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Assessing the Benefits of Avoided Climate Change: Cost-Benefit Analysis and Beyond

Federal Decision-Making on the Uncertain Impacts of Climate Change: Incremental vs. Non-Incremental Climate Decisions

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Federal Decision-Making on the Uncertain Impacts of Climate Change: Incremental vs. Non-Incremental Climate Decisions

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Abstract

From judicial, to executive, to legislative decisions, all three branches of the U.S. federal government have developed a more urgent need for information on the potential impacts of climate change. The information requirements vary dramatically across the broad range of legal, energy, climate, and other decisions. This paper begins with a review of recent federal decision processes that have drawn on climate change impacts information. The paper then defines the impacts information requirements of these decisions by characterizing the types of decisions and the physical and economic nature of greenhouse gases and climate change. Throughout the paper, a clear distinction is drawn between policies with incremental effects on climate and those designed to manage climate. The paper goes on to describe the state of impacts knowledge in light of the information requirements of incremental and non-incremental decisions and discusses decision-making challenges associated with using the available information. The paper concludes by deriving fundamental principles and components of an analytical framework for developing and utilizing climate change impacts information in federal decision-making, and identifies critical information gaps that should be addressed.

[1] Steven Rose was asked to write this paper while still at the U.S. Environmental Protection Agency (EPA). However, this paper does not reflect the views of EPA or EPRI and its members.

1. Introduction

Over the past three years, the United States government has developed a more urgent interest and need for information on observed and potential impacts of climate change. All three branches of the federal government—judicial, executive, and legislative—have confronted decisions that engendered an additional appetite for impacts information. The types of decisions covered a varied and broad range of issues, including domestic legal, energy, climate, and species protection, as well as the international negotiations process. While each decision called for information on impacts, the type and threshold of information required differed. This paper decomposes and defines the climate change impacts information needs of federal decision-making, and discusses the challenges associated with the information currently available for decisions that can have either minor or significant climate implications. The paper draws a clear distinction between policies with incremental climate effects and those with larger impacts that are designed to manage climate change. The paper assesses the research literature in light of these two types of decisions. The paper then derives a fundamental analytical framework for developing and utilizing climate change impacts information in federal decision-making.

Recognizing and defining information requirements is valuable for designing analyses, assembling the necessary data, and identifying information gaps. The impacts information required can be thought of as being determined by two factors: the type of decision being made and the scientific and economic nature of the problem. This paper characterizes these factors. Understanding the state of the art is also essential for making actual climate related decisions. Recognizing the state of current information, as well as what additional information will likely be available in the future, is fundamental to characterizing the information challenges to climate change decision-making and the types of decisions that are supported. It is also valuable for defining research priorities.

Section 2 of this paper provides with an overview of recent federal decision processes that have utilized some form of climate change impacts information. Section 3 characterizes the types of decisions at issue as well as the scientific and economic nature of greenhouse gas (GHG) emissions and climate change, which has implications for the scope and approach of analysis, including cost-benefit analysis, net benefit assessments, and discounting. The result is a topography of impacts analyses and information requirements. Section 4 considers the state of relevant climate change knowledge and decision-making challenges in the context of important decision-making issues. Section 5 derives the principles and components of an analytical framework for assessing impacts, and it identifies several information development priorities. The paper should be considered an analytical complement to the recent National Research Council publication that recommends organizational processes for developing, disseminating, and facilitating the use of climate change vulnerability and response information (NRC, 2009).

2. Recent federal decision processes

Over the past three years, all three branches of the federal government have confronted decisions that required climate impacts information. The decisions covered a varied and broad range of issues, including domestic legal, energy, climate, and species protection, as well as the international negotiations process. This section briefly describes these various decision types.

Legal decisions. Over the past three years, federal courts were confronted with two notable cases where climate change impacts were critical issues.

- *U.S. Supreme Court (2007)*. The U.S. Supreme Court ruled on whether the U.S. Environmental Protection Agency (EPA) had the authority under the Clean Air Act and obligation to make a determination on whether GHG emissions from the U.S. transportation sector "cause or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare."[2] The court ruled that EPA did have both the authority and the responsibility. In 2009, EPA issued a proposed endangerment finding for public comment and subsequently finalized the finding at the end of year (see the Clean Air Act discussion below).
- *U.S. 9th Circuit Court (2007).* The U.S. 9th Circuit Court ruled on whether the U.S. National Highway Transportation and Safety Administration (NHTSA) was arbitrary and capricious in implying a zero value for the benefits of reduced GHG emissions in setting new Corporate Average Fuel Economy (CAFE) standards for light trucks for model years 2008-2011. The court ruled that NHTSA could not assume a zero dollar value and needed to develop an estimate.[3]

Energy policy. A variety of energy policies were caught in the wake of the 9th Circuit Court's decision referenced above, and agencies were confronted with the challenge of having to consider the monetary value of changes in GHG emissions associated with their proposed rules.

- *CAFE standards (2008-2009)*. Following the 9th Circuit's decision, NHTSA issued a proposed rulemaking for CAFE standards for passenger vehicles and light trucks for model years 2011-2015 based on, among things, NHTSA's own estimates for the domestic marginal benefit of reducing GHG emissions.[4] NHTSA received comments on the estimates, as well as the proposed rule in general, and issued a Final Environmental Impact Statement associated with the rule. However, the final rule

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[2] Massachusetts v. EPA, 127 S. Ct. 1438 (2007).

[3] Center for Biological Diversity vs. National Highway Traffic Safety Administration, United States Court of Appeals for the Ninth Circuit, No. 06-71891, November 15, 2007.

[4] NHTSA's proposed standard was based on a value of \$7/tCO_2 in 2011 (2006\$), about \$6/tCO_2 in 2007 given NHTSA's assumed growth rate of 2.4 percent/yr. NHTSA also performed sensitivity analyses with a range of \$0 to \$14/tCO_2 (approximately \$0 to \$13/tCO_2 in 2007). *DOT (NHTSA) Average Fuel Economy Standards, Passenger Cars and Light Trucks, MY 2011-2015,* http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.43ac99aefa80569eea57529cdba046a0/.

was not issued before the end of 2008 and was passed to the Obama administration, which placed a hold on all pending regulations. NHTSA has since issued a final rule for only model year 2011 vehicles that includes revised marginal benefit estimates and a declaration to work with other agencies to develop future estimates. NHTSA found the revised estimates to be inconsequential in setting the standard.[5]

- *Improved appliance efficiency (2008-2009)*. The U.S. Department of Energy (DOE) recently finalized energy conservation standards for residential gas kitchen ranges and ovens that were initially proposed under the Bush administration. In separate rulemakings, DOE issued new energy conservation standards for commercial air conditioning equipment in 2008, beverage machines in 2009, and small electric motors in 2010. All four sets of standards are based on specific monetary estimates of the marginal benefit of reduced GHG emissions, though not the same estimates.[6] The small motors final rule is the first to use newly derived marginal benefits estimates from a 2010 interagency analytical guidance document.[7]
- *Twenty-in-Ten (2007)*. President Bush issued an executive order to reduce U.S. transportation gasoline use by twenty percent by 2010 through a combination of alternative fuels and improved vehicle efficiency.[8] However, the order was

[5] Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Year 2011 (http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.43ac99aefa80569eea57529cdba046a0/). The revised marginal benefit estimates were $2, $33, and $80/tCO$_2$ for a change in emissions in 2007 (and in 2007 dollars) and rising at 2.4 percent/year. When the $33 and $80 values, which are characterized as global values, were considered, other estimated benefits associated with the policy (i.e., the value of reduced domestic dependence on energy imports) were reduced to zero based on an argument that they were inconsistent with using global values for GHG valuation.

[6] For the gas range and oven and air conditioning equipment standards, DOE used values of $0 and $20/tCO$_2$ in 2007 (2007$) with an assumed growth rate of 2.4%/yr. The proposed gas range and oven rulemaking characterized these estimates as domestic marginal benefit estimates. For the beverage machine standards, DOE used a value of $20/tCO$_2$ in 2007 (2007$) with an assumed growth of 3.0%/yr. DOE also carried out sensitivity runs using values of $5, $10, $34, and $56/tCO$_2$. Gas ranges and ovens standard: Department of Energy, 10 CFR Parts 430, Energy Conservation Program: Energy Conservation Standards for Certain Consumer Products (Dishwashers, Dehumidifiers, Electric and Gas Kitchen Ranges and Ovens, and Microwave Ovens) and for Certain Commercial and Industrial Equipment (Commercial Clothes Washers), Final Rule, *Federal Register*, Vol. 74, No. 66, April 8, 2008, pp. 16040-16096. Air conditioning equipment standard: Department of Energy, 10 CFR Part 431, Energy Conservation Program for Commercial and Industrial Equipment: Packaged Terminal Air Conditioner and Packaged Terminal Heat Pump Energy Conservation Standards: Final Rule, *Federal Register*, October 7, 2008, pp. 58813-58814. Beverage machine standard: Department of Energy, 10 CFR Part 431 Energy Conservation Program: Energy Conservation Standards for Refrigerated Bottled or Canned Beverage Vending Machines; Final Rule. Federal Register, Vol. 74, No. 167, August 31, 2009, pp. 44914-44968. Small electric motors standard: Department of Energy, 10 CFR Part 431, Energy Conservation Program: Energy Conservation Standards for Small Electric Motors; Final Rule, *Federal Register*, March 9, 2010, pp. 10874-10948.

[7] U.S. Government Interagency Working Group on Social Cost of Carbon (2010). Issued with DOE small motors rule March 9, 2010. Four global marginal benefits estimates are provided for emissions changes in 2010 that rise over time: $4.7, $21.4, $35.1, and $64.9/tCO2 (in 2007$), where the $21.4 is regarded as the “central” value and was used in the small motors rule standard.

