Climate Change Risk Management

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Foreword

The American Meteorological Society's Policy Program advances science and services relating to weather, water, & climate for the benefit of all people. Our goal is to help the nation and world avoid risks & realize opportunities associated with the earth system.

We focus on three primary approaches to accomplish this goal:

- We develop capacity within the scientific community for effective and constructive engagement with the broader society.
- We inform the broader society directly about established scientific understanding and the latest high-impact research results.
- We expand the knowledge base needed to use scientific understanding for societal advancement, particularly through our studies, research, and analysis.

The study presented here examines potential policy responses to climate change. It identifies our risk management options and explores their strengths and weaknesses.

There is a great need for this study for two reasons. First, because our ongoing and increasing emissions of greenhouse gases pose substantial risks to society. Second, because large gaps remain in our consideration of potentially beneficial policy options. For a comprehensive and successful risk management strategy to emerge, we'll need to explore a much larger set of policy options.

We offer studies like this one in the belief that our policy decisions have the best chance to benefit society if we ground them in the best available knowledge and understanding. This study on climate change risk management will help round out policy discussions, in part, by identifying those areas that haven't gotten the attention that they may need.

Paul Higgins
Director, AMS Policy Program

Key Findings and Recommendations

As a public and policy issue, climate change boils down to four overarching issues: 1) climate is changing; 2) people are causing climate to change; 3) the societal consequences of climate change are highly uncertain but include the potential for serious impacts; and 4) there are numerous policy options for climate change risk management, most of which are well characterized (i.e., have known strengths and weaknesses). These four conclusions are based on comprehensive assessment of scientific understanding and each is the result of multiple independent lines of evidence.

Climate change risk management approaches generally fall into four broad categories: 1) mitigation—efforts to reduce greenhouse gas emissions; 2) adaptation—increasing society's capacity to cope with changes in climate; 3) geoengineering or climate engineering—additional, deliberate manipulation of the earth system that is intended to counteract at least some of the impacts of greenhouse gas emissions; and 4) knowledge-base expansion—efforts to learn and understand more about the climate system, which can help support proactive risk management.

By reducing emissions, mitigation reduces society's future contributions to greenhouse gas concentrations in the atmosphere. Ultimately, this can help reduce the amount that climate will change and thereby increase the potential that societal impacts will remain manageable. Approaches to reducing emissions fall into several categories. These include 1) regulation; 2) research, development, and deployment of new technologies; 3) conservation; 4) efforts to increase public awareness; 5) positive incentives to encourage choices that lower emissions; and 6) adding a price to greenhouse gas emissions, which creates incentives to reduce emissions broadly.

Adding a price to greenhouse gas emissions is a particularly noteworthy policy option because it would be expected to have a broad-reaching impact on emissions; it has received a great deal of attention from the research community; and it has been a focus of policy discussions since climate change emerged as a public issue.

Adaptation involves planning for climate impacts, building resilience to those impacts, and improving society's capacity to respond and recover. This can help reduce damages and disruptions associated with climate change. Adaptation policy can include regulation to decrease vulnerability (e.g., through land-use planning and building codes); response planning; disaster recovery; impact assessment for critical systems and resources (e.g., water, health, biological systems, agriculture, and infrastructure); observations and monitoring; and efforts to minimize compounding stresses such as traditional air pollution, habitat loss and degradation, invasive species, and nitrogen deposition.

Geoengineering refers to deliberate, often global-scale, manipulations of the climate system. Two categories of geoengineering are most prevalent within scientific and policy discussions: solar radiation management (offsetting human-caused warming due to greenhouse gas emissions by reflecting incoming sunlight back to space) and carbon removal and sequestration (extracting carbon dioxide from the air and storing it deep in the ground or ocean).

Geoengineering could potentially help lower greenhouse gas concentrations in the atmosphere, counteract the warming influence of increasing greenhouse gas concentrations, address specific climate change impacts, or offer desperation strategies in the event that abrupt, catastrophic, or otherwise unacceptable climate change impacts become evident. Geoengineering could also create new sources of risk because attempts to engineer the earth system on a large scale could lead to unintended and adverse consequences.

Research, observations, scientific assessments, and technology development can help reveal risks and opportunities associated with the climate system and support decision-making with respect to climate change risk management. Expanding the knowledge base allows policy makers to understand, select, and refine specific risk management strategies and to thereby increase the effectiveness of risk management efforts. Knowledge-base expansion can, in some cases, also reveal entirely new opportunities for protecting the climate system or reducing the risks of climate change impacts. As a result, policies to expand the knowledge base can underpin and support the proactive risk management strategies described above (mitigation, adaptation, and geoengineering).

None of the risk management options is mutually exclusive. Indeed, comprehensive climate change risk management almost certainly includes a combination of policy responses. However, policy choices necessarily integrate both objective information about the climate system and our relationship with it, and subjective value judgments such as whether we are more averse to the risks of changes in climate or the policy responses, the ways we assess issues of fairness among nations and peoples, and the consideration we give to cultural heritage or nonhuman species. This creates a complex and often contentious risk management challenge.

Introduction

As a policy topic, climate change boils down to four overarching issues: 1) climate is changing; 2) people are causing climate to change; 3) the societal consequences of climate change are highly uncertain but include the potential for serious impacts; and 4) there are numerous policy options for climate change risk management, most of which are well characterized (i.e., have known strengths and weaknesses) (Higgins 2014, from which portions of this section are adapted).

Climate is changing. The scientific conclusion that climate is changing is overwhelming because there are many separate lines of evidence that all agree and that have been verified by many different experts (Stocker et al. 2013). Think of it this way: if you feel heat, smell smoke, hear a fire alarm, and see flames then you have independent confirmation from four senses that there's a fire. The evidence is conclusive.

People are causing climate to change. This conclusion is based on multiple independent lines of scientific evidence.

