledged the economic damage from climate change. Russia generated almost 30 percent of state revenue in 2020 from fossil fuel companies, including $40 billion in gas sales to Europe.
- More than 20 countries rely on fossil fuels for greater than 50 percent of total export revenues, and most will continue to struggle to diversify their sources of export revenue because of entrenched political interests, endemic corruption, and the lack of economic and legal institutions. Most already face major governance and instability challenges, with Algeria, Chad, Iraq, and Nigeria most at risk from falling fossil fuel prices because they have higher break-even prices, according to industry reporting.
- A decline in fossil fuel revenue would further strain Middle Eastern countries that are projected to face more intense climate effects—such as very high heat and extended droughts—because it will reduce available resources needed to adapt or build more resilient infrastructure.

provide additional zero- to low-carbon options, such as green hydrogen, floating offshore wind, and small modular nuclear reactors. The potential to gain an edge in markets that could be worth hundreds of billions to trillions of dollars is fueling increasingly intense competition.

Use of Contentious Economic Tools To Advance Climate Interests

Countries most likely will wield contentious financial and economic tools to advance climate policies and defend their national economies. Some countries are looking to impose costs on foreign goods produced in countries with relatively weak carbon reduction standards to protect domestic producers who are complying with more stringent standards.

- The EU plans to propose a new Carbon Border Adjustment Mechanism for implementation as early as 2023, to protect EU firms in certain sectors from competing with companies from countries with weaker climate rules and emissions prices, according to open-source reporting.
- Australia, China, India, Russia, South Africa, and Ukraine have criticized the use of such mechanisms as a disguised form of protectionism.

Climate Change Effects Exacerbating Geopolitical Flashpoints

Key Judgment 2: **The increasing physical effects of climate change are likely to exacerbate cross-border geopolitical flashpoints as states take steps to secure their interests.** The reduction in sea ice already is amplifying strategic competition in the Arctic over access to its natural resources. Elsewhere, as temperatures rise and more extreme effects manifest, there is a growing risk of conflict over water and migration, particularly after 2030, and an increasing chance that countries will unilaterally test and deploy large-scale solar geoengineering—creating a new area of geopolitical disputes.

Growing Strategic Competition in the Arctic

We assess that Arctic and non-Arctic states almost certainly will increase their competitive activities as the region becomes more accessible because of warming temperatures and reduced ice. Competition will be largely economic but the risk of miscalculation will increase modestly by 2040 as commercial and military activity grows and opportunities are more contested.

- Diminishing sea ice probably will increase access to shipping routes that can reduce trade times between Europe and Asia by about 40 percent for some vessels. In addition, onshore oil and natural gas deposits, as well as an estimated $1 trillion worth of precious metals and minerals will become more available, but some high-cost offshore oil and gas projects could become unprofitable if the energy transition speeds up.

- Warming ocean temperatures probably will push Bering Sea fish stocks northward into the Arctic Ocean, according to a NOAA study, which could increase commercial and illegal fishing activity in the region and exacerbate regional disputes between Arctic and non-Arctic states over fishing rights.

- Coastal erosion and thawing permafrost will damage critical infrastructure. Massive investment in infrastructure would be needed to maximize the economic potential of the region, ranging from new ports to mining, offering foreign powers an opportunity to gain a foothold by investing in new infrastructure and rebuilding and hardening existing infrastructure.