[8] Executive Order 13432: http://georgewbush-whitehouse.archives.gov/news/releases/2007/05/20070514-2.html.

overtaken by the Energy Independence and Security Act of 2007 (EISA), which included a renewable fuels provision (discussed next).[9]

- *Renewable Fuels Standard (RFS) (2009)*. EISA included, among other things, a mandate for 36 billion gallons of renewable fuels by 2022. The proposed rule was issued May 2009 under the new administration.[10] The rule has a requirement to consider GHG emissions changes, setting minimum lifecycle emissions reduction levels for each renewable fuel type. The proposed rule also uses estimates for the marginal benefit of GHG emissions reductions published by EPA in 2008.[11] The methods and estimates differ significantly from those in NHTSA and DOE rulemakings at that time. Section IV of this paper discusses these EPA estimates. The final rule was issued early in 2010 and included the marginal benefits estimates used in DOE's 2009 beverage machines rule.[12]

Climate policy. Climate change impacts information has only indirectly entered into the discussions of alternative legislative and regulatory proposals for regulating GHG emissions. However, quantified information has seeped into the federal climate policy dialogue surrounding the potential regulation of GHGs under the Clean Air Act.

- *Legislative proposals for GHG mitigation (2008-2009)*. A variety of Congressional proposals for mandated reductions in GHG emissions have been offered, including economy-wide cap-and-trade bills, sector specific emissions control bills, and multi-pollutant bills. For example, leading cap-and-trade proposals were offered in the Senate by Senators Lieberman, Warner, and Boxer and, more recently, by Senators Kerry and Boxer and, in the House of Representatives, by Representatives Waxman and Markey.[13] The proposals focus on GHG emissions reductions, not specifically on climate change impacts.

- *Clean Air Act (2008-2009)*. EPA published an Advanced Notice of Proposed Rulemaking (ANPR) in 2008 discussing the mechanisms and issues associated with potential regulation of GHG emissions under the Clean Air Act.[14] The ANPR also discussed issues associated with estimating the benefits of GHG emissions

[9] Public Law 110-140.

[10] Environmental Protection Agency, *Federal Register*, 40 CFR Part 80, Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program; Proposed Rule. Vol. 74, No. 99, May 26, 2009, pp. 24904-25143.

[11] U.S. EPA (2008). Also, Section 5.3 of the renewable fuels Draft Regulatory Impact Analysis presents and discusses the EPA marginal benefit estimates and calculates total benefits for emissions reductions associated with the proposed rule (http://www.epa.gov/otaq/renewablefuels/index.htm).

[12] Environmental Protection Agency, 40 CFR Part 80, Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program, Final Rule. Submitted for publication in the Federal Register February 3, 2010. Docket ID No. EPA-HQ-OAR-2005-0161.

[13] S. 3036: Lieberman-Warner Climate Security Act of 2008, as amended by Boxer. S. 1733: Kerry-Boxer Clean Energy Jobs and American Power Act of 2009. H.R. 2454: Waxman-Markey American Clean Energy and Security Act of 2009.

[14] U.S. Environmental Protection Agency, Advanced Notice of Proposed Rulemaking (ANPR): Regulating Greenhouse Gas Emissions under the Clean Air Act, http://www.epa.gov/climatechange/anpr.html.

reductions and applying the estimates.[15] As mentioned above, EPA has since issued a proposed and final endangerment finding for GHG emissions under the CAA. Specifically, the EPA administrator found that concentrations of GHGs in the atmosphere threaten the public health and welfare of current and future generations. The administrator also found that GHG emissions from new motor vehicles and engines contribute to the GHG pollution which threatens public health and welfare. The finding included supporting technical material on GHG emissions, climate change, and impacts.[16] The endangerment finding is a prerequisite for regulating GHG standards under the CAA if not preempted by separate climate legislation. In 2009, EPA issued a related proposed rule jointly with NHTSA to regulate light-duty vehicle GHG emissions under the CAA, where the GHG emissions standard translates into CAFE standards for MY 2012-2016 passenger vehicles and light duty trucks. [17]

- *California Greenhouse-Gas Waiver Request (2008-2009)*. The California Air Resources Board requested a waiver of pre-emption under the Clean Air Act for regulating GHG emissions of certain new motor vehicles beginning with model year 2009. The waiver would have allowed California to issue its own GHG emissions regulations for vehicles. In 2008, EPA subsequently denied the waiver stating that California did not have "compelling and extraordinary conditions" required for issuing its own GHG standard. In a letter prior to the official notice, EPA noted that the climate change "challenge is not exclusive or unique to California and differs in a basic way from the previous local and regional air pollution problems addressed in prior waivers [given to California]." However, under the new administration, EPA reconsidered its previous decision and granted California the waiver on June 30, 2009.[18] Prior to granting the waiver, a number of other states had announced plans to adopt the California vehicle GHG standard; however, the Obama administration had also announced plans for a national GHG standard for light duty vehicles through 2016 that were consistent with the California standard.[19] As noted in the

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[15] See Section III.G of EPA's ANPR, as well as the Technical Support Document on Benefits of Reducing GHG Emissions, U.S. Environmental Protection Agency, June 12, 2008, www.regulations.gov (U.S. EPA, 2008).
[16] Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act, signed December 7, 2009, published December 15, 2009, effective January 14, 2010. Federal Register (Docket ID No. EPA-HQ-OAR-2009-0171, www.regulations.gov). U.S. Environmental Protection Agency, Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act, signed April 17, 2009, published April 24, 2009 in the Federal Register (Docket ID No. EPA-HQ-OAR-2009-0171, www.regulations.gov). The finding and Technical Support Document are also available at http://epa.gov/climatechange/endangerment.html.
[17] The proposed rule used the same marginal benefit value used in the final DOE beverage machine standard discussed above, as well as the same range of values for sensitivity analysis. Environmental Protection Agency, 40 CFR Parts 86 and 600, Department of Transportation National Highway Traffic Safety Administration, 49 CFR Parts 531, 533, 537, Proposed Rulemaking To Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Proposed Rule, Federal Register, Vol. 74, No. 186, September 28, 2009, pp. 49454-49789. Also see http://www.epa.gov/oms/climate/regulations.htm.
[18] http://www.epa.gov/OMS/ca-waiver.htm.
[19] http://www.epa.gov/OMS/climate/regulations/420f09028.htm.

CAA discussion above, a proposed rule for the national vehicles emissions standard was issued and received public comment.

Other domestic policies. Climate change impacts information was also considered in other domestic policy decisions.

- *Listing of threatened or endangered species (2008)*. The U.S. Department of Interior issued an interim rule in May of 2008 that listed the polar bear as a threatened species under the Endangered Species Act (ESA) due to the observed and expected continued loss of sea ice habitat.[20] The department later issued a special rule under ESA revising the earlier listing rule such that "any incidental take of polar bears that results from activities that occur outside of the current range of the species is not a prohibited act under the ESA." In a corresponding press release, the department clarified that statement with the following more extensive statement: "Based on the extensive analysis associated with the polar bear listing rule it has been determined that activities and federal actions outside Alaska do not currently show a causal connection impacting individual polar bears. Therefore, no consultation is warranted at this time for any such activities and actions. This provision ensures that the ESA is not used inappropriately to regulate GHG emissions."[21]
- *Consideration in new and existing facility approval (2008-2009)*. In the last days of President Bush's administration, EPA issued an interpretive memo that GHG emissions cannot be considered by federal officials reviewing permit requests for new power plants because GHG emissions are still not regulated under the CAA.[22] President Obama's administration granted a petition and decided to reconsider this position.[23] In September 2009, EPA released a proposed rule under the CAA for comment that proposes GHG thresholds for new and existing industrial facilities above which permits are required that demonstrate use of the best available control technologies and energy efficiency measures to minimize GHG emissions.[24]

International negotiations. The United Nations Framework Convention on Climate Change (UNFCCC) states as its ultimate objective the stabilization of atmospheric GHG concentrations at a level that would prevent dangerous interference with the climate

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[20] http://www.doi.gov/issues/polar_bears.html

[21] "New Rule Unifies Domestic and International Conservation Laws to Manage Polar Bear," U.S. Fish and Wildlife Service, News Release, December 11, 2008, http://www.fws.gov/news/newsreleases/showNews.cfm?newsId=27A58FDE-922A-2B50-ED394D030EE543BD, accessed 1-8-09.

[22] Stephen L. Johnson memo, December 18, 2008, http://www.epa.gov/nsr/documents/psd_interpretive_memo_12.18.08.pdf.

[23] Lisa P. Jackson letter to the Sierra Club, February 17, 2009, http://www.epa.gov/air/nsr/guidance.html. In related activity, EPA's Region 9 office recently requested remand of the Prevention of Significant Deterioration (PSD) permit issued under the previous administration for a new 1500 MW New Mexico coal-fired power plant to allow for reconsideration (Desert Rock Energy Facility Motion for Voluntary Remand, April 27, 2009, http://www.epa.gov/region/air/permit/desert-rock/).

[24] Environmental Protection Agency, Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule, September 30, 2009, http://www.epa.gov/NSR/actions.html#sep09.

system. Deciding what this level should be, and when and how it should be achieved, requires scientific knowledge about projected impacts associated with different GHG concentration pathways, as well as judgment and policy decisions regarding costs to achieve different targets and risk tolerance. There is currently no scientific or global policy consensus on the stabilization level that satisfies this objective. However, a recent statement joint statement from delegates at the UNFCCC's 15th Conference of Parties in Copenhagen, Denmark suggests greater coalescing:

> *"We agree that deep cuts in global emissions are required according to science, and as documented by the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius, and take action to meet this objective consistent with science and on the basis of equity. We should cooperate in achieving the peaking of global and national emissions as soon as possible…and that a low-emission development strategy is indispensable to sustainable development."*[25]

The Kyoto Protocol to the UNFCCC was negotiated with only a general sense of how its interim targets were steps towards the UNFCCC stabilization objective. Current international negotiations regarding the appropriate global magnitude and timing of emissions reductions are driven by both perceived potential impacts and the expected costs of reductions. For instance, in 2007, the European Commission issued a communiqué stating that "[b]y 2050 global emissions must be reduced by up to 50 percent compared to 1990, implying reductions in developed countries of 60-80 percent by 2050…," with developing countries also needing to significantly reduce emissions by an unspecified amount. The Commission's objective was "…to limit global average temperature increase to less than 2°C compared to pre-industrial levels…, [which would] limit the impacts of climate change and the likelihood of massive and irreversible disruptions of the global ecosystem."[26] In July 2009, the G-8 countries, including the U.S., appear to have endorsed this objective.[27] Of course, both the cumulative potential impacts and their distribution are relevant information for the negotiations, as are the total level of emissions, the distribution of emissions, and the cost of reductions, as is the total and distribution of emissions and costs.