The same is true for climate change. The evidence that climate is changing comes from more than a dozen independent measurements including 1) temperature increases in the air measured over land and the oceans using thermometers, 2) temperature increases in the air measured by satellites, 3) warmer ocean temperatures (i.e., greater heat content), 4) melting glaciers throughout the world (the vast majority), and 5) species shifting their ranges (i.e., where they live) and changing the timing of their key life events (e.g., migration, reproduction, and periods of activity). These, and other, independent lines of evidence demonstrate that climate is changing.

People are causing climate to change. Multiple independent lines of scientific evidence demonstrate this as well (Stocker et al. 2013). Basic math and the growing chemical signature of carbon from fossil fuels in the atmosphere demonstrate that people are causing carbon dioxide concentrations to increase. The warming influence of greenhouse gases is clear based on laboratory experiments, evidence from past changes in climate due to greenhouse gases, and the role of greenhouse gases on other planets (e.g., Venus is much hotter than Mercury despite being further from the sun).

Additional lines of evidence relate to the patterns of climate change underway. These patterns match the characteristics expected from greenhouse gases well and do not match the characteristics we would expect from the other factors that could change climate such as the sun, volcanoes, aerosols, land-use patterns, or natural variability. It is possible that these other factors could have contributed a small net-warming or net-cooling influence on the climate system recently (Stocker et al. 2013). However, this is in addition to the human contribution to climate to change and small by comparison.

Think of it like a whodunit where the list of suspects is the potential causes of climate change. Critically, each suspect has a unique fingerprint. Scientists have worked hard to identify the potential causes of climate change and the patterns of change they would produce. The changes in climate that we've witnessed over the last several decades match the fingerprint of greenhouse gases well and do not match what we would expect to see from the usual suspects: the sun, volcanoes, aerosols, land-use patterns, or natural variability. The combination of fingerprint analysis with what we know about greenhouse gases is conclusive evidence that humans are causing climate to change.

The societal consequences of climate change in the decades ahead are hard to predict…different experts who assess climate change risks often reach very different conclusions.

The societal consequences of climate change in the decades ahead are hard to predict because exactly how climate will change and how capable human society will be at absorbing climate impacts are issues characterized by deep uncertainty. This deep uncertainty will almost certainly remain for the foreseeable future.

For example, different experts who assess climate change risks often reach very different conclusions. Some experts think the consequences of climate change over the next several decades are most likely to be small—perhaps a few percent of GDP (Tol 2009). They tend to foresee some combination of stabilizing climate feedbacks, lower sensitivity of physical systems, biological resources, and social institutions to climate changes, and greater capacity for human society to deal with climate impacts. This latter capacity could result, in part, from humanity's considerable scientific and technological capabilities.

Other experts see climate change as a much more serious risk to society (Barnosky et al. 2012; Hansen et al. 2012; Rockström et al. 2009). The reasons for this include that the changes in climate expected over the next several decades are faster than anything the world has experienced since the start of human civilization (i.e., over the past 10,000 years) and will take us to climate conditions that are entirely unprecedented for human society. Furthermore, the physical characteristics of the planet, the biological resources on which society depends, and the social systems that we have developed are all heavily adapted to existing conditions because those conditions have been relatively stable for thousands of years. This increases the potential for changes in climate to be disruptive. Finally, relatively small changes in climate have, at times, had large consequences on societies locally or regionally (Diamond 2005), illustrating the potential for serious consequences of climate change.

Even in the absence of deep uncertainty over climate change's consequences—illustrated by the divergence in views among subject matter experts—climate change represents a difficult risk management challenge. Policy responses necessarily integrate both objective information about the climate system and our relationship with it and subjective value judgments, most notably whether we are more averse to the risks of changes in climate or the policy responses; the ways we assess issues of fairness among nations and peoples; and the consideration we give to cultural heritage or nonhuman species. This creates a complex and often contentious risk management challenge.