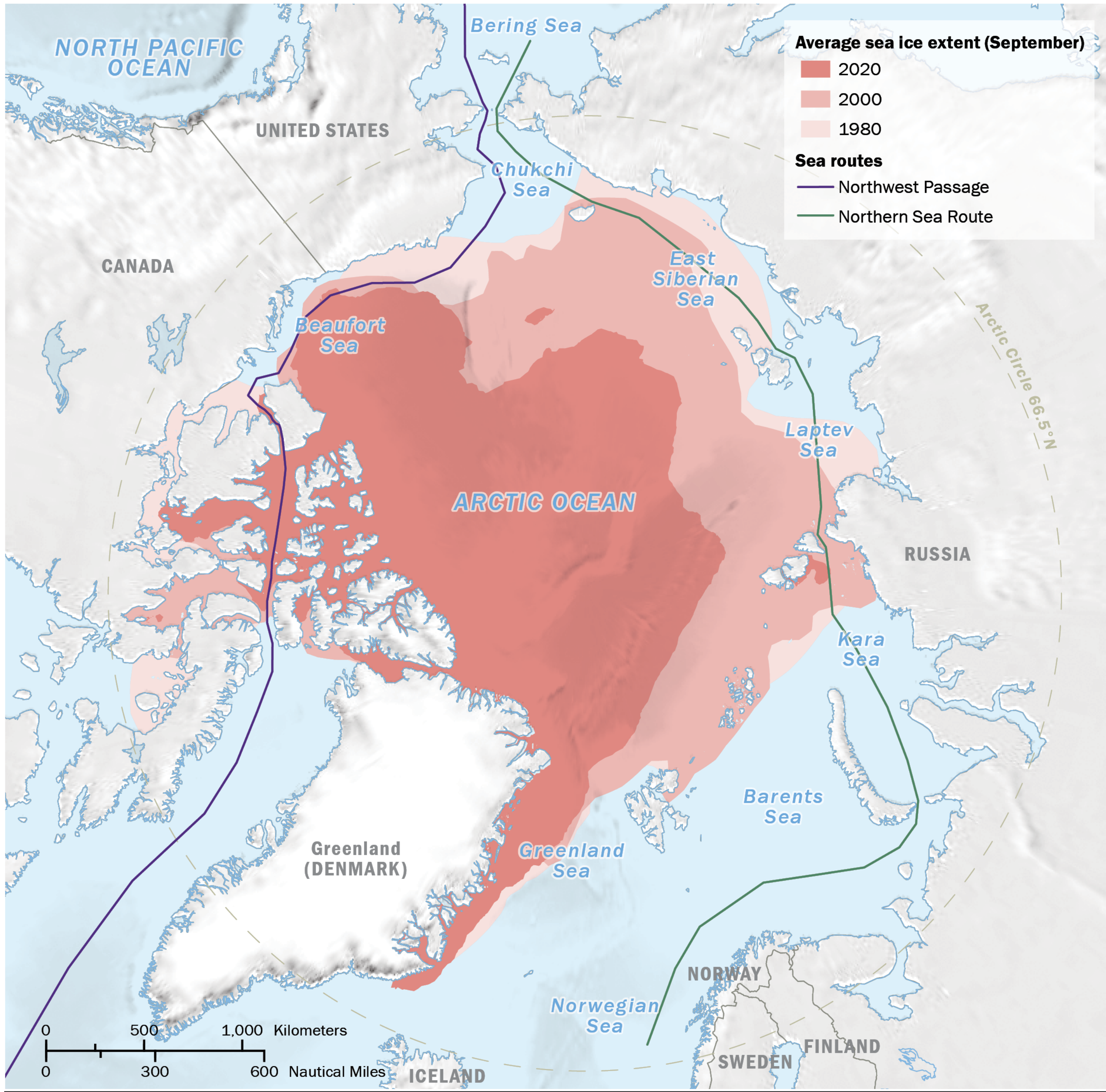
Military activity is likely to increase as Arctic and non-Arctic states seek to protect their investments, exploit new maritime routes, and gain strategic advantages over rivals.

The increased presence of China and other non-Arctic states very likely will amplify concerns among Arctic states as they perceive a challenge to their respective security and economic interests. China, France, India, Japan, South Korea, and the United Kingdom have released Arctic strategies mostly focused on economic opportunities, but some address security issues, which has prompted Russian policymakers to repeatedly state since 2018 that non-Arctic countries do not have a military role in the region.

Contested economic and military activities will increase the risk of miscalculation, and deescalating tensions is likely to require the adaptation of existing or creation of new forums to address bilateral or multilateral security concerns among Arctic states. Although the scope of the Arctic Council—the leading intergovernmental forum promoting cooperation among Arctic states—specifically excludes military security, Russia intends to broach security concerns with the other Arctic states while chairing the council from 2021 to 2023, according to Russian officials' public statements, and may propose alternate forums to discuss those issues.

Climate Change Reducing Ice, Amplifying Strategic Competition in the Arctic

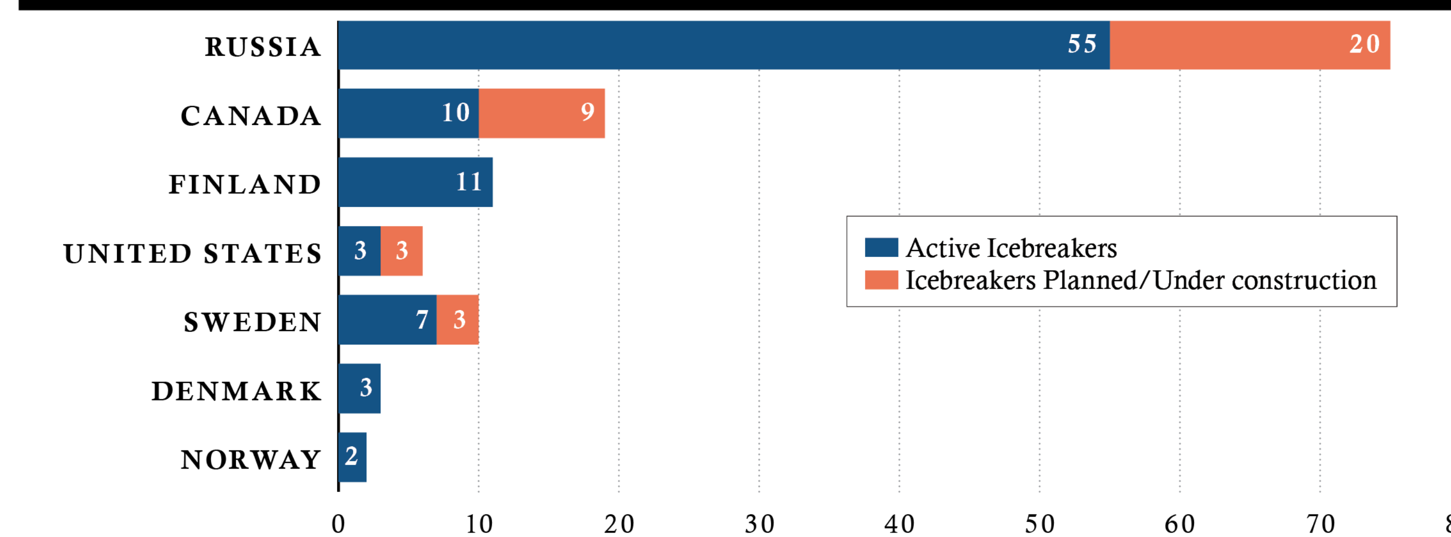
Warming temperatures are melting sea and glacial ice, eroding coastlines, thawing permafrost, and causing more frequent wildfires that are longer in duration and intensity. Since 2000, temperatures in the Arctic have risen more than twice the global average, according to the National Oceanic and Atmospheric Administration (NOAA), and in September 2020, the Arctic sea ice extent was at the second lowest on record, behind 2012, according to the National Snow and Ice Data Center.