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[25] Copenhagen Accord (http://unfccc.int/meetings/cop_15/items/5257.php).

[26] Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions – "Limiting global climate change to 2 degrees Celsius - The way ahead for 2020 and beyond," January 10, 2007, http://ec.europa.eu/environment/climat/future_action.htm (accessed January 21, 2009).

[27] White House Press Release, July, 9, 2009, Meeting the International Clean Energy and Climate Change Challenges, http://www.whitehouse.gov/the_press_office/Fact-Sheet-Meeting-the-International-Clean-Energy-and-Climate-Change-Challenges/. Some specifics are absent in the press release, such as the base years for determining emissions reductions and the maximum level of acceptable climate change.

3. Information and impacts analyses requirements

What impacts information is needed to support the types of decisions described in the previous section? In answering this question it is helpful to work through two steps. First, it is useful to characterize the problem statements (i.e., the objectives of the decisions) and how impacts information is used. A different level and type of information is needed in each case, and the application of the information varies. The second step is to think about the scientific nature of the problem being evaluated and the relevant economic principles that follow. The results from the two steps define the scope of the information needed and the analyses required.

Types of decisions

Each of the various decisions in Section 2 can be characterized as having one of the following objectives: determining if a threat exists, setting a technological standard, mandating a pathway for emissions, or evaluating a predefined policy (Table 1). Each is discussed below.

- *Determining if there is a threat.* In this case, the objective is to determine if there is a threat significant enough to merit further action. This category can be further refined into (i) *determining if there is a potential threat* and (ii) *determining if there is a threat that justifies regulation*. The Supreme Court decision falls into the former, while the actual finding on endangerment, which is in EPA's hands and would trigger a regulatory process under the Clean Air Act, falls into the latter. The California waiver request, DOI's listing of the polar bear, and EPA's consideration of GHGs in new facility approval also fall into the latter category. Impacts information is used to determine if additional action should be considered.[28] These types of decisions primarily require biophysical information on potential climate change and ecosystem and anthropogenic impacts, but do not call for precision in the information like some of the other types of decisions. For example, demonstrating the crossing of a quantitative threshold or specifying a monetized effect is not required. Furthermore, point estimates (versus distributions or ranges) can be sufficient for judging if further consideration is merited.
- *Setting a technological standard.* The objective is to mandate a standard for technology, and specific impacts data is used in defining the level. The NHTSA and DOE decisions described in Section 2 for setting minimum vehicle and appliance efficiency requirements are examples. In this setting, monetized impacts information is part of the calculus of determining the specific level of the standard. Specifically, monetary estimates for the resulting changes in impacts are used in a cost-benefit analysis to identify a regulatory option that either maximizes net monetary benefits by equating

[28] If EPA decides to consider GHG emissions in the approval of new facilities, the agency will be confronted by a new decision: how to include consideration. This decision is similar to the decision of setting a technological standard that is discussed further below.

marginal benefits to marginal costs, or evaluates alternatives based on the ratio of benefits to costs.

Table 1. Decision types and characteristics of impacts information requirements.

		Types of impacts information						
Type of decision	**Decision process**	**Qualitative/ quantitative**	**Nonmonetary/ monetary**	**Observed/ projected**	**Domestic/ Global**	**Incremental/ non-incremental**	**Point/ distribution**	**Information requirements**
Determining if there is a potential threat	U.S. Supreme Court ruling	Primarily qualitative relationships	Primarily nonmonetary information	Primarily observed impacts	Domestic	Non-incremental	Distribution	Lowest
	U.S. 9th Circuit Court ruling				Ambiguous	Incremental		
	New facility approval*				Ambiguous	Incremental		
Determining if there is a threat that justifies regulation	EPA endangerment ruling	increasingly quantitative ↓	increasingly monetary ↓	increasingly future looking ↓	Domestic	Non-incremental		↓
	California GHG waiver request				Domestic	Non-incremental		
	Threatened species listing of the polar bear				Global**	Non-incremental		
Evaluating a predefined policy	Twenty-in-Ten				Global**	Incremental		
	Renewable Fuels Standard				Global**	Incremental		
Mandating a pathway for emissions	Clean Air Act				Global**	Ambiguous		
	Legislative proposals				Global**	Non-incremental		
	International negotiations				Global**	Non-incremental		
Setting a technological standard	CAFE standards	Quantitative relationships	Monetary information	Projected impacts	Global**	Incremental	Point	Highest
	Appliance efficiency standards				Global**	Incremental		

** This refers to EPA's deliberations on whether to consider GHG emissions in the approval of new facilities. With its proposed rule on GHGs and industrial source permitting, the agency is confronting a new decision—how to consider emissions. This decision is similar to the decision of setting a technological standard.*
*** Global information for welfare maximizing decision-making, but domestic information is informative.*

- *Mandating a pathway for emissions.* The objective in this case is to define a permissible GHG emissions pathway through time. Impacts information would be useful to evaluate the implications of alternative pathways. Legislative proposals, the Clean Air Act, and international negotiations have this objective. Under the Clean Air Act traditionally, science based health and ecosystem end points have defined the permissible criteria pollutant emissions levels, such as mortality and morbidity rates, irrespective of costs. However, GHG emissions control proposals to date have not been defined by specific end points. This is not surprising given the degree of uncertainty associated with particular impacts. However, prescribing an emissions pathway implicitly defines some level of acceptable risk of climate change impacts. Each individual emissions pathway generates a probability distribution over specific outcomes. The choice of a specific emissions pathway implies a selection of the corresponding level of risk. This type of decision therefore requires risk information, i.e., characterizations of the range of potential impacts and ideally both the magnitude and probability of impacts. The information could be both quantitative and more qualitative where the sign alone (i.e., direction of change) can be useful information.
- *Evaluating a predefined policy.* In this case, a standard is mandated by Congress or the president and impacts information is used simply for evaluating the climate change benefits of the chosen policy. The Renewable Fuels Standard and 20-in-10 policy are examples of this type of process. Of course, impacts information of some type may have been considered in developing the mandate, which is akin to mandating a pathway for emissions as described above.

The following categories of impacts information that could be needed by each type of decision: qualitative and quantitative, non-monetary and monetary, observed (i.e. historical) and projected, domestic and global, incremental and non-incremental, and point estimates and distributions (or simply ranges) of estimates (Table 1).[29] Not all decisions require every type of information. For instance, the Supreme Court decision can rely more on observed non-monetary information, in particular quantified biophysical impacts and more qualitative information (e.g., the direction of change), while non-climate policies with incremental emissions implications (relative to global emissions), such as the RFS, need not be as concerned about changes in the likelihood of catastrophic impacts (such as a slowing of the Atlantic thermohaline circulation). The table also lists the decisions by objective type in an order representative of increasing demand for information precision. For instance, standard setting has a much higher information requirement bar than threat determination. Global versus domestic and incremental versus non-incremental impacts

[29] Non-monetary impacts are defined here to include quantified biophysical, social and cultural impacts, where biophysical is broadly defined to include all physical effects (e.g., atmospheric, oceanic, hydrologic, weather, ecosystem, and human health). Monetary impacts include monetary estimates of market and non-market effects, where the former includes things like production and infrastructure values, and the latter includes willingness to pay estimates for outdoor recreation, environmental services, species effects, and natural amenities.

information requirements are discussed below with respect to the nature of GHGs and the state of the art respectively.

The physical and economic nature of greenhouse gases and climate change

Understanding the physical nature of the environmental issue is essential for two reasons: properly characterizing and addressing the social problem, and identifying the appropriate information needed for decision-making. Environmental concerns in general are issues of externalities and public goods, where the actions of individuals or entities do not take into account the full societal costs and benefits of their actions, leaving others involuntarily affected. This section discusses the scientific nature of GHGs and the economic principles relevant to climate change policies that follow.

Physical nature of GHGs and climate change. GHG emissions are different from traditionally regulated emissions, such as those regulated under the Clean Air Act, in several important ways. First, GHGs have global implications. Unlike criteria air pollutants, GHGs are chemically stable and therefore mix well in the atmosphere such that they can affect climate globally (IPCC WGI, 2007). Where criteria pollutants tend to have health and environmental impacts close to their emission sources, each unit of GHG emissions, regardless of the location of its source in the world, affects regional climates throughout the world; and therefore, impacts regional biophysical systems. Working Group II of the IPCC notes that "[o]bservational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases" (IPCC WGII, 2007).

Second, because of their long atmospheric lifetimes and inertia in the climate system, GHGs have very long-run implications, such that emissions today accumulate in the atmosphere, combining with past and future emissions, and thereby affecting future climate for decades to centuries or longer. This also means that there is already a degree of commitment to future climate change given past and current GHG emissions, and likewise a delay in the climate and impacts response to GHG reductions.

Third, projected changes in climate could result in or contribute to impacts that exceed thresholds in the dynamics of geophysical and biophysical systems and are irreversible on the timescale of centuries or longer. For example, "[s]ome large-scale climate events have the potential to cause very large impacts, especially after the 21st century," including "[v]ery large sea-level rises that would result from widespread deglaciation of Greenland and West Antarctic ice sheets [and] imply major changes in coastlines and ecosystems, and inundation of low-lying areas, with greatest effects in river deltas" (IPCC WGII, 2007). The resilience of many ecosystems is also likely to be exceeded this century by "…an unprecedented combination of climate change, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification), and other global change drivers (e.g., land use change, pollution, over-exploitation of resources)" (IPCC WGII, 2007). While scientists are still uncertain about the probability of any given threshold event occurring in a particular year, the significant nature of such events still provides cause for concern among many researchers and policymakers regarding the potential effects of climate change.