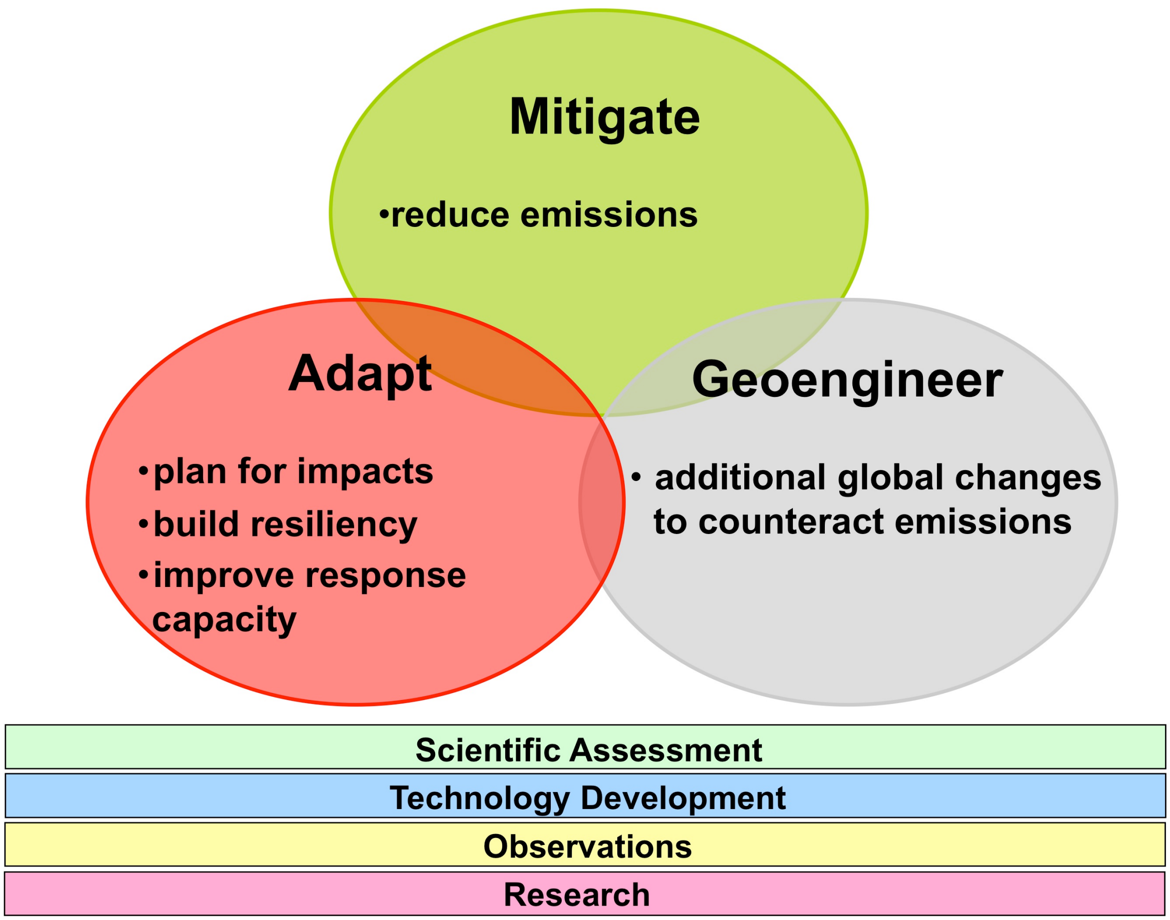

Figure 1. Climate change risk management consists of three proactive risk management strategies (mitigation, adaptation, and geoengineering) & efforts to expand the knowledge base with respect to the climate system through research, observations, technology development, and scientific assessments.

Policies relating to climate change can be thought to fall into four broad categories (Figure 1): 1) mitigation—efforts to reduce greenhouse gas emissions (for greater detail see Edenhofer et al. 2014); 2) adaptation—increasing society's capacity to cope with changes in climate (for greater detail see Field et al. 2014); 3) geoengineering or climate engineering—additional, deliberate manipulation of the earth system that is intended to counteract at least some of the impacts of greenhouse gas emissions; and 4) knowledgebase expansion—efforts to learn and understand more about the climate system, which can help support each of the three proactive risk management strategies [mitigation, adaptation, and geoengineering (Higgins 2010)].

Policy responses necessarily integrate both objective information about the climate system and subjective value judgments.

Mitigation can be viewed as being a little like disease prevention (e.g., exercise, eat well, and don't smoke). Adaptation is like managing illness (e.g., take medicine to cope with symptoms and alleviate problems). Geoengineering is a little like organ transplantation—best avoided because it is risky but it is still potentially better than the alternative even if you happen to be the first (or only) patient.

Each category of response consists of a broad family of potential options (described in greater detail below). In some cases the boundaries between the categories becomes somewhat fuzzy (e.g., efforts to reduce emissions might increase adaptive capacity in some cases and vice versa). Indeed, many experts characterize geoengineering approaches as mitigation or adaptation (Edenhofer et al. 2014; Field et al. 2014) rather than a separate category of risk management.

Of course, none of the proactive risk management options are mutually exclusive—we could simultaneously enact policies intended to mitigate, adapt, and geoengineer in a range of combinations. Indeed, comprehensive climate change risk management almost certainly includes a combination of solutions drawn from all three families of proactive risk management.

Mitigation

By reducing emissions, mitigation reduces society's future contributions to greenhouse gas concentrations in the atmosphere. Ultimately, this can help reduce the amount that climate will change and thereby increase the potential that societal impacts will remain manageable. However, climate has already changed and the planet will continue to warm due to past emissions, which makes some climate impacts unavoidable. Mitigation does little to help with these ongoing and entrained changes in climate.

Mitigation could also cause overly high energy prices, or the premature retirement of capital equipment. Similarly, some efforts to reduce emissions could lead to adverse secondary consequences. For example, policies to promote biofuel production could lead to inefficient uses of land, water, or agricultural crops. The use of biofuels could also exacerbate air pollution or contribute to the degradation of water quality.

However, mitigation might also confer benefits unrelated to climate change risk management (often called cobenefits). For example, reducing emissions of greenhouse gases would likely reduce some traditional forms of air pollution (e.g., emissions from coal-fired power plants), which would benefit public health. Similarly, mitigation would likely lead to a reduction in oil consumption. This would help reduce environmental impacts associated with oil drilling, transport, and use while lessening dependence on foreign oil, which could improve national and economic security.

Approaches to reducing emissions fall into several categories. These include 1) regulation; 2) research, development, and deployment of new technologies; 3) conservation; 4) efforts to increase public awareness; 5) positive incentives to encourage choices that lower emissions; and 6) adding a price to greenhouse gas emissions, which creates incentives to reduce emissions broadly.

Regulations often specify what activities are permitted and the manner in which they may be conducted. This can include (among others) specifying fuel efficiency standards for vehicles, determining land-use practices, establishing mandates to use specific emission control technologies, making some practices illegal, establishing renewable energy requirements (renewable portfolio standards), or enacting building codes and construction practices that help reduce energy consumption such as requiring the use of energy efficient appliances and establishing minimum required amounts of insulation.

Research, development, and deployment can help create or improve next-generation technologies, including those that might help reduce emission. Conservation of energy or biological resources (e.g., forests and wetlands) can help reduce emissions associated with energy use or deforestation. Public awareness campaigns can help ensure that people understand the implications of their choices and encourage individuals to adopt practices that reduce emissions. Similarly, positive incentives such as tax breaks or subsidies can help shape consumer preferences toward products and choices that result in lower emissions.

Adding a price to greenhouse gas emissions is a particularly noteworthy policy option because it would be expected to have a broad-reaching impact on emissions, has received a great deal of attention from the research community, and has been a focus of policy discussions since climate change emerged as a public issue. Three economic principles suggest that adding a price to greenhouse gas emissions might be a beneficial way to manage climate change risks.