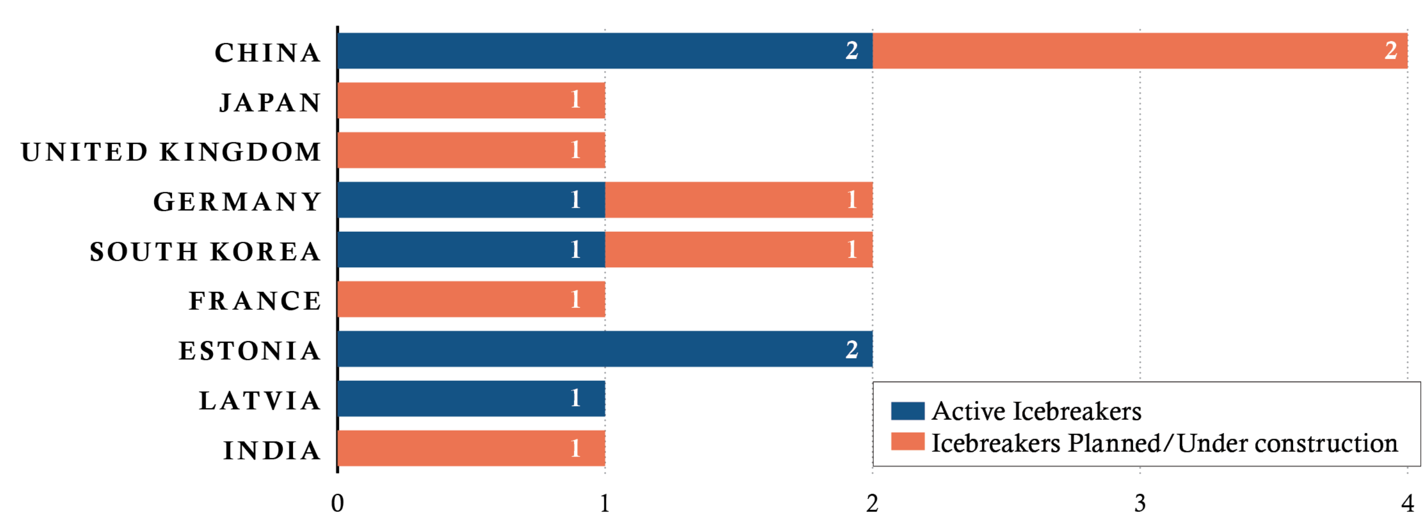
Growth In Icebreakers Enabling Access in the Arctic

Arctic and non-Arctic countries are increasing their icebreaking capabilities to advance their economic, scientific, and security interests as the region becomes more accessible. Icebreakers capable of operating in the Arctic probably will enable countries to capitalize on shorter shipping routes, extract natural resources, conduct scientific research, and improve their overall security posture.

ARCTIC COUNTRIES



NON-ARCTIC COUNTRIES



Graphic only depicts icebreakers that serve in the Arctic and does not include icebreakers operating elsewhere in the world.

Increased Strains Over Water and Migration

Outside the Arctic, we judge that transboundary tensions probably will increase over shared surface and groundwater basins as increased weather variability exacerbates preexisting or triggers new water insecurity in many parts of the world. Forecasted climate change effects on local and regional weather—including loss of glaciers and more frequent and extreme droughts and floods—will make water management, resource allocation, and service provision more complex and difficult, and probably more contentious. Although scientific forecasts are not precise enough to pinpoint likely flashpoints, we assess that several areas are at high risk.

- Pakistan relies on downstream surface water from heavily glacier-fed rivers originating in India for much of its irrigation, and requires frequent data from India on river discharges in order to provide advanced warning to evacuate villages and prepare for flooding.

- The Mekong River basin already is an area of growing dispute over dam building, largely by China, that threatens the smooth flow of water for agriculture and fishing on which other countries rely heavily, particularly Cambodia and Vietnam.

- In the Middle East and North Africa, about 60 percent of surface water resources are transboundary and all countries share at least one aquifer, according to the World Bank. Several aquifers are also vulnerable to salt water intrusion, even from minor rises in sea levels, increasing the potential for conflict.

- Some key bodies for resource management, such as the Nile Basin Initiative, will increasingly become sidelined unless they develop enforcement mechanisms to cajole cooperative behavior among states. Nearly half the world's 263 international river basins—encompassing about half the global population—lack cooperative management agreements to help defuse tensions in shared basins, according to the UN, and most existing agreements are not flexible enough to address disruptions in weather patterns and reduced water flow caused by climate change.