Fourth, given physical inertia in the climate system, as well as inertia in the economic system, substantially altering climate from projected business-as-usual conditions will require large GHG emissions mitigation beyond the mitigation opportunities within any one country (IPCC WGIII, 2007).

Finally, the impacts of climate change are inherently uncertain. Uncertainties exist all along the casual chain—from global socioeconomic projections, to emissions, to climate and atmospheric responses, to biophysical responses, to impacts and adaptation reactions, and in the feedbacks back to the socioeconomic system.

Economic principles. A number of fundamental economic principles follow directly from the scientific qualities of GHGs and climate change. As is the case with other pollutants, anthropogenic climate change results from a market failure: emitters of GHG emissions fail to take into account the impacts of these emissions on others. When unaccounted for, these impacts are referred to as externalities. However, GHG emissions are different from most air pollutants. Because GHGs mix well in the atmosphere, they are a global pollutant, and because GHGs are long-lived in the atmosphere, they are a stock pollutant (i.e., they accumulate in the atmosphere and increase atmospheric concentrations). As a result, GHGs have global and inter-generational externalities: a ton of GHG emitted from any source in any location can cause impacts throughout the globe—both to the source country and abroad—and can impact multiple generations. Given the scope of the externalities, climate change can be characterized as a global and inter-generational public goods problem.

Public goods are defined in economics by two key properties: non-rivalry and non-excludability (Samuelson, 1955). In the climate change context, non-rivalry means that the use or consumption of the public good by one country or generation does not reduce the availability of that good to another country or generation. In other words, the level of benefits received in North America from reduced global warming is not affected by the level of benefits received in Africa. Non-excludability means that no one country or generation can be excluded from being affected by changes in climate. The implication is that a GHG emissions reduction anywhere will have the same global and temporal benefit.

How much of the climate change public good should be provided? In other words, how much anthropogenic climate change should be allowed? According to the principles of welfare economics, we should seek the level that maximizes net societal benefits (i.e. that is economically efficient). Maximizing net societal benefits requires internalizing all societal benefits and costs—both direct private benefits and costs as well as all externalities. Therefore, the efficient spatial and temporal scope is determined by the scope of the externalities, not by geopolitical boundaries or the lifespan of current decision-makers.

The implication is that domestic policies can only be economically efficient if they account for the global and long-run implications of their effects on GHGs. Conceptually, this outcome would require that each country mitigate up to the point where their domestic marginal cost equals the global marginal benefit (Nordhaus, 2006).[30] The use of global marginal benefits would internalize the global externalities of reducing a unit of emissions and therefore correct for the spatial market failure. Internalizing the generational externality requires consideration of the effects on multiple generations, including those well beyond current living generations. Therefore, the benefits of an emissions reduction should include the present value of the stream of climate change impacts for the life of the GHG and any subsequent climate system inertia consequences.[31] This raises the issue of discounting. How should public decision-makers weigh future effects in current decisions? This topic is addressed following additional discussion of domestic decisions.

Individual countries might consider focusing solely on their domestic marginal benefit of emissions reductions.[32] In this case, a country equates its domestic marginal benefit to its domestic marginal cost of emissions reductions. The mitigation undertaken would be lower than if all the international externalities had been internalized since the domestic marginal benefits felt directly within a county's borders are only a fraction of the global marginal benefits. The mitigation would generate domestic benefits, as well as positive externalities for other countries. However, there would continue to be a market failure with decisions based on domestic marginal benefits because the remaining domestic emissions would be produced without accounting for their full cost to society, i.e., their international intertemporal effects. If all countries internalized the full cost of their emissions, the world as a whole would be better off than if each country internalized only the domestic externalities of their emissions in their decisions. Moreover, in addition to being inefficient, there is expected to be little appreciable mitigation of GHGs globally if every country considered GHG mitigation from its domestic marginal benefits perspective, and therefore little resulting response in the climate (Nordhaus, 1995).

An additional complication for evaluating GHG reduction benefits is that domestic decisions may affect the level of emissions in other countries. Emissions internationally could be affected by either international climate policy reactions to the domestic policy (such as reciprocal adoption of a mitigation policy) and/or production reactions (such as increased international production in response to higher U.S. production costs). A failure to account for these indirect feedback effects could result in biased estimates of changes in projected impacts to the domestic policy because the net climate change response, and the benefits realized domestically and globally, are a function of the net change in *global* emissions.

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[30] Uncertainties can complicate actual application of this economic efficiency rule (discussed later). Nonetheless, the principle is still sound.

[31] For example, thermal inertia associated with the time lag in the response of oceans to atmospheric temperature changes. It is because of this inertia, and the atmospheric lifetime of greenhouse gases, that global average temperature and sea level will continue to rise even if greenhouse gases emissions are stabilized (Meehl *et al.*, 2005).

[32] NHTSA and DOE followed this approach in their proposed 2008 CAFE and appliance efficiency rulemakings.

As discussed in Section 4, actually identifying the optimal level of provision of the climate public good is problematic on its own. Coordinating autonomous decision-makers to achieve that level is an additional significant challenge. Economic game theory can be helpful in thinking about the strategic behavior of countries with respect to climate policy. Achieving a significant reduction in projected climate change is a type of assurance game.[33] International coordination is required because it is technically infeasible for individual regions to reach the provision level on their own with mitigation within their own borders. Essentially, there is a provision threshold that must be met to assure that the benefit is provided. With respect to climate change, the cooperative threshold could be a temperature level above which there are impacts deemed unacceptable to society or a geophysical threshold associated with a catastrophic event such as the collapse of the West Antarctic Ice Sheet (both of which could be implied by the UNFCCC ultimate objective to prevent dangerous anthropogenic interference). Each of these examples is associated with implied atmospheric concentrations of GHGs, permissible global emissions, and therefore global emissions reductions from a reference case. These cases can be described as having a threshold that must be met for the public good to be provided, or a loss avoided.

The benefits of the climate change mitigation assurance game would be defined by impacts assessments, which could characterize the potential risks and the required global responses for reducing them by varying degrees. Decision-makers could then weigh the information in defining the provision threshold associated with unacceptable impacts.[34] Impacts information is essential to characterizing the changes in risk and associated cooperative thresholds.

Because there is a minimum amount of coordination required to provide the good in an assurance game, free riding incentives are diminished. While the benefits and costs of providing the public good are not evenly distributed across countries, there is an increased incentive to participate for each region that receives a benefit, where the benefit includes direct benefits as well as value for international concerns—such as national security, humanitarian, potential use value, and existence values. In a prisoner’s dilemma game, the dominant strategy is to not cooperate. That is not the case in the assurance game. Instead, participants are strategically inclined to act as a group—either for full cooperation or no cooperation at all. Furthermore, participation is self-enforcing, as each participant will want to participate and continue to participate if others participate. Finally, it is economically rational for participants (regions) to reveal their plans for emissions reductions to other participants to encourage cooperation. The experimental economics

[33] For a good discussion of assurance games, see Cornes and Sandler (1996) and Sandler (1997).
[34] Avoided climate change impacts are not the only potential benefits of GHG mitigation. For instance, there may also be benefits associated with air quality, energy use, technological change, and future economic competitiveness.

literature has validated these points in finding increased participation in actual decisions for providing public goods with minimum cooperative participation requirements.[35]

While an assurance game does not guarantee provision of the public good, it increases the strategic incentives for participation, revelation, and sustained commitment. The resulting environment is also conducive to coordination, such as coordinating the least-cost form of group participation via, for example, cost-effective financial or technological transfers that equates the marginal cost of participation across countries.

Finally, given the substantial emissions and climate uncertainties, there is significant uncertainty in quantifying many aspects of climate change and climate change impacts, including those associated with characterizing thresholds and the risk of exceeding them (IPCC WGI, WGII, WGIII, 2007; U.S. CBO, 2005). Large uncertainty has bearing on valuation, discounting, and the overall decision approach. For instance, society values reductions in risk, as reflected in different rates of return for high and low risk financial assets. However, deterministic estimates of the value of climate change impacts do not reflect the uncertainty and risk related to climate change, or attitudes towards risk, and therefore ignore the value of reducing risk (i.e. the risk premium). As a result, deterministic estimates underestimate the benefits of emissions reductions, which could be substantial for risks like potential catastrophic events (Weitzman, 2007, 2009).

The large degree of uncertainty also affects the discounting of impacts. Discounting is used in the aggregation of benefits or costs over time and the discount rate reflects trade-offs between current and future consumption or private investment. Activities that increase (decrease) emissions are very long-run investments in additional (avoided) impacts over a period of 100 years and longer. As a result, the valuation of impacts will be particularly sensitive to the discount rate used.

Unfortunately, current markets fail to capture the long-run returns associated with changes in GHG emissions. Climate change investments should be compared to similar investments via the discount rate. However, investments in climate change represent longer-term investments than those represented in financial markets. There is also a potential for significant impacts from climate change, where the exact timing and magnitude of these impacts are unknown and may be irreversible. Overall, the long time horizon and potential for large impacts imply a more uncertain investment than represented in current markets, and therefore greater potential for low economic growth conditions.

As a result, it is practical to consider lower interest rates than current market rates based solely on economic efficiency arguments.[36] A three percent discount rate represents observed interest rates from long-term *intra*-generational (within generation) investments

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[35] E.g., Bagnoli and Lipman (1989); Isaac et al. (1989); Bagnoli and McKee (1991); Rose et al. (2002); Rondeau et al. (2005).

[36] Intergenerational equity arguments are frequently offered as justification for low (even zero) discount rates (see, for example, Portney and Weyant, 1999). The discussion here considers only economic efficiency.