The first economic principle is that having less of something (greenhouse gas emissions in this case) almost certainly requires an increase in the price of those activities that cause it. This is because a price increase for emitting activities encourages both increases in efficiency (a reduction in emissions for a given amount of the activity) and also frugality (reduced engagement in the activity) (Daly 2007). Critically, increasing the efficiency of an activity without a corresponding increase in the price makes engaging in the activity cheaper, which encourages more of the activity. As a result, efficiency gains without an increase in the price of an activity may not lead to emissions reductions.

The second economic principle is that incorporating the costs associated with climate change into the price emitters pay for their emissions (i.e., through an additional price on emissions) would be expected to increase overall economic well-being. This is because economic well-being is maximized when individual decision-makers (the entity choosing to emit in this case) pay all costs and receive all benefits associated with the activity.

Greenhouse gas emissions result, in part, from six separate market failures.

Currently, the societal consequences of climate change are distributed across the entire population, including future generations. As a result, potentially significant economic costs associated with greenhouse gas emissions (i.e., the societal costs of climate damage) are shifted away from those who choose to emit. Instead, the people who endure the consequences of climate change pay those costs. This constitutes an economically harmful subsidy that emitters receive from the broader society. Incorporating the costs of climate damage into the price paid by emitters would reduce that subsidy and therefore bring net economic benefits.

Note, however, that greenhouse gas emissions result, in part, from six separate market failures (Higgins 2010). These include 1) that the cost of climate damages associated with emissions are not included in the price paid by the emitter (i.e., a negative externality is unaccounted for, as described above); 2) split incentives, in which the narrow interests of a decision-maker are maximized when creating much higher costs for someone else (e.g., a landlord's incentive to minimize capital investment expenses even when doing so ensures that their tenants excess energy expenses will be greater than the landlord's savings on capital equipment); 3) imperfect information, in which decision-makers do not know or understand their options and the implications of their choices; 4) monopoly power, which limits consumer choices for low-emission alternatives; 5) long-lived (fixed or immobile) factors of production, which locks in less efficient technologies because the existing capital stock makes emitters less responsive to market signals; and 6) a nonexistent market for climate stability because the private sector simply cannot provide and price public goods such as a stable climate.

Adding a price to emissions addresses the first market failure (the externality) but is insufficient or ineffective at addressing the other market failures. This means that including a price on emissions that accounts for climate damages associated with emitting would likely be insufficient for fully addressing all the relevant market failures that contribute to human-caused climate change (i.e., greenhouse gas emissions).

Furthermore, we cannot quantify precisely the cost of climate damage associated with emitting greenhouse gases because the consequences of climate change are characterized by deep uncertainty, as described above. This means we cannot know the economically optimal price to add to emissions. In practice, adding a price to greenhouse gas emissions will either be too high or too low to maximize economic benefits.

Incorporating the costs associated with climate change into the price emitters pay for their emissions would be expected to increase overall economic well-being.

A price that is too high (i.e., that exceeds the cost of climate damage associated with emissions) would sacrifice some economic well-being relative to a lower price because energy prices would be too high. A price that is too low (i.e., that fails to account for the costs of climate damage) would sacrifice some economic well-being relative to a higher price because too much climate damage would occur.

This illustrates part of the risk management challenge of emission pricing. In general, aggressive mitigation could lead to overly high prices for energy and the early retiring of capital equipment whereas weak mitigation increases the chances of economic, social, and environmental harm from avoidable climate change impacts. Risk aversion to climate change implies erring on the side of a price on emissions that is more likely to be too high than too low. Whereas risk aversion to price increases for energy implies erring on a price that may result in excessive climate damage.

The third economic principle related to emissions pricing is that market mechanisms are generally the most economically efficient way to reduce emissions. This means that a price-based approach can be expected to result in the greatest amount of emissions reduction for the least cost or, equivalently, the most emissions reduction for a given cost. An important caveat to this basic conclusion is that it applies when the externality constitutes the dominant market failure because the additional market failures involved may be more responsive to non-market based approaches (e.g., regulation).

Despite these basic economic principles, adding a price on emissions may be insufficient or undesirable. As noted above, the price on emissions will necessarily be too high or too low because we cannot know what the actual damages to the climate system will be from a given amount of emissions and a price-based approach cannot address the full range of market failures.

Adding a price to greenhouse gas emissions could also have significant distributional consequences (i.e., there would be winners and losers) even while overall economic benefits would be expected to increase. Depending on the specific details of the policy design those distributional consequences could be severe, particularly for heavy emitters or low income families. Furthermore, losses are likely narrowly distributed whereas benefits are broadly distributed. This creates both legitimate questions of fairness and political challenges for climate policy (described below).

Adding a price to greenhouse gas emissions could also have significant distributional consequences (i.e., there would be winners and losers).

In addition, at least some policy options for mitigation require allocating scarce resources toward emissions reduction efforts (e.g., investing in low-emission technologies). In the event that the consequences of climate change turn out to be less significant than expected, investments in mitigation could constitute an inefficient use of limited resources. Note, however, that this does not apply to approaches that reduce market failures (i.e., adding a corrective price on emissions). Although emission pricing seems to require the use of scarce resources because energy prices may rise, it is actually reducing a hidden subsidy (i.e., emitters avoiding the costs of climate damage that they cause) as previously described. Finally, societal values other than maximizing economic efficiency also matter, perhaps more than economic efficiency, in some cases. For example fairness, the role for people in shaping the Earth's characteristics and functioning, and the acceptability of causing impacts on cultural heritage or other species are all questions outside the realm of economic efficiency.

In general, there are two market-based approaches for adding a price on emissions. Policy makers can set a limit on the amount of emissions (a cap or limit on the quantity of emissions) and allow emitters to buy and sell permits to emit. This approach (often called cap-and-trade) leaves it to the market to determine the price of emitting. Alternatively, policy makers can determine the price that emitters must pay when they emit (a fee or a corrective tax). This approach leaves it to the market to determine the quantity of emissions. Notably, these two approaches have much in common because emission prices and quantities are linked and both are market mechanisms for addressing climate change.