We judge that cross-border migration probably will increase as climate effects put added stress on internally displaced populations already struggling under poor governance, violent conflict, and environmental degradation. Triggers for increased migration are likely to include droughts, more intense cyclones—with accompanying storm surges—and floods. Given the multiple factors that drive migration and the uncertainties in regional climate models, we are unable to project total numbers of climate migrants. However, countries and displaced people will increasingly see climate change as a driver, and it will contribute to instability when it upsets socioeconomic, political, and demographic dynamics, and strains ties between originating and receiving countries.

- Around 10 percent of the population of Bangladesh lives along exposed coastal areas vulnerable to sea level rise and saltwater intrusion, and the country is projected to add more than 20 million people by 2040. Since 1993, India has been erecting a fence along its 4,000-kilometer border with Bangladesh.

- Displaced populations—especially from small island nations—will increasingly demand changes to international refugee law to consider their claims and provide protection as climate migrants or refugees, and affected populations will fight for legal payouts for loss and damages resulting from climate effects.

- The need for investments in adaptation technologies to manage water stress and reduce a potential driver of migration could create expanded markets for advanced technologies, such as water storage and reuse systems. The UN's Global Commission on Adaptation calculates that a $1.8 trillion investment by 2030 in early warning systems, resilient infrastructure, dryland agricultural crop production, mangroves, and water resource management would yield more than $7 trillion of benefits in avoided costs from climate change effects.

Risk of Unilateral Geoengineering Increasing

We assess there is a growing risk that a country would unilaterally test and possibly deploy large-scale solar geoengineering technologies as a way to counter intensifying climate effects if it perceived other efforts to limit warming to 1.5°C had failed. Without an international agreement on these technologies, we assess that such a unilateral effort probably would cause blowback. Geoengineering intentionally cools the planet by reflecting a fraction of solar radiation back to space or allowing thermal radiation to escape, but it does not address other climate effects such as ocean acidification. A large-scale deployment of stratospheric aerosol injection (SAI)—which mimics the natural cooling effect of a volcanic eruption by adding small reflective particles to the upper stratosphere—could have a global impact. Another technology—marine cloud brightening—uses aerosols to increase cloud reflectivity to cool ocean temperatures on a more localized scale.

- Large-scale geoengineering could be internationally disruptive because of its potential to substantially affect the Earth's biosphere, which would change global weather patterns and provide climate benefits to some regions at the expense of others. Depending on the scale and location of deployment, it could change weather systems in the United States.

- Researchers in several countries, including Australia, China, India, Russia, the United Kingdom and the United States, as well as several EU members, are exploring geoengineering techniques. We assess that the lack of any country-level dialogue or governance body to set regulations and enforce transparency over research increases the possibility that state or nonstate actors will independently develop or deploy the technology—possibly covertly—in a manner that risks conflict if other nations blame them for a weather disaster they believe was caused by geoengineering.

Highly Vulnerable Countries of Concern

Key Judgment 3: **Scientific forecasts indicate that intensifying physical effects of climate change out to 2040 and beyond will be most acutely felt in developing countries, which we assess are also the least able to adapt to such changes. These physical effects will increase the potential for instability and possibly internal conflict in these countries, in some cases creating additional demands on US diplomatic, economic, humanitarian, and military resources.** Despite geographic and financial resource advantages, the United States and partners face hard and costly challenges that will become more difficult to manage without concerted efforts to reduce emissions and cap warming.

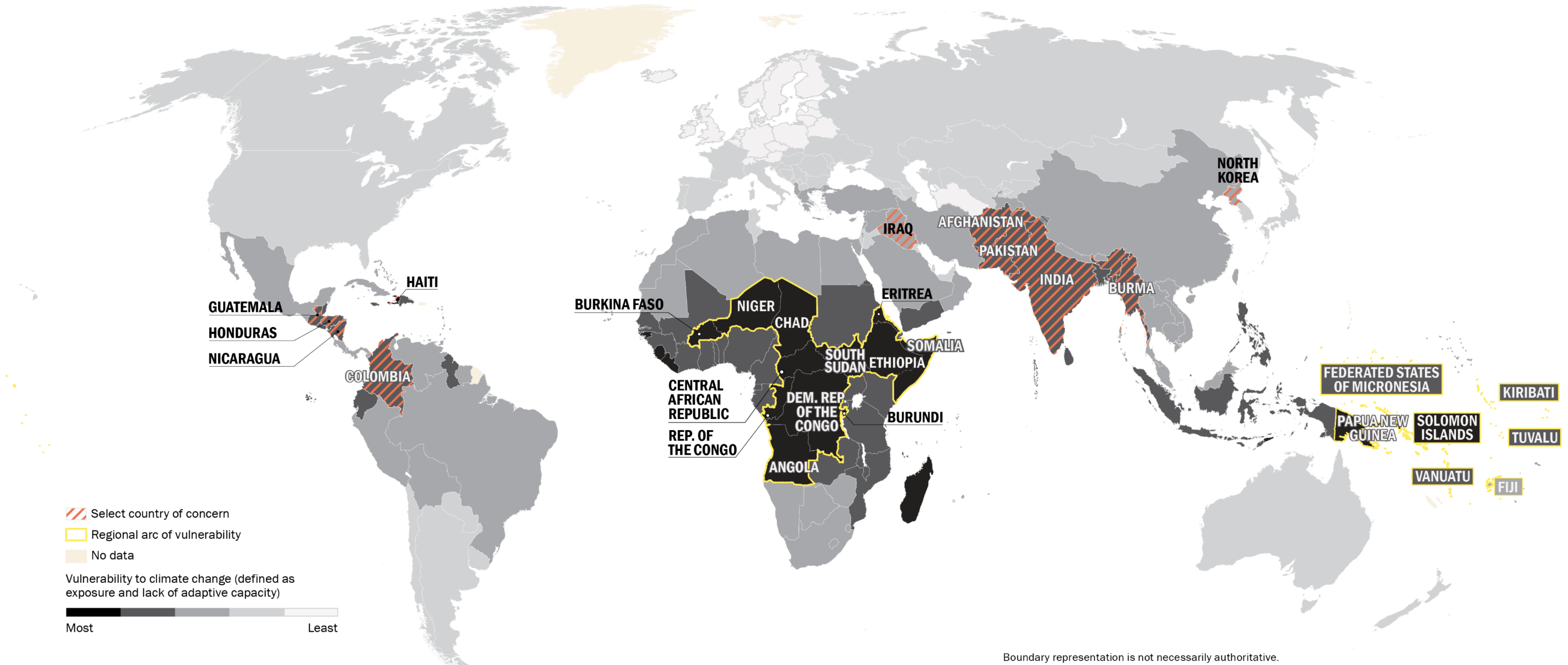
- The IC identified 11 countries and two regions of great concern from the threat of climate change. These countries of concern are highly vulnerable to the physical effects and lack the capacity to adapt, suggesting that building resilience to climate change in these countries would be especially helpful in mitigating future risks to US interests.