(net of risk premiums). With inter-generational investments, the horizon is longer and the uncertainty greater, including the potential for climate damages to economic growth. Rates of three percent or lower are consistent with conditions associated with the even longer-run uncertainty in economic growth, as well as the consumption effects of climate change impacts and the risk of high impact climate damages (which could reduce or reverse economic growth). Intra-generational consumption trade-offs, which are relevant because monetary estimates of the impacts of climate change are primarily consumption effects, are commonly valued at three percent.[37]

Given the extra long time horizon, it is also practical to consider that economic growth is likely to change over time, and therefore so will the discount rate. Uncertain interest rates would be practical to consider as well with modeling of uncertainty in economic growth and other parameters. In this context, the imputed (or effective) future discount rates will decline over time as investment uncertainty and risk increase and alternative futures with low discount rates dominate expected net present value calculations.[38] However, applications with uncertain discount rates should take steps to ensure consistency between the discount rate trajectories and future economic growth.[39]

Overall, in situations with large uncertainties, such as climate change and climate change impacts, economics recommends an iterative risk management framework as being appropriate for guiding policy (Manne and Richels, 1992; IPCC WGIII, 2007, Chapter 3). In such a framework, decisions are based on a policy defined “acceptable” level of risk and the course is revisited and revised as new information becomes available. This approach stands in marked contrast to cost-benefit analysis designed to identify an optimal decision and outcome or net benefit evaluations designed to identify net positive alternatives. The

[37] U.S. CBO (2005, p. 20) discusses using the rate of return from long-term government bonds as a rough proxy for very-long-term rates of return, noting that “funds continuously reinvested in 10-year U.S. Treasury bonds from 1789 to the present would have earned an average inflation-adjusted return of slightly more than 3 percent a year.” U.S. EPA (2000) recommends a consumption rate of interest of two to three percent based on historical rates of return for relatively risk-free investments, such as U.S. Treasury securities (adjusted for taxes and inflation). U.S. OMB (2003) uses three percent to represent the rate at which society discounts future intra-generational consumption flows to their present value. The rate is based on the real rate of return on long-term government debt over the last thirty years of 3.1 percent. While U.S. EPA (2000) and U.S. OMB (2003) identify inter-generational discount rates of 1 percent to 3 percent (0.5 percent to 3 percent for EPA), they require that analysis also be performed with 3 percent and 7 percent discount rates. Rates of three percent and lower are consistent with intergenerational issues, as discussed in this paper, while seven percent is inconsistent with these issues and not readily supportable. Note that EPA and OMB are in the process of revising their analytical guidance, including their discounting sections.

[38] This approach to discounting has been shown to be conceptually appropriate for greenhouse gas (GHG) emissions-related investments with extremely long-run implications and is not subject to time inconsistency problems (Newell and Pizer, 2001, 2003; Weitzman, 1999; Pearce, 2002). Furthermore, it has been shown that constant discounting can substantially undervalue the future (Newell and Pizer, 2001). For example, a constant 7 percent rate could undervalue net present benefits by 95 percent or 21 percent depending on the model of interest rate uncertainty over time and a starting rate of 7 percent, and 700 percent or 440 percent for a starting rate of 4 percent.

[39] Specifically, the discount rate should be a function of economic growth. Independent estimates of uncertain discount rates and economic growth projections would likely be inconsistent.

next section discusses the state of climate change information, including uncertainties, and describes the resulting complications for decision-making.

4. State of knowledge for incremental and non-incremental decisions

Knowing what data and analyses you need is necessary, but not sufficient. We must also understand the types of information available to the decision process in order to design more robust decisions. This section discusses the state of impacts related information for supporting policies with incremental (small) and non-incremental (large) global GHG emissions implications. In so doing, the section stresses the importance of acknowledging the difference between policies with incremental and non-incremental effects. Policy questions about the cost of inaction, economically optimal mitigation policies, or the GHG benefits of particular legislative proposals are concerned with large changes in global emissions. Many non-climate policies, such as CAFE, RFS, and appliance efficiency standards, have relatively small net effects on global GHG emissions. Current analytical capabilities are better suited to analysis of incremental emissions changes. In addition to this primary issue, the discussion also highlights other fundamental issues and challenges for decision-makers: comparing marginal benefits and marginal costs, partial characterizations of uncertainty, risk valuation, information inconsistencies, and non-monetary information. First, we discuss some common issues for both incremental and non-incremental impacts analyses.

Overall, impacts information is limited, with partial geographic and sector coverage. There are significant fundamental data limitations, especially climate and biophysical data, which

Box 1. Categories of uncertainty (for each, there are historical and projected uncertainties)

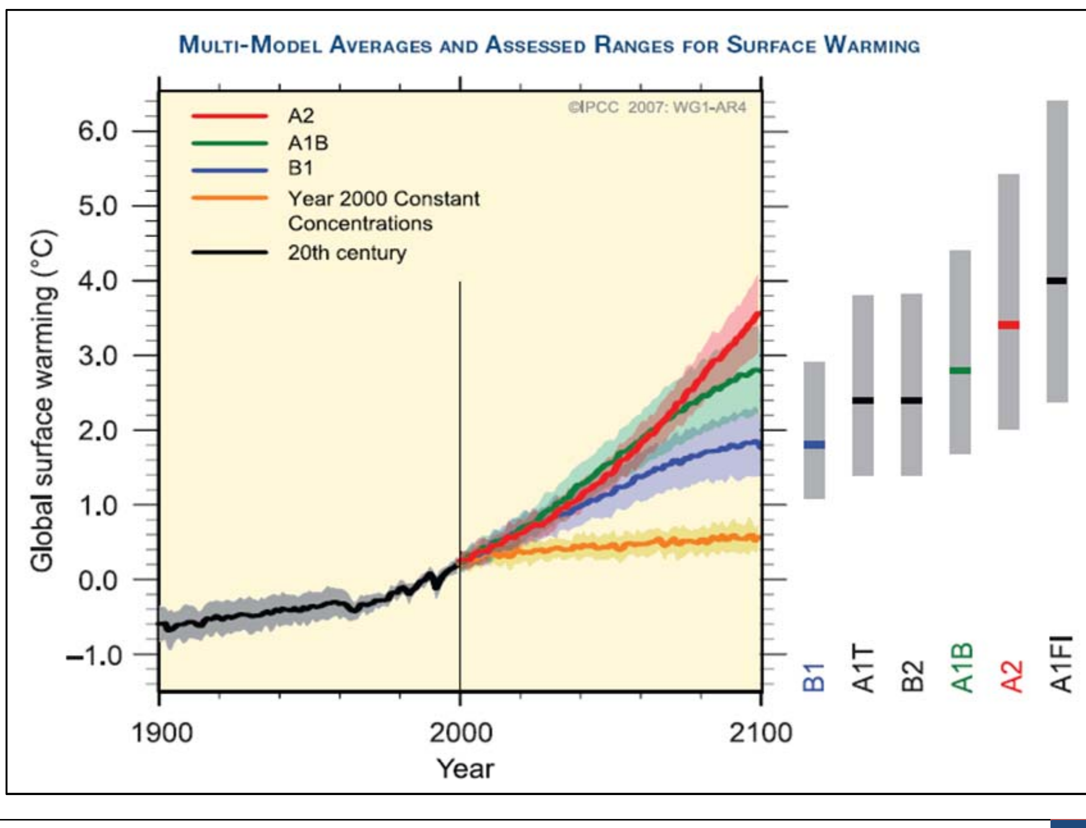
- Socioeconomic, e.g.,
  - Demographics – size, composition, and location of population
  - Income – wealth levels and rates of per capita growth
  - Economic elasticities – dictate responsiveness to changes in relative prices and income
  - Preferences – defines demand for goods and services, domestic and imported
  - Technological – e.g., costs, R&D, diffusion, current vs. new technology, rates of change, market responsiveness
  - Resource endowment availability and productivity
- Emissions and sequestration
- Biophysical response, e.g.,
  - Climate
  - Carbon cycle
  - Nitrogen cycle
  - Biogeophysical
  - Terrestrial ecosystem
- Impacts – exposure, adaptive capacity and response, net effect, feedbacks to economic and biophysical dynamics
- Policy – climate and non-climate (e.g., air quality, energy, development, technology)

are essential inputs into economic analyses. Impacts information will only evolve as quickly as the data. Second, uncertainties abound, from emissions through to net impacts. Box 1 provides a high-level list of uncertainty categories. Given the temporal and spatial scope and that we are considering potential biophysical and economic outcomes that extend well beyond observations, there are limits to how much we will ever be able to resolve the uncertainty. For instance, it is impossible to forecast the economy in 2100 with accuracy, or to know when exactly the West Antarctic Ice Sheet will collapse. Even probabilistic analysis and expected utility theory, which are very appealing and appropriate for analyzing climate change, are challenged by data constraints in estimating distributions. So, what do we know?

Policies with incremental GHG emissions changes

When concerned about incremental global emissions reductions (increases), it is reasonable to ask, is there a measurable benefit (cost)? This question can be broken down into is there an incremental climate signal, and is there a value? Current IPCC climate change projections (Figure 1) suggest that there is about a 1 degree Celsius uncertainty range by 2100 for any emissions scenario. The true uncertainty range is likely even larger (discussed later). This suggests that the impacts of marginal emissions changes would be lost in the noise and not produce a measurable climate signal. In other words, we could not say that a marginal emissions reduction will result in an *x* degree reduction in global