Hybrid approaches that combine elements of both approaches are also possible. For example, cap-and-trade can include a price ceiling (an upper limit on prices at which additional permits are always sold) or a price floor (a minimum price on emissions at which permits are always purchased). Similarly, a fee-based hybrid might include automatic increases in the price if emissions quantities exceed an upper limit (Higgins 2013).

These policy approaches must determine the initial price (or quantity) of a pricing mechanism and the rate that it changes over time (Higgins 2010, from which the remainder of this section is adapted). Higher prices (or lower quantities) translate into larger, faster emission reductions but may trigger larger price increases for energy and transportation.

Emission fees or permits can be collected at the oil well, coal mine, or point of entry for imports (upstream), closer to where the actual emissions occur (i.e., the individual vehicle or power plant—downstream), or in between (e.g., petroleum refineries). Upstream implementation helps ensure comprehensive coverage of emissions, generally reduces the administrative burden placed on regulators and emitters, and minimizes transaction costs. Notably, the point where a fee or permit is collected determines only the entity that is responsible for compliance. It does not determine who ultimately must pay the cost associated with emissions because market forces generally determine how that cost is shared between producers and consumers.

In general, there are two market-based approaches for adding a price on emissions: 1) cap-and-trade; 2) a direct fee or corrective tax on emissions.

Revenues generated from adding a price on emissions could be used in a wide range of ways. For example, revenues could be used to lower existing taxes, to invest in research and development of low-emission technologies, to assist those most heavily hit by the fee, or be returned in lump-sum payments to people, amongst other options.

How these revenues are used can reduce or exacerbate distributional consequences. For example, a tax shift—one that applies the revenue generated from a fee to lowering existing taxes—or the lump-sum return of revenues to people on an equal per capita basis would increase the progressivity of the approach. Similarly, the disproportionate impact on heavy emitters can be softened by providing a small number of permits freely (cap-and-trade) or by directing some of the revenue generated by a fee to hard-hit sectors.

Emission pricing can include offsets or credits for emissions reductions that occur elsewhere (e.g., carbon capture and sequestration, forestry projects, and international mitigation efforts) and the banking or borrowing of permits. Offsets can encourage emission reductions, and reduce the costs of achieving a given level of climate protection. However, offsets also pose challenges because seemingly legitimate reductions may not last over time. Borrowing and banking help even out potential price fluctuations in a cap-and-trade system.

Nationwide efforts in the United States to incorporate a price on greenhouse gas emissions have had limited legislative success to date. In 2009 the U.S. House of Representatives passed the American Clean Energy and Security Act—a cap-and-trade approach that sought to reduce emissions by 83 percent, relative to 2005, by 2050. However, the Senate did not pass the bill and so the bill expired at the end of the legislative session.

State and regional approaches within the United States to price greenhouse gas emissions have begun, however. For example, a collection of northeastern states (currently nine) have formed the subnational scale Regional Greenhouse Gas Initiative (RGGI)—a cap-and-trade system to reduce carbon emissions from power plants within those participating states. The initial emissions targets used by RGGI beginning in 2009 proved to be too high due to larger-than-expected emissions reductions associated with fuel switching (from coal to natural gas) and the economic recession. In 2014 the cap under RGGI was reduced to account for these developments and additional declines of 2.5 percent per year through 2020 were included.

California has also initiated a number of policies to reduce emissions. The centerpiece of these efforts is a cap-and-trade approach with a goal to reduce emissions to 1990 levels by 2020. Additional legislative efforts in California seek to increase the use of renewable energy for electric power generation (i.e., a renewable portfolio standard), to reduce vehicle emissions, and to enhance carbon sequestration in forests.

In 2007 the U.S. Supreme Court found that the 1990 Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to consider regulating carbon dioxide, the primary manmade greenhouse gas. EPA found in 2009 that greenhouse gas emissions endanger human health and well-being which requires EPA to regulate emissions without further congressional action.

In 2013, EPA proposed new standards to limit carbon emissions from new power plants. In 2014, EPA established a plan to reduce greenhouse gas emissions from existing power plants. The approach requires a roughly 30 percent reduction in carbon emissions by 2030, relative to 2005 emissions. EPA's approach was upheld by the Supreme Court when challenged.

Nevertheless, President Obama and many members of Congress have stated a preference for addressing climate change through new legislation. Indeed, some legislation under active consideration would block EPA's authority to regulate carbon dioxide under the Clean Air Act.

The Energy Independence and Security Act of 2007 raised fuel efficiency standards for vehicles. The implications of this for greenhouse gas emissions are hard to assess because increasing efficiency without increasing prices actually encourages emitting activities, as described above.

Coordinated international efforts to reduce greenhouse gas emissions date back to the 1992 United Nations Framework Convention on Climate Change (UNFCCC), which President George H. W. Bush negotiated and Congress ratified. The UNFCC requires the United States and other nations to "avoid dangerous anthropogenic interference with the climate system." This led to the Kyoto Protocol in 1997, which attempted to establish mandatory cuts for developed countries through a negotiated treaty. Contentious political issues among and within countries have limited participation and success of the Kyoto Protocol and subsequent efforts to adopt binding emission targets internationally.

In 2009 the Copenhagen Accord signaled a shift in the current international approach toward reducing greenhouse gas emissions through voluntary emission targets and actions taken by individual nations with the idea that these voluntary efforts may encourage similar efforts by other nations and thereby create a positive feedback cycle for emissions reductions.

Adaptation

Adaptation involves planning for climate impacts, building resilience to those impacts, and improving society's capacity to respond and recover. This can help reduce damages and disruptions associated with climate change. Adaptation might also help with existing threats due to current weather patterns (e.g., routine and severe weather events) or from other natural and human-induced disasters unrelated to climate change. This represents an important potential cobenefit of efforts to build adaptive capacity to climate change.