- Five of the 11 countries are in South and East Asia—**Afghanistan, Burma, India, Pakistan,** and **North Korea**; four countries are in Central America and the Caribbean—**Guatemala, Haiti, Honduras,** and **Nicaragua**; **Colombia** and **Iraq** round out the list.

- Climate change is also likely to increase the risk of instability in countries in Central Africa and small island states in the Pacific, which clustered together form two of the most vulnerable areas in the world.

Climate Change in Select Highly Vulnerable Countries of Concern

The IC identified 11 countries and two regions of great concern from the threat of climate change. Building resilience in these countries and regions would probably be especially helpful in mitigating future risks to US interests. Two regional arcs also stand out because these groups of countries are clustered together, are relatively poor, and have little capacity to assist their neighbors.



- More broadly, developing countries are likely to need to adapt to a mix of challenges that climate change will exacerbate. Ineffective water governance in developing countries will increase their vulnerability to climate effects, undermining livelihoods and health. Some will face new or more intense diseases and lower yields from existing staples of their agriculture. In addition, insurgents and terrorists may benefit—we assess that most of the countries where al-Qa'ida or ISIS have a presence are highly vulnerable to climate change.

Select Countries of Concern

We assess that the 11 countries especially are likely to face warming temperatures, more extreme weather, and disruption to ocean patterns that will threaten their energy, food, water, and health security. Intensifying and more frequent heat waves and droughts will create water supply volatility and probably strain their electric utility operations, while growing economies and populations will increase electricity demands to handle rising temperatures.

- Warm countries that rely on thermoelectric power plants for electricity generation are particularly vulnerable because more frequent and intense droughts and higher evaporation rates from rising temperatures are likely to interrupt their access to water to cool power plants. Rising temperatures also make the plants less efficient and more costly to operate.

- For the fifth consecutive year, prolonged dry spells and excessive rains have devastated maize and bean crops in Central America's dry corridor. Yields for these and other crops in Guatemala, Honduras, and Nicaragua are projected to decline significantly because of climate change, according to a UN study, raising the prospect of food insecurity and a drop in crucial export commodities.

- More frequent and intense cyclones are likely to contaminate water sources and increase vector populations and the diseases they transmit in several of the 11 countries. Models suggest dengue incidence probably will increase in Afghanistan, Guatemala, Haiti, Honduras, India, Iraq, and Pakistan, according to scientific studies.

- Rising temperatures and increased precipitation probably will amplify mosquito and diarrheal disease outbreaks in South Asian and Central American countries, worsening health outcomes and causing additional loss of life, according to scientific studies and the WHO.

- Climate change probably will accelerate the loss of biodiversity—the variability among all living organisms—faster than at any point in human history, leading to more extinctions of plants and animals that can no longer survive in their traditional habitats and risking ecosystems that global populations rely on for food and medicinal production.

We judge that the 11 countries especially will lack the financial resources or governance capacity to adapt to climate change effects, heightening the risk of instability-induced migration and displacement flows—including to the US southern border—and increasing their already substantial needs for foreign aid and humanitarian assistance. Foreign governments, international institutions, and private investment can offer financial aid, technical expertise, and climate adaptation technologies to alleviate some of these difficulties—such as food and water insecurity and urban poverty—but in the 11 countries, these efforts are likely to be hindered by poor governance, weak infrastructure, endemic corruption, and a lack of physical access.

- Several factors have made an outsized contribution to countries' declining adaptive capacity, including being heavily dependent on imported energy and external resources for health services, and having low electricity access.

- Climate change is likely to contribute to economic and social stress and become an increasing migration push factor, especially for poor farmers in Central America, who make up 30 percent of the working population. Climate-induced population movements into cities are likely to compound factors of social or political instability, such as uncontrolled urbanization, high rates of unemployment, and growing slums.