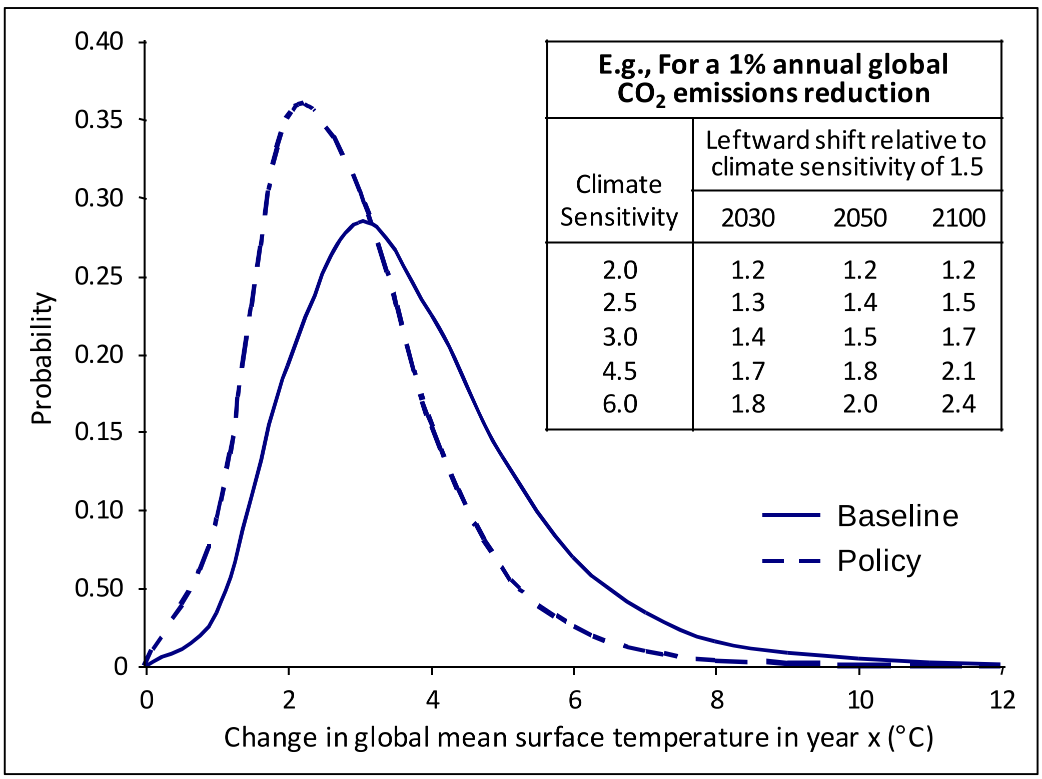
Figure 1. Historical and Projected Global Mean Surface Temperatures (*Source: IPCC WGI 2007)*



average temperature in year *y* with any degree of certitude. However, given the uncertainties, we should be looking at a different metric. We should instead look for the climate signal in the likelihood of potential climate change: will a marginal emissions reduction result in a decrease in the probability of an increase in global average temperature of *x* degrees by year *y*? Figure 2 provides an illustration of this type of signal. Under a policy, does the distribution for global mean surface temperature shift left and become more compact, with the right tail shifting further than the left tail?

Current capabilities can provide this type of information. For instance, the embedded table in Figure 2 presents results from a straightforward evaluation of global average surface temperature responses under alternative climate sensitivities to a small annual reduction in global CO_2 emissions (1 percent per year).[40] The reduction in projected temperature is largest for a climate sensitivity of 6, and smallest for a climate sensitivity of 1.5. Given the right skewed probability distribution of climate sensitivity,[41] ceteris paribus, the distribution of projected temperatures is therefore shifting to the left and becoming more

Figure 2. Illustrative reduction in the probability of higher global mean surface temperatures in some outyear x.



E.g., For a 1% annual global CO_2 emissions reduction			
Climate Sensitivity	Leftward shift relative to climate sensitivity of 1.5		
	2030	2050	2100
2.0	1.2	1.2	1.2
2.5	1.3	1.4	1.5
3.0	1.4	1.5	1.7
4.5	1.7	1.8	2.1
6.0	1.8	2.0	2.4

[40] Calculations performed with the MAGICC model (Model for the Assessment of Greenhouse-gas Induced Climate Change, Wigley and Raper, 1992; Raper et al., 1996; Wigley and Raper, 2002) using the Clarke et al. (2007) baseline emissions for the MiniCAM model.

[41] The IPCC states that climate sensitivity is "likely" (> 66 percent probability) to be in the range of 2°C to 4.5°C and described 3°C as a "best estimate", which is the mode (or most frequent) value. The IPCC goes on to note that climate sensitivity is "very unlikely" (< 10 percent) to be less than 1.5°C and "values substantially higher than 4.5°C cannot be excluded." IPCC WGI (2007).

compact as the right end of the distribution shifts further than the left. Specifically, the leftward shift in the right-tail is nearly twice that in the left-tail in 2030, and the ratio increases in later years. In other words, the risk of higher temperatures is reduced, even if only just a bit, which has implications for the risk of impacts. Similar phenomena are at the heart of more sophisticated analysis of non-incremental emissions changes (e.g., den Elzen and van Vuuren, 2007). Therefore, a signal can be established. That leaves us with the value question.

Conceptually, for policies valuing incremental changes in net global emissions, we should consider a marginal value. The economics literature has been generating marginal value estimates for over a decade (see the meta analysis of Tol, 2008). These estimates are commonly referred to as the social cost of carbon (SCC). The SCC is the net present value of climate change impacts over 100 plus years of one additional net global ton of GHGs emitted to the atmosphere at a particular point in time. It is a theoretically appropriate metric for monetizing the benefits of incremental global GHG emissions reductions. Estimating the SCC requires global modeling frameworks with consistent integrated socioeconomics, emissions, climate change, and impacts. Current capability is limited to aggregated integrated models due to data limitations. Not surprisingly, when modeling the biophysical and economic systems of the globe for more than 100 years there are inherently large uncertainties.

Table 2. Marginal benefits estimates – e.g., summary of EPA estimates for changes in emissions in year 2007 and 2030 for 2 percent, 3 percent, and 7 percent discount rates (2006$) (*Source: U.S. EPA 2008)*

		~ 2%			~ 3%			~ 7%		
		Low	Central	High	Low	Central	High	Low	Central	High
Meta global	2007	-3	68	159	-4	40	106	n/a	n/a	n/a
	2030	-1	134	314	-2	78	209	n/a	n/a	n/a
FUND global	2007	-6	88	695	-6	17	132	-3	-1	5
	2030	-3	173	1372	-3	33	261	-1	0	11
FUND US	2007	0	4	16	0	1	5	0	0	0
	2030	0*	9	32	0*	2	11	0*	0*	0*

** USEPA (2008) notes that these estimates, if explicitly estimated, may be greater than zero, especially in later years. See USEPA (2008) for the full footnote.*

Table 2 provides estimates published by EPA in 2008 (U.S. EPA, 2008). These estimates are presented because the methods and estimates provide a useful illustration of uncertainties and many of the challenges and controversies associated with estimating the SCC. For a focused discussion of these issues and the most recent federal SCC estimates and their use, see Rose (2010). EPA undertook two analytical analyses and generated ranges of estimates for different discount rates and year of emissions change. The estimates include global values from a meta analysis of peer reviewed estimates that is a refinement of the Tol (2005, 2008) meta analyses, and a consistent set of domestic & global estimates using a single model that has published regularly in the peer reviewed literature (the "Climate

Framework for Uncertainty, Negotiation, and Distribution", i.e., FUND).[42] Global SCCs are all that currently exist in the peer reviewed literature.

The estimates are relevant for incremental policies off of a baseline projection without climate policies. They are not estimates of "optimal" marginal benefits, which would result from equating the marginal benefits and marginal costs of emissions reductions. See U.S. EPA (2008) for additional methodological details and a discussion of the estimates, including a comparison to Tol (2005), and guidance on application of the estimates.[43]

The few important general points are illustrated in Table 2. Note that these points are ubiquitous, in that they are applicable to the entire SCC literature, not just EPA's estimates. First, given uncertainties, ranges of SCC estimates are appropriate, based on alternative assumptions of key scientific and economic parameters, as well as models, where multiple models can provide more robust results than a single model. For instance, higher values are associated with higher climate sensitivities, higher projected emissions, slower economic growth per capita globally and regionally, and lower discount rates. Second, SCC estimates for emissions changes in subsequent years are higher due to a larger marginal effect on net damages. The IPCC suggests that the SCC increases 2 percent to 4 percent per annum (IPCC WGII, 2007, Chapter 20). Three percent was applied in Table 2. Other recent preliminary work using FUND with "central" assumptions produced average annual growth rates of 2.8 percent and 4 percent for the period 2005-2030.[44] Third, impacts from an emissions change today (~2007) are felt well into the future. This is made obvious by looking at results across discount rates. For example, in Table 2, the mean (central) FUND global value for an incremental change in 2007 emissions is \$88, \$17, or minus \$1/tCO_2 depending on whether the consumption discount rate is 2 percent, 3 percent, or 7 percent. The higher discount rate reduces the weight of future impacts to essentially zero—leaving only some near-term net beneficial effects (primarily due to crop CO_2 fertilization). Finally, the domestic estimates are only a small fraction of the global values, illustrating the relative extent of the international externalities of domestic emissions. Consistent with the earlier theoretical discussion of efficient public goods provision, a global SCC value therefore

[42] The meta-analysis followed Tol (2008) and estimated Fisher-Tippett distributions for estimates that satisfied the following criteria: peer reviewed, from a more recent study (i.e., published after 1995), not equity weighted (i.e., regional aggregations were simple sums), and based on intergenerational consumption discount rates of approximately 2 percent and 3 percent. Fisher-Tippett was used because the sample was right-skewed with a thick right tail, and discount rates of 2 percent and 3 percent are consistent with EPA and OMB guidance on intergenerational discount rates (EPA, 2000; OMB, 2003). The FUND estimate ranges were generated from sensitivity analysis with respect to climate sensitivity, socio-economic and emissions baseline scenarios, and consumption discount rates of approximately 2 percent, 3 percent, and 7 percent. The low, central, and high columns in Table 2 are the 5th percentile, mean, and 95th percentile for the meta-analysis, while for FUND, they are the lowest, weighted average, and highest values from sensitivity analysis.

[43] Tol (2005) was used by the IPCC WGII (2007). Tol (2008) is an update of Tol (2005).

[44] Estimates generated by the author in collaboration with Richard Tol and David Anthoff. The SCC growth rate of 2.8 percent was generated using a consumption discount rate of 2 percent, while the SCC growth rate of 4 percent used a consumption discount rate of 3 percent. The FUND baseline and a climate sensitivity of three were used in deterministic scenarios for both.

internalizes more of the global and temporal externalities associated with GHG emissions/reductions in the U.S. or anywhere.