Implementing adaptation policies successfully may require detailed consideration of location-specific factors because climate change impacts will vary geographically and depend on the uneven distribution of societal resources and institutions.

Adaptation also has potential limits or downsides. It is possible that some climate impacts will be too severe to manage through adaptation. Efforts to promote adaptive capacity could also prove maladaptive (counterproductive) due to uncertainties over future climate projections and the expected impacts of climate change on physical systems, biological resources, and social institutions.

Adaptation policy can include regulation to decrease vulnerability (e.g. through land use planning and building codes); response planning; disaster recovery; impact assessment for critical systems and resources (e.g., water, health, biological systems, agriculture, and infrastructure); observations and monitoring; and efforts to minimize compounding stresses such as traditional air pollution, habitat loss and degradation, invasive species, and nitrogen deposition.

Implementing adaptation policies successfully may require detailed consideration of location-specific factors because climate change impacts will vary geographically and depend on the uneven distribution of societal resources and institutions. As a result, centralized policy responses may be somewhat more limited for adaptation than for mitigation or geoengineering.

Nevertheless, centralized regulations have potential to promote adaptive capacity by altering land-use patterns on a wide scale (e.g., floodplain development, management of coastal zones, and insurance practices) in ways that increasingly account for potential climate change impacts. Similarly, centralized approaches to disaster relief efforts, the establishment and design of wildlife reserves, and management of water and agricultural resources could all help account for vulnerabilities anticipated by climate change.

In addition, centralized adaptation policies can potentially promote decentralized efforts by creating broadly useful sources of 1) scientific information about climate change impacts and vulnerabilities; 2) information about the potential advantages and disadvantages of particular adaptation measures and the specific conditions under which different options work best; 3) support for (or incentives to) encourage local and or regional-level adaptation planning and implementation, including the provision of technical expertise and/or financial resources; and 4) monitoring and reporting on the effectiveness of adaptation efforts.

Numerous adaptation efforts are underway within the United States including efforts at state and local levels of government. Federally, the 1990 Global Change Research Act (GCRA) requires a National Assessment of climate change impacts and response options every four years. The GCRA also established the U.S. Global Change Research Program (described below). In 2013 President Obama established a Council on Climate Preparedness and Resilience, which provides interagency coordination of federal adaptation efforts, and released a Climate Action Plan, which seeks to prepare the United States for the impacts of climate change.

Geoengineering

Geoengineering refers to deliberate, often global-scale, manipulations of the climate system (AMS 2013). In general, the goal of geoengineering would be to counteract the effect of human greenhouse gas emissions or their consequences. Geoengineering could potentially help lower greenhouse gas concentrations in the atmosphere; counteract the physical impact of increasing greenhouse gas concentrations; address specific climate change impacts; or offer desperation strategies in the event that abrupt, catastrophic, or otherwise unacceptable climate change impacts become evident.

Geoengineering could also create new sources of risk because attempts to engineer the earth system on a large scale could lead to unintended and adverse consequences. Notably, the complexity of the earth system (which couples numerous physical and biological systems and processes) and society's relationship to the earth system (which involves further coupling with social institutions) makes it challenging for scientific research to fully identify and quantify the potential consequences associated with geoengineering. As a result, the potential impacts from geoengineering could inadvertently compound the dangers associated with climate change.

Even to the extent that potential consequences of geoengineering can be well characterized, those consequences would almost certainly differ among countries and individuals. This raises potentially complex legal, ethical, diplomatic, and national security concerns. Furthermore, the potential for geoengineering as a desperation strategy could distract from mitigation and adaptation efforts, which may have a higher probability of contributing positively to risk management.

Nevertheless, two categories of geoengineering are most prevalent within scientific and policy discussions: solar radiation management and carbon removal and sequestration.

Geoengineering refers to deliberate, often global-scale, manipulations of the climate system.

The goal of solar radiation management is to increase the earth's reflectivity to incoming solar energy (e.g., by injecting reflective particles into the atmosphere or increasing the brightness or distribution of certain types of cloud cover). This could, in principle, reflect incoming shortwave solar radiation by an amount that matches the increased heat trapping (i.e., longwave radiation) due to increased greenhouse gas concentrations in the atmosphere. Although shortwave and longwave radiation are likely not entirely interchangeable, this could reduce the magnitude of human disturbance of the overall energy balance of the climate system.

Solar radiation management might be a relatively fast-acting option for quickly reversing some of the warming associated with increasing greenhouse gas concentrations. However, solar radiation management represents a substantial global-scale manipulation of the earth system that would be likely to have broad reaching impacts, some of which may be difficult to predict.

The goal of carbon removal and sequestration is to capture some of the increased carbon in the atmosphere that results from human activities and store that carbon away from the atmosphere, most likely in either the ocean or below ground (i.e., geologically). This could be challenging to do at a scale that matches current and expected greenhouse gas emissions. However, the risk of adverse impacts associated with sequestration is generally considered to be lower than for solar radiation management.

Finally, other large-scale interventions might be designed to reduce specific climate impacts. For example, the massive deployment of sea walls, efforts to protect continental ice sheets through snow making or preserving activities, or the use of assisted movement for biological systems might all be conducted at a sufficiently large scale to be considered geoengineering.

Notably, geoengineering likely wouldn't address all potential impacts associated with greenhouse gas emissions. Solar radiation management, for example, will not reduce the amount of carbon dioxide in the air or the ocean and would therefore have no impact on ocean acidification or the direct effects of carbon dioxide enrichment on biological systems.

Policy options for geoengineering generally fall into five categories. We could conduct research and analysis in order to develop or vet potential options. We could study the impacts and potential unintended consequences. We could create punitive measures to discourage reckless for unilateral attempts to geoengineer. We could create policies that promote cooperation and transparency or help ensure that governance issues would be addressed. Of course, policies could also seek to implement geoengineering approaches.