- Diminished energy, food, and water security in the 11 countries probably will exacerbate poverty, tribal or ethnic intercommunal tensions, and dissatisfaction with governments, increasing the risk of social, economic, and political instability.

Regional Arcs of Vulnerability

Climate change is likely to increase the risk of instability in countries in Central Africa and small island states in the Pacific. These countries are all highly exposed to climate change and have little adaptive capacity. In addition, they are clustered together to create regions in which the United States or its allies may be called upon to provide humanitarian aid, settle disputes, or accept migrants.

Climate change most likely will slow economic and human development in **Central Africa**, a region that already is conflict-prone and heavily reliant on humanitarian assistance. Countries in the region are highly exposed to increased droughts, flash flooding, and related environmentally driven diseases, and also rank among the lowest in the world in access to education, electricity, health, and sanitation.

- Under-resourced and ill-equipped militaries will face severe strains when they are called upon to respond to more natural disasters in their own and neighboring countries.

Low-lying **Pacific Islands** are highly vulnerable to climate change because of their minimal adaptive capacity and high exposure to tropical storms and rising sea levels. Although no island nation is forecast to disappear by 2040, about 20 percent of their landmass is projected to face annual wave flooding from higher seas that will damage infrastructure and threaten food and water security because of saltwater intrusion of groundwater resources, according to a 2018 study by NOAA and USGS.

- Climate change also may hasten the collapse of commercial fisheries that already are under severe strain from overfishing, according to the Pacific Community, which will harm local diets and economies. Regional fish consumption is three-to-five times the global average, foreign fishing licenses make up a large share of government revenue, and onshore processing provides jobs, according to a UN study.

Finally, we assess that many other countries are comparatively more exposed and **have fewer resources to adapt to climate change effects, although some probably will experience opportunities that mitigate their challenges.**[1] **The following are illustrative examples:**

- More variable precipitation is likely to widen China's south–north water disparity, challenging its ability to irrigate agricultural areas in its water-deficient northeast and further drive its dam construction on rivers upstream from neighboring countries. However, it is likely to have the financial and technological resources to compete successfully in markets for solar and other clean energies and limit the damage from climate impacts, such as more intense cyclones and river flooding.

- North Korea's poor infrastructure and resource management probably will weaken its ability to cope with increased flooding and droughts, exacerbating the country's chronic food shortages. Increasing extremes in seasonal weather variations may reduce reservoir water stores during droughts while damaging infrastructure during the rainy monsoon season.

- Saudi Arabia will face moderate exposure and has some ability to adapt, while Iran probably will face more frequent droughts, intense heat waves, and expanding desertification that, combined with poor water management, will lower food production and increase import costs during the coming decades, increasing the risk of instability, localized conflict, and displacement.

- Egypt is less exposed to climate change effects than many countries, and Brazil and Mexico have greater capacity to adapt to such changes.

- Russia is likely to experience infrastructure damage from permafrost thaw, more frequent and intense wildfires, and increased erosion. Moreover, existing agricultural regions probably will experience longer and more frequent droughts. Russia, however, will benefit from the opening of Arctic trade routes and may benefit from longer growing seasons to increase crop production in other regions.

The United States and others, however, are in a relatively better position than other countries to deal with the major costs and dislocation of forecasted change, in part because they have greater resources to adapt, but will nonetheless require difficult adjustments. Climate impacts such as excessive heat, flooding, and extreme storms will prove increasingly costly, require some military shifts, and increase demands for humanitarian assistance and disaster relief operations. Adjusting to such changes will often be wrenching, and populations will feel negative effects in their daily lives that will become more difficult to reverse without successful efforts to reduce net emissions and cap warming temperatures. The impacts will be massive even if the worst human costs can be avoided. The energy transition is already rapidly shifting investment, creating new industries while devastating others.

- The United States and key states in the developed world have greater technological capability and financial resources to adapt to climate change, and are likely to realize some benefits in terms of technological competitiveness and agriculture. Should warmer temperatures and longer growing seasons yield lower heating costs and increased agricultural production, most of the beneficiaries outside Russia are likely to be in the high latitudes, such as Canada and Scandinavian countries.

- Climate effects are likely to compel militaries in areas prone to coastal flooding and saltwater inundation to alter operations, and changes to ocean temperature and chemistry probably will require changes to maritime requirements and sensors, according to a National Defense University report.[2]

- Affected militaries also probably will have to adapt acquisition requirements and expend resources to harden or rebuild critical infrastructure. The United Kingdom is expecting increased calls to respond to humanitarian disasters and is preparing equipment and designing its forces for a world that is 2-4°C warmer than it was in the late 19th century, according to a UK Ministry of Defense study released in March.[3] Although militaries will absorb these expenses in normal recapitalization programs spread over decades, the costs to adapt will force tradeoffs with other modernization priorities.

Annex A: Events That Would Change Our Assessment

This NIE's key judgments are based on assessments regarding the speed of the energy transition away from fossil fuels and deployment of CDR technologies, the trajectory of intensifying physical effects from climate change, and countries' responses to these effects in ways that increase tension and affect US national security. The following four scenarios highlight some of the developments that could alter our main judgments and their underlying assumptions.