In addition to learning from the SCC estimates, it is also important to assess the estimates. First, there are substantial data deficiencies, because data are not available for every impacts category and region. As a result, transfer assumptions have to be used and more aggregate relationships are modeled (e.g., global mean temperature changes and national net agricultural impacts). Second, according to the IPCC, current estimates are "very likely" underestimated due to omitted impacts, including non-market values, threshold impacts (e.g., species extinction, catastrophic events), weather extremes (e.g., droughts, heavy rains, winds), and weather variability (IPCC WGII, 2007).[45] Furthermore, current estimates do not capture societal attitudes towards changes in risk, i.e., the value people have for reducing the likelihood of potential negative impacts (the risk premium). Current SCC modeling also does not capture global economic & social feedbacks, domestic willingness to pay for international impacts, and potential implications for other country action. Table 3 from EPA lists the included and omitted impacts categories for FUND, which is indicative of the state of the art.[46] Finally, non-CO_2 GHGs, such as nitrous oxide, methane, and fluorinated gases, will have different marginal values and growth rates over time than the marginal value of CO_2 emissions (IPCC WGII, 2007). Non-CO_2 GHGs have very different atmospheric lifetimes and radiative forcing effects, and therefore different climate and marginal impact implications. Using SCCs with carbon dioxide equivalent estimates of non-

Table 3. Lists of Impacts Modeled and Omitted from Current FUND Modeling *(Source: U.S. EPA, 2008)*

Impacts currently modeled in FUND	Examples of impacts omitted from current FUND modeling
• Agricultural production • Forestry production • Water resources • Energy consumption for space cooling and heating • Sea level rise dry land loss, wetland loss, and coastal protection costs • Forced migration due to dry land loss • Changes in human health (mortality, morbidity) associated with diarrhea incidence, vector-borne diseases, cardiovascular disorders, and respiratory disorders • Hurricane damage • Loss of ecosystems/biodiversity	• Catastrophic events (e.g., Antarctic ice sheet collapse) • Risks from extreme weather (e.g., death, disease and economic damage from droughts, floods, and fires) • Air quality degradation (e.g., increased ozone effects including premature mortality, forest damage) • Increased infrastructure costs (e.g., water management systems, roads, bridges) • Increased insurance costs • Social and political unrest abroad that affects U.S. national security • Damage to foreign economies that affects the U.S. economy • Domestic valuation of international impacts • Costs from uncertainty and changes in risk • Arctic sea ice melt and global transportation & trade

[45] In the IPCC report, "the following terms [were] used to indicate the assessed likelihood, using expert judgment, of an outcome or a result: Virtually certain > 99 percent probability of occurrence, Extremely likely > 95 percent, Very likely > 90 percent, Likely > 66 percent, More likely than not > 50 percent, Unlikely < 33 percent, Very unlikely < 10 percent, Extremely unlikely < 5 percent."

[46] The list of omitted FUND impacts is characterized as an initial, partial list.

CO_2 GHG emissions is practical for the moment. However, explicit estimates for the social cost of each non-CO_2 GHG will allow us to better capture the atmospheric and impacts trade-offs between gases.

Policies with non-incremental GHG emissions implications

Despite the fact that the SCC is well known, though not necessarily well understood (discussed below), and well represented in the literature, current estimates are not robust enough to guide the design of policies for significantly altering climate. A very different type of impacts analysis is required for evaluating and guiding non-incremental emissions changes.[47] Conceptually, as discussed previously, economic theory suggests mitigating emissions such that marginal benefits (i.e. the SCC) and marginal costs are equated over time. However, fundamental issues undermine this approach.

Comparing marginal benefits and marginal costs. The SCC is one type of published marginal value. Table 4 provides a representative sample of different types of marginal values. Unfortunately, differences between these marginal values are not well understood; and, as a result, they are inappropriately compared. There are two types of marginal benefit estimates in the literature—non-optimal and optimal. Table 2 presented estimates of the former that are marginal values off of a baseline (or reference) scenario.[48] Table 4 includes the baseline SCC cited by a number of petitioners in the NHTSA CAFE case that went before the U.S. 9th Circuit Court.[49] Optimal SCCs, on the other hand, are the result of attempting to find an optimal emission pathway that equates the marginal benefits and costs quantified in a model over time.

There are also two types of marginal cost estimates in Table 4—investment adders and mitigation. Investment adders are ad hoc per unit carbon dioxide emissions premiums applied to energy supply options by state energy providers. They are designed to force utilities to internalize the potential costs of future GHG regulations into current energy supply investment decisions. Marginal costs of mitigation represent the estimated expected private sector cost of the last unit of a future emissions reduction associated with a legislative proposal, emissions allowance trading market, or cost-effective global climate stabilization regime (given assumed projected baseline conditions, technologies, and biophysical and economic dynamics).

[47] The line between incremental and non-incremental is currently not well-defined. Qualitatively, non-incremental changes are large enough to result in domestic and international biophysical and market transformations and feedbacks, and the net global emissions changes affect exposure to impacts and the likelihood of surpassing thresholds.

[48] There are also non-optimal SCC estimates off of stabilization pathways (e.g., U.K. Defra, 2007). Most SCC estimates in the literature are baseline SCCs. For purposes here, the important distinction is optimal vs. non-optimal.

[49] This value is only one of the meta analysis peer review means from Tol (2005).

It is impractical to use optimal SCCs or adders in a marginal benefit and cost comparison since the former has already considered marginal costs in its derivation and the later values are arbitrary and not indicative of an emissions reduction level or pathway.

Table 4. Other Representative Marginal GHG Values (2006$/t$CO_2$)[50]

		2007	2015	2030
Baseline	CBD v. NHTSA comment [a]	25	31	49
Optimal	Nordhaus (2008) [b]	8	12	--
Investment adder	California Public Utilities Commission [c]	10	15	28
	Idaho Power Company [d]	15	22	47
Regional mitigation	Lieberman-McCain [e]	--	14	30
	Lieberman-Warner [f]	--	21	44
	Waxman-Markey [g]	--	13	27
	EU-ETS (futures contracts) [h]	$27 (2008)	$30 (2012)	--
	Deutsche Bank (forecast for 2008-2020) [i]	$46 (2008-2012)	$46 (2013-2020)	--
Global mitigation	3.4 W/m^2 stabilization (Clarke et al. 2007) [j]	--	--	54-122

a. *Center for Biological Diversity vs. National Highway Traffic Safety Administration, United States Court of Appeals for the Ninth Circuit, No. 06-71891, November 15, 2007. A number of petitioners referenced the Tol (2005) $50/tC (1995 dollars for emissions changes circa 1995) meta analysis mean from peer reviewed studies. The value in the table has been converted to 2006 real dollars, carbon dioxide units, and adjusted for the different emissions years assuming a 3 percent growth rate (the midpoint of the IPCC WGII (2007) range of 2 percent to 4 percent).*

b. *Nordhaus (2008) provides optimal SCCs for 2005 and 2010 in 2005$/tC. The estimates in this table were grown in accordance with the growth associated with the Nordhaus' 2005 and 2010 estimates*

c. *Public Utilities Commission of the State of California, 2007. Energy Division Resolution I.D. # 6931, Resolution E – 4118, October 4, 2007, http://www.cpuc.ca.gov/PUBLISHED/COMMENT_RESOLUTION/73147.htm.*

d. *Idaho Power Company, 2004. Technical Appendix for the 2004 Integrated Resource Plan, July 2004, http://www.idahopower.com/energycenter/irp/2004/2004IRPFinal.htm. Estimates grown assuming a 5 percent interest rate, which is the growth rate for the California Public Utilities Commission's value from 2004-2023.*

e. *United States Environmental Protection Agency's Analysis of Senate Bill S.280 in the 110th Congress, The Climate Stewardship and Innovation Act of 2007, http://www.epa.gov/climatechange/economicanalyses.html.*

f. *Murray, B. and M. Ross, 2007. The Lieberman-Warner America's Climate Security Act: A Preliminary Assessment of Potential Economic Impacts Lieberman-Warner, NI PB 07-04, Nicholas Institute for Environmental Policy Solutions, Duke University, October, http://www.nicholas.duke.edu/institute/econsummary.pdf.*

g. *U.S. EPA (2009).*

h. *Climate Market Daily, Volume 3 Issue 224, November 15, 2007.*

i. *Deutsche Bank, 2007. "Banking on Higher Prices: We See EUAs at E35/t Over 2008-20", Global Markets Research, July 23, 2007.*

j. *The range reflects the range of results from the three models reported on in Clarke et al. (2007). The corresponding CO_2 concentration level for 3.4 W/m^2 is 450 ppm, which is approximately a 550 ppm CO_2 equivalent concentration level.*

Unfortunately, comparing what is left—non-optimal SCCs and marginal mitigation costs—is also problematic (e.g., Holladay and Schwartz, 2009).

[50] All values in table 5 were adjusted to 2006$/t$CO_2$. Some sources provided explicit values or growth rates for future years. Others were grown for future years using the estimates given or growth rates from similar types of estimates. See table notes for details.

Current non-optimal marginal benefit and marginal mitigation cost estimates have for the most part been generated independently by impact or mitigation studies respectively. As a result, they are derived from different frameworks with different assumptions and scenarios for population, income, technology, emissions, climate change, and the carbon cycle. In addition, most SCC estimates represent the value of the first unit of emissions reduction in a particular year off of a baseline, while marginal cost values for mitigation represent the value of the last unit of reduction (presumably in the same year) off of a different socioeconomic and biophysical condition. Another issue is the failure to account for *net* changes in global emissions when using SCC estimates. SCC estimates—global and domestic—are only valid for a unit change in global emissions. Emissions estimates associated with domestic policies are frequently not estimates of global emissions changes. The SCC can only legitimately be applied to net global emissions changes. Finally, some try to make marginal comparisons in a specific year. These are not particularly meaningful because the annual growth rates for marginal benefit and costs are not the same, with the former growing as a function of atmospheric concentration, socioeconomic condition, and proximity to thresholds, while the later rises at the average risk free rate of interest for private investment.[51] Overall, these methodological and conceptual inconsistencies invalidate comparison. Not to mention the additional complication of uncertainties and omissions in SCC estimates, as well as uncertainty in marginal cost estimates.