Climate system research spans numerous disciplines and subdisciplines including those within atmospheric sciences, oceanography, hydrology, biology, cryology, & paleoclimate, among others.

To date, U.S. federal climate policy has rarely considered geoengineering explicitly. However, efforts to promote carbon capture and storage (CCS) and overcome the barriers to deployment of CCS are widespread. Furthermore, at least one international treaty that the United States has ratified, the Environmental Modification Convention (ENMOD), may currently prohibit at least some forms of geoengineering, particularly solar radiation management.

Expanding the Knowledge Base

Policies can also be designed to expand the knowledge base relating to the climate system or to reveal information relating to the management of risks associated with climate change.

Research, observations, scientific assessments, and technology development can help reveal risks and opportunities associated with the climate system and support decision-making with respect to climate change risk management. Expanding the knowledge base allows policy makers to understand, select and refine specific risk management strategies and thereby increase the effectiveness of risk management efforts. Knowledge-base expansion can, in some cases, also reveal entirely new opportunities for protecting the climate system or reducing the risks of climate change impacts. As a result, policies to expand the knowledge base can underpin and support the proactive risk management strategies described above (mitigation, adaptation, and geoengineering).

Climate system research spans numerous disciplines and subdisciplines including those within atmospheric sciences, oceanography, hydrology, biology, cryology, and paleoclimate, among others. Determining the societal consequences of climate variability and change depends on understanding how human systems depend on and will respond to potential impacts on physical systems, biological resources, and social institutions. That also requires information from disciplines in the social sciences, including (but not limited to) economics, sociology, history, and political science (Steinbuck and Higgins 2013).

The U.S. Global Change Research Program (USGCRP) coordinates and integrates climate research over 13 executive branch departments and agencies. The total requested budget for FY 2015 that falls within the scope of the USGCRP is $2.5 billion, which would be a $12 million (0.5 percent) increase over FY 2014. Note, however, that this does not account for inflation, which is currently about 1.7 percent per year. Therefore, USGCRP funding would decrease slightly. It is also important to note that funds counted within the USGCRP framework are allocated directly to the agencies and each agency has discretion in what it counts as being within the framework. Therefore, the number reported for USGCRP does not account for all climate-related research and year-to-year changes in USGCRP funding can reflect accounting changes rather than actual changes to agency requests.

The Political Landscape

There are several political obstacles to climate change risk management in general and to pricing greenhouse gas emissions in particular.

Climate change can be characterized as a “wicked problem” (Rayner 2006). This means climate change, as a public issue, is characterized by 1) contradictory certitudes (i.e., different people believe—as fact—different things that are actually incompatible), 2) having redistributive implications for entrenched interests, 3) being related to deeper problems (e.g., the scale of human activities relative to the earth system), 4) having relatively little room for trial-and-error learning, and 5) tending to be incompletely solvable (i.e., we must live with climate change in some sense).

As a result, policy deliberations (and public debates) about climate science are often at odds with the assessments of the relevant subject matter experts. This is because the complexity of the issue and the underlying science increases the potential for nonexperts to be unaware of expert assessments and more prone to believing rhetorical arguments that seem convincing even when those arguments do not withstand the scrutiny of the expert community. This contributes to political polarization with respect to climate change.

Policy deliberations about climate science are often at odds with the assessments of the relevant experts.

Furthermore, individuals and companies that are most likely to be hurt by emission pricing (e.g., the coal industry and coal-fired electricity generators) generally know that a price on emissions could harm them, care about a relatively small number of other issues, and tend to be politically powerful and well organized. In contrast, the benefits of emission pricing (i.e., climate protection) are broadly distributed among everyone, including future generations. Most of these beneficiaries take the climate system for granted and do not fully recognize the risk climate change poses. This means we tend to care about a wide range of issues often much more than we care about climate change. As a result, the constituency for climate protection is a relatively disorganized group that is politically weak. These differences between the winners and losers create significant political obstacles to enacting policy solutions.

To some degree, these challenges are exacerbated at the international level because both the contribution to (and risk exposure from) climate change are unequal among people. For example, many of the impacts of climate change are expected to be most severe for countries and peoples who have contributed minimally to the atmospheric stock of greenhouse gases (e.g., low-emitting small island states, which face limited options for adaptation, and developing countries, which may be highly vulnerable to climate changes and possess limited adaptive capacity). This separates the sense of urgency to respond to climate change from the capability of doing so. Of course, these differences also contribute to the complex ethical dimensions of climate policy.

The global nature of climate change also creates potential challenges for climate policy. There is a genuine need for a coordinated global effort because atmospheric greenhouse gas concentrations are well mixed (i.e., emissions anywhere in the world contribute equally to climate changes). This need for coordinated efforts makes unilateral action more difficult and potentially less effective. It also creates a powerful rhetorical political at argument against action. Why should one nation begin to reduce its emissions when another expresses no similar plan to do so?

There are potential policy solutions to these challenges. For example, unilateral action by one nation could be conditional (i.e., incorporate incentives and protections that depend on international cooperation) or include border tax adjustments to account for those who do not incorporate climate damage into prices paid by emitters (which constitutes a subsidy).

The Broader Context of Climate Policy

Climate change risk management is one aspect of climate policy, which encompasses decision-making over the broader range of topics that relate to the climate system. Climate policy includes efforts to increase understanding of weather and climate events as well as approaches to managing risks and realizing opportunities associated with current weather patterns, climate variability, and climate change (natural and human caused). Increased knowledge and understanding of the climate system results primarily from scientific observations and research. Weather and climate services help apply that knowledge and understanding for societal benefit (AMS 2012 on which portions of this section are partly based).