A major breakthrough in and large-scale deployment of zero-carbon energy or CDR technologies *would alter our assessment that the global energy transition is not on pace to meet the Paris Agreement goal of limiting warming to 1.5°C.* Multiple venture-backed startup companies could utilize their capital—combined with improved computational and materials science—to develop a breakthrough in nuclear fusion, a near endless source of energy that governments have been researching since the 1950s without success. In addition, the discovery of a cheap CDR technique or a new and highly profitable use for CO_2 could create a market incentive for companies and countries to remove CO_2 from the atmosphere on a large enough scale to spur a deep decarbonization pathway that results in the globe reaching net zero emissions well before 2050.

A global climate disaster that mobilizes massive collective action from all countries and populations—such as clear evidence that we are nearing a tipping point in the Earth's system faster than expected—*would alter our assessment that countries are going to argue about who bears more responsibility to act.* New observations could indicate the irreversible and significantly faster than expected melting of Greenland and the West and East Antarctic glaciers—which currently are modeled to raise sea levels by upwards of a quarter meter by 2040, and more than one meter by 2100 under a high emissions scenario—could threaten hundreds of millions of people living in coastal communities. Alternatively, new evidence could emerge indicating the near term collapse of the Atlantic Meridional Overturning Circulation (AMOC) that risks altering North Atlantic air temperatures in excess of 7°C; current observations give scientists high confidence that climate change is weakening the AMOC, a critical part of Earth's climate system that transfers warm water northward and cold water southward.

Overt military action, especially by a non-Arctic state, that significantly escalates tension in the region and results in a sidelining of Arctic diplomacy *would challenge our judgment that increased activity in the Arctic, while raising the possibility of miscalculation, is unlikely to result in outright conflict because of the harsh operating environment and existing mechanisms for cooperation.* Persistent challenges to Russia's supremacy of the Northern Sea Route by a non-Arctic state's military could result in armed conflict with Russia if diplomatic negotiations had stalled and foreign militaries continued to operate in what Moscow views as its territorial waters. Alternatively, if a non-Arctic state, especially China, were to begin regular, large-scale military operations in the area to protect an economic foothold in the region, the risk of conflict with Arctic states could increase and contribute to a buildup of forces.

A successful geoengineering deployment at scale that results in global cooling without negatively disrupting weather patterns *would challenge our judgment that unilateral deployment without global consensus would raise international tensions and risk blowback.* A country fearing the existential threat from sea level rise could initiate a geoengineering program that begins to dim the planet and artificially reduces global temperatures. After witnessing the successful demonstration, other states might support increased geoengineering, both to avert the worst aspects of climate impacts and to avoid having to transition away from fossil fuels. Given the lingering environmental impact of emissions and the risk of a massive climate shock from accumulated emissions if the geoengineering program suddenly ceased, countries probably would continue to gradually decarbonize energy production and pursue CDR so they could wean off geoengineering.

Annex B: The Progress of Climate Modeling—View From the Chair of the US Interagency Group on Integrative Modeling

Scope Note: DOE's Director of Earth and Environmental Sciences Division authored this annex because he is a member of the Climate Security Advisory Council (CSAC) and chairs the Interagency Group on Integrative Modeling, which coordinates US Government modeling efforts in support of the US Global Change Research Program.

Today's computer climate models trace their origins to the 1950s and the development of prototype atmospheric circulation models to estimate the distribution of nuclear fallout after an explosion. In 1967, NOAA established a climate group that produced the first model-based simulations showing that a doubling of CO_2 could lead to significant warming of the Earth's climate. Ultimately, projections from these and other early modeling capabilities led to the formation of the Intergovernmental Panel on Climate Change (IPCC).

As of this year, more than 30 major climate-modeling centers worldwide make multi-decadal projections, each with access to a supercomputer of at least 10-petaflop capacity. The United States and Europe have the most advanced models, the most notable being NSF's National Center for Atmospheric Research, NOAA's Geophysical Fluid Dynamics Laboratory, NASA's Goddard Institute for Space Studies, DOE's national laboratory–led modeling efforts, Germany's Max Planck Institute for Meteorology, and the UK Met Office's Hadley Center. Australia, Canada, China, Japan, and Switzerland also have modeling centers.

Climate modeling is coordinated worldwide by the World Climate Research Programme (WCRP), which is sponsored by the UN World Meteorological Organization, International Council for Science, and UNESCO. WCRP helps scientists exchange information on various model capabilities and strategies. The IPCC produces a climate assessment every seven years using the 'all inclusive' approach by combining predictions from all modeling centers worldwide. The US Global Change Research Program (USGCRP), on the other hand, produces the National Climate Assessment every four years using only US models. The USGCRP coordinates efforts across the US climate modeling community to learn from each other and avoid unnecessary duplication.

Increasing Complexity and Fidelity

The evolution of climate models has been one of increasing complexity run on faster and larger computers. The first climate models examined how the Earth's energy balance and atmosphere might vary over time, and only considered atmospheric physics and rudimentary representations of the oceans and land. In time, scientists added more detail, such as ocean and land chemistry and biology.

By 1990, better computers meant models could run at 400-kilometer (km) spatial resolutions and make generalized projections showing that rising levels of atmospheric CO_2 increased regional and global temperatures. However, these models could not display extreme weather events—such as hurricane impacts on cities—because of coarse resolutions, and they did not include other complicated feedbacks caused by other greenhouse gases or changes in the biosphere, such as permafrost thaw, ice sheet melt, or deforestation.

Climate models have advanced remarkably in the past 15 years. By 2005, faster computers allowed climate models to run at 150-km resolution, enabling the representation of some details of human activities such as large-scale energy infrastructure and agriculture impacts. By 2010, the first petaflop-scale supercomputers and new scientific findings from field experiments allowed the inclusion of biogeochemical and hydrological processes. By 2015, melting of glaciers and shelving were included, allowing for better sea level rise predictions, along with greater detail on marine fisheries.

In 2018, climate models began to include the role of humans and human systems—a major step forward in assessing climate effects on human security—allowing them to examine the connections between climate, socioeconomics, global agriculture, infrastructure, and trade on targeted resolutions of 50 km or less. By 2020, US researchers were testing various methodologies to evaluate the risks and benefits of climate interventions, such as geoengineering.

Evaluating for Accuracy

Scientists are continually testing models for their accuracy in predictions. Climate models operate by solving a very large set of sophisticated equations for three-dimensional grids in the atmosphere and oceans. The land surface is more difficult because of the incredible variety of watersheds, ecosystems and glaciers, but modeling centers with the world's fastest computers are incorporating variable grid sizes for land features, like glaciers, to obtain more accurate sea level rise projections.

Scientists use a 'hindcasting' technique to test and evaluate the accuracy of models. They run the model from several decades in the past and compare its projections to real world and long-term observable data from NASA's remote sensing satellites, NOAA's ground-based monitors, and many other US and international agencies. Hindcasting has shown that models are robust in describing climate warming on continental scales, but not as accurate in projecting regional phenomena, such as the details of Arctic sea ice retreat, evolving coastal precipitation patterns, and impacts of storms on human systems. In general, there is reduced accuracy when models project more localized.

Reducing Uncertainty

Current research on reducing uncertainty out to 2050 focuses on two key areas, those caused by overly simplistic or missing representation of processes and interrelationships, and spatial grids that are not yet small enough to address key questions. The first set of uncertainties includes: (a) cloud–aerosol interactions; (b) medium-term modes of variability such as El Niño/La Niña that influence global precipitation patterns and severe droughts; (c) cryosphere changes such as permafrost thaw, sea ice coverage, and land ice melt that influence methane release and sea-level rise; and (d) extreme events that impact built infrastructures and populations. Longer-term projections are also sensitive to scenarios of future policies to reduce greenhouse gas emissions.

Scientists target the second source of uncertainty about spatial resolution by adding details to heterogeneous systems within smaller grids and porting the models to increasingly powerful computers. In general, the more powerful the computer, the higher the possible resolution. Most modeling centers are currently operating with 25-km resolution, with the exception of a DOE model that will operate at 3-km resolution by the end of this year. With the understanding of key questions from policymakers, warfighters, and the IC, science agencies steer their investments to tackle and reduce one or more of these uncertainties.

Climate scientists perform tens to hundreds of ensemble runs for each climate simulation, where each run has slight perturbations on the same initializing data or small changes in parameterizations, in order to reduce the uncertainty that comes with incorporating larger numbers of complicated and uncertain equations. A modeling center will then produce an average of all the ensemble runs and compile a best estimate of the future climate. Each modeling center has a slightly different approach in how they construct their model—such as parameterizations, grid size, and number of ensemble runs—which means the climate projections from one modeling center may differ from another center.

Future Work on Attribution and Tipping Points

Since climate change is increasing extreme weather event trends, a growing field is trying to answer the question of what fraction of an individual event can be attributed to climate change. Improvements in big data collection and processing, along with more advanced computers, most likely will advance our knowledge of attribution. In addition, scientists are working to improve models to better answer the question of when a given component of either the regional or global climate system will approach or pass a tipping point, an area of high importance given the risks associated with it—the state of science currently is still unable to adequately answer this question.

Annex C: Challenges of Projecting the Macroeconomic Impacts of Climate Change

The macroeconomic impacts of climate change out to 2040 are highly uncertain because of the divergent estimates and methodological approaches employed in a wide range of economic models, including different assumptions, baselines, time horizons, and variables. The future economic impacts of climate change will also depend in large part on the extent to which policies and actions mitigate these potential impacts, further complicating longer-term estimates of costs and benefits.

A key variable is the potential for technological breakthroughs that substantially favor varying mixes of energy production and distribution and of carbon removal and storage. In recent years, a growing number of studies have argued that pursuing mitigation and adaptation measures can also provide opportunities to spur economic growth, potentially by more than the dislocations and disruptions projected for some economic sectors, such as oil and gas.

- Other economic and many climate experts argue that existing assessments of the potential future economic risks of climate change underestimate many of these risks, possibly greatly. In particular, they argue that widely used models omit many factors that are difficult to quantify, discount future costs and benefits, and fail to consider climate thresholds, tipping points, or the dynamic impact of numerous shocks.

- Some researchers argue that the physical impacts of climate change, including the destruction of infrastructure and physical capital, disruptions in global supply chains, and more unpredictable food commodity supply cycles, could lead to more output and price variability and pose significant additional challenges in forecasting macroeconomic impacts.

As a result, we judge that state and nonstate actors will increasingly push for regulations mandating climate change–related risk disclosure in the financial system to protect against these macroeconomic impacts. The United States will have opportunities to influence regulatory frameworks and reporting standards.

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