Weather and climate observations reveal dangers from severe weather, create a long-term record for assessing climate variability and change, and provide a rigorous basis for the development, testing, and validation of the models used for forecasts and predictions. Weather and climate observations provide information on temperature, precipitation, humidity, cloud cover, and other atmospheric conditions. Observations also record physical conditions at the Earth surface (e.g., coastal inundation, the status of water resources, timing of lake and river freezing and thawing, etc.), and biological characteristics (species ranges, and the timing of seasonal events such as bud burst, flowering, leaf drop, and migration). These observations come from surface (terrestrial, oceanic, and cryospheric), airborne, and satellite-based instruments.

Weather and climate science… expands opportunities for commerce and helps society minimize weather-and climate-related dangers.

Weather and climate science consists of basic and applied research (analysis and experiments) conducted in the laboratory, in the field, or in computer models. Research expands our knowledge and understanding of the characteristics and functioning of the climate system. The knowledge that results helps us identify and characterize risks and opportunities associated with the climate system. This can expand opportunities for commerce and help society avoid or minimize weather-and climate-related dangers. Scientific research on the climate system is conducted in academic institutions, government agencies, and the private sector (including for-profit and not-for-profit organizations).

Weather and climate services help society apply knowledge and understanding about the climate system for societal benefit. Most notably, services help improve public health and safety, expand economic opportunities, protect environmental resources, and promote national security. Weather and climate services can include weather forecasts and warnings; flood and drought prediction and monitoring; natural hazard preparedness and response; public health monitoring; disease prevention and control; assessment and management of fire risk; and decision support for water resources, agriculture, transportation, and other key economic sectors.

For example, weather and climate forecasts support agricultural decision-making such as which crops to plant and how to time operational decisions (when to plant, irrigate, fertilize, or control for pests). Weather and climate forecasts also help identify when social challenges or unrest may arise because of reduced crop yields.

Taken together, observations, science, and services relating to weather and climate support efforts to meet basic human needs such as the provision of food, shelter, energy, health and safety and help create new opportunities for social and economic advancement.

Policy choices relating to the climate system influence vulnerability and resilience to weather and climate events. This may include decisions about how much to invest in (and how best to conduct) observations, science, and services. Climate policy also includes choices relating to building codes, land-use patterns, disaster insurance requirements and subsidies, disaster preparation and response, recovery, and monitoring.

Government agencies at all levels (national, regional, and local) fund scientific research, maintain observations, provide weather and climate services, and determine the balance of research investments among disciplines and between basic and applied objectives. For example, the national meteorological and hydrological services such as the National Weather Service in the United States provide data, forecasts, and warnings. Within the private sector, both for-profit companies and humanitarian institutions provide weather and climate services. These services inform and support routine activities for people and businesses and help protect life and property from extreme weather events.

U.S. federal climate policies arise from actions of the legislative, executive, and judicial branches (in some cases with branches acting alone but usually in combination). Of particular importance are the federal budget (determined by Congress and the President), international treaties (negotiated by the President and ratified by a two-thirds vote in the Senate), and the creation, interpretation, and implementation of legislation (in which all three branches have a role). Legislative action to establish or change laws is often challenging for contentious issues like climate change because it requires simultaneous agreement of a majority of members of the House of Representatives, a super-majority in the Senate (60 of 100), and the President.

References and Further Reading

AMS, 2012: Earth Observations, Science and Services for the 21st Century. Washington, DC. [Available online at http://www.ametsoc.org/oss].

AMS, cited 2013: Geoengineering the climate system: A policy statement of the American Meteorological Society. [Available online at https://www.ametsoc.org/policy/2013geoengineeringclimate_amsstatement.pdf.]

Barnosky, A. D., and Coauthors, 2012: Approaching a state shift in Earth's biosphere. *Nature,* **486,** 52–58, doi:10.1038/nature11018.

Daly, H. E., 2007: *Ecological Economics and Sustainable Development: Selected Essays of Herman Daly*. Edward Elgar, 270 pp.

Diamond, J., 2005: *Collapse: How Societies Choose to Fail or Succeed*. Viking Books, 575 pp.

Edenhofer, O., and Coauthors, 2014: *Climate Change 2014: Mitigation of Climate Change*. Cambridge University Press, in press.

Field, C. B., and Coauthors, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, in press.

Hansen, J., M. Sato, and R. Ruedy, 2012: Perception of climate change. *Proc. Natl. Acad. Sci. USA,* **109,** E2415–E2423, doi:10.1073/pnas.1205276109.

Higgins, P. A. T., 2010: Design principles and remaining needs for U.S. federal climate policy: Emission fees. *Bull. Amer. Meteor. Soc.,* **91,** 601–609, doi: 10.1175/2009BAMS2885.1

Higgins, P. A. T., 2013: Frameworks for pricing greenhouse gas emissions and the policy objectives they promote. *Energy Policy,* **62,** 1301–1308, doi:10.1016/j.enpol.2013.07.041.

Higgins, P. A. T., 2014: Climate change as a public and policy issue. *Bull. Amer. Meteor. Soc.,* **95,** 780–781.

Rayner, S., 2006: Wicked problems: Clumsy solutions—Diagnoses and prescriptions for environmental ills. Jack Beale Memorial Lecture on Global Environment, James Martin Institute for Science and Civilization, 12 pp. [Available online at http://www.insis.ox.ac.uk/fileadmin/InSIS/Publications/Rayner_-_jackbealelecture.pdf.]

Rockström, J., and Coauthors, 2009: Planetary boundaries: A safe operating space for humanity. *Nature,* **461,** 472–475.

Steinbuck, J. V., and P. A. T. Higgins, 2013: Climate in the FY 2014 budget. Research and Development FY 2014, AAAS Rep. XXXVIII, American Association for the Advancement of Science, 195–201.

Stocker, T. F., and Coauthors, 2013: *Climate Change 2013: The Physical Science Basis*. Cambridge University Press, 1535 pp. [Available online at www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf.]

Tol, R. S. J., 2009: The economic effects of climate change. *J. Econ. Perspect.,* **23,** 29–51, doi:10.1257/jep.23.2.29.