Internally consistent models that endogenously model both benefits and costs can overcome these issues (e.g., Nordhaus, 2008; Tol, 2009); however, they are still confronted with and confounded by an even more basic issue—uncertainty.

Uncertainty about impacts is certainly the largest single factor complicating decisions. The uncertainties make it difficult to use impacts information to define economically efficient standards or an emissions pathway. Instead of a specific deterministic (or expected) point or pathway of points where the marginal benefits of emissions changes equal the marginal costs, we are confronted with a range of benefit (as well as cost) possibilities as analysts and decision-makers must prudently consider a spectrum of potential long-run assumptions. As a result, economically optimal standards cannot be specified, and even benefit-cost ratios are less reliable. Likewise, socially optimal price paths, while conceptually attractive, cannot be identified with confidence given quantified and unquantified uncertainties.

Uncertainty analysis, which considers expected values, changes in the distribution of different outcomes, and attitudes towards risk, is conceptually and practically preferable. However, with the characteristics of distributions uncertain, and important unquantified risks, it is unlikely to ever be able to boil information down to a single number or path that is robust and defensible enough for setting economically optimal standards or an emissions

[51] If inconsistencies were addressed, a better comparison would be to compare the net present value of total benefits and total costs.

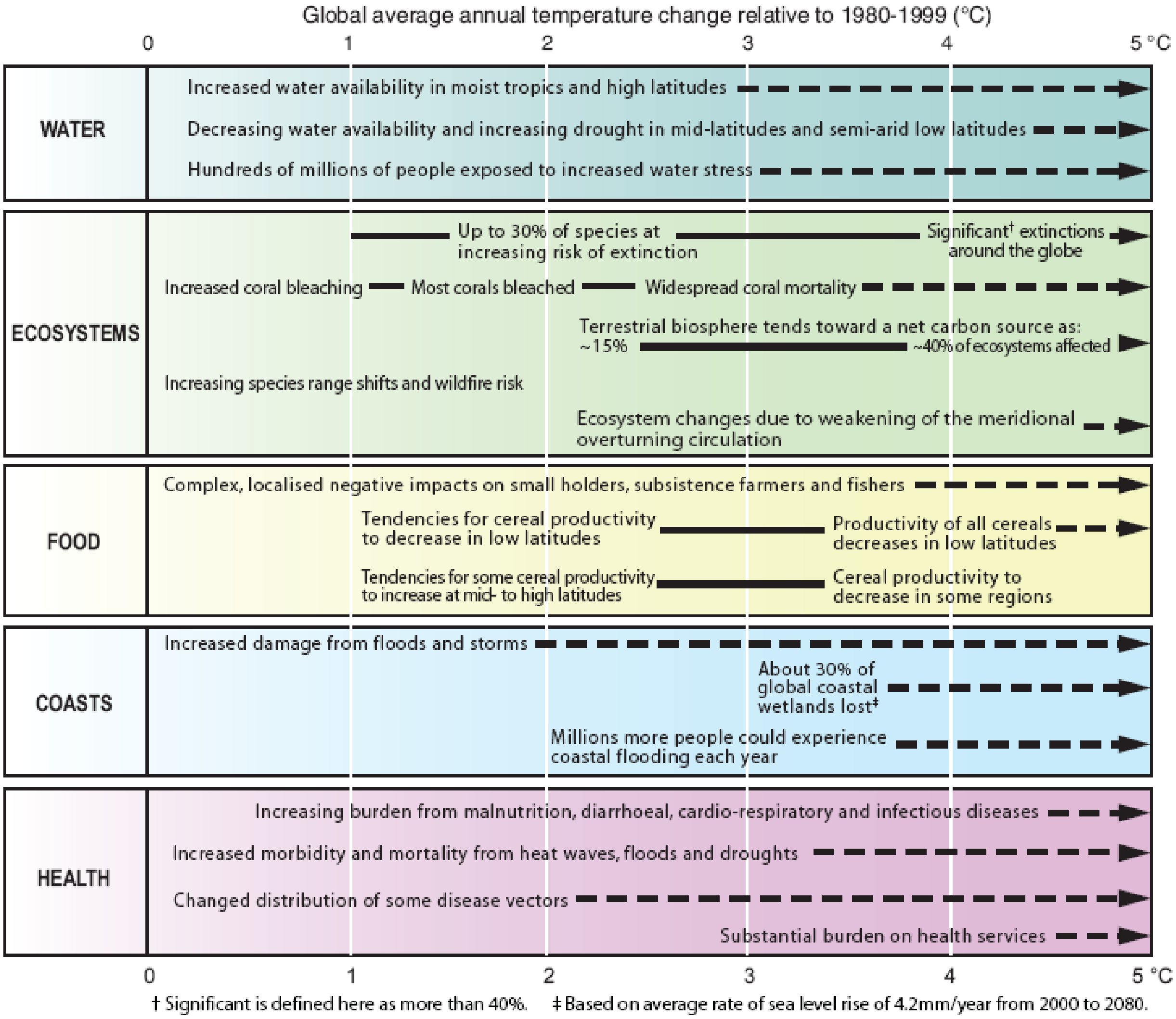
pathway. Nonetheless, optimal pathway analysis can still be instructive in that it can provide benchmarks for sensitivity analysis that explores the quantified and unquantified uncertainty space.

Quantifying non-incremental changes. Policies with non-incremental effects—on emissions and/or economic and biophysical systems, require frameworks able to capture interactions and feedbacks in and between economic and biophysical systems that are expected with higher levels of emissions reductions and large shifts in climate. Current SCC modeling frameworks do not capture these elements. Furthermore, the primary climate and impacts information currently available for estimating non-incremental benefits is, in and of itself, difficult for policy-makers to lean on.

Current information provides a fairly incomplete picture with respect to the implications on non-incremental changes in emissions, climate, and potential impacts. Overall, we cannot characterize distributions of most impacts, much less emissions and climate, especially thresholds and potential impacts outside of observed variability. Nor can we monetize many impacts. For instance, the IPCC's summary of current climate modeling characterizes only a part of the uncertainty. Figure 1 represents model uncertainty, i.e., the range of results across models. What is missing is parametric uncertainty, i.e., a distribution of results from a single model with varying parameter assumptions. If parametric uncertainty were also included, the uncertainty bands for each emissions pathway would be wider.

There are also complications to using the current impacts literature to estimate a total impact response to large climate changes. Net impacts of climate change are determined by more than climate change. Ecosystem and socioeconomic system conditions and responses are key determinants. Figure 3 from the IPCC WGII (2007) Summary for Policy Makers, is a nice visual cross-sector summary of potential impacts with increasing levels of global average temperature change. A different visual representation of the same information was generated by Smith et al. (2009). However, these figures should be viewed and used with caution for three reasons, especially for use as a sliding scale to estimate avoided impacts. First, the information was generated from disparate studies with different methodologies and applications, and fundamental differences in assumptions. As a result, it is difficult to construct a consistent comprehensive picture of change in impacts across sectors and regions. For instance, the water impacts for a 3 degrees Celsius increase are not necessarily correlated with those for food and health. Domestically, we face the same problem trying to, for example, construct a consistent picture of heat health impacts in Chicago, snow pack changes in the Sierra Nevada, precipitation effects on Midwest agriculture, sea level effects on Florida (gradual changes and storm surge, and potentially those associated with West Antarctic ice sheet collapse), and forest fire and pest changes in Canada that effect the carbon cycle and US timber markets.

Figure 3. Summary Impacts Information by Sector (*Source: IPCC WGII 2007)*



Second, an additional related complication in the current literature is that uncertainty at one impacts scale confounds the utility of information at another scale. For example, uncertainty in spatial downscaling diminishes the utility of grid-level impacts results.

Third, consideration of the interactions across impact categories (sectors) and global regions is minimal to non-existent. For example, how might vector borne illness incidence in different countries be affected by water scarcity, agricultural productivity and trade, and changes in migration patterns? Third, potential avoided impacts for decreases in projected temperature changes have not yet been explicitly modeled and estimated in the literature. Significantly adjusting the climate will require large scale socioeconomic transformation to produce the necessary mitigation (e.g., Clarke et al., 2007), and large anthropogenic emissions reductions will alter atmospheric composition and chemistry, and ocean and terrestrial ecosystems, and subsequently natural endowments from business as usual projections. In other words, the world will be a different socioeconomic and biophysical place under large-scale mitigation, with resulting changes in the exposure and vulnerability to climate change.

Unfortunately, our understanding of the transformation itself is fairly incomplete. While there have been significant advances (IPCC WGIII, 2007, Chapter 3), we only have a partial characterization here as well. Table 5 provides a summary of the recent climate stabilization scenarios literature, parsed into six stabilization level categories. While the ranges for the timing and level of emissions reductions are very useful for characterizing the relative demands of more stringent targets, the results, like the temperature change results in Figure 1, only capture model uncertainty, and only partially. For instance, a different trajectory will be cost-effective for a particular stabilization target under alternative plausible assumptions for future population and income growth, regional participation in abatement, non-climate policies, technology (availability, cost, and diffusion), or biophysical parameters and responses.

Table 5. Characteristics of Post-Third Assessment Report Stabilization Scenarios (*Source: IPCC WGIII 2007; IPCC SR 2007)*

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005 = 375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d,e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

5. Conclusions – principles and components of an impacts assessment framework

This paper assessed the climate change impacts information needs of federal decisions through two steps. First, it evaluated a variety of recent decisions that considered impacts. Next, it described the biophysical and economic nature of GHGs and climate change. The paper then reviewed the state of impacts knowledge for policies with incremental versus non-incremental implications for GHG emissions and climate change. That section also highlighted challenges that confront decision-makers who need to work with the information available. A number of conclusions can be derived from these discussions that should be viewed as principles for impacts decision-making and basic components for an analytical framework. These are presented below. This section also identifies various research opportunities for improving impacts analysis capabilities, and ultimately our understanding.

Principles for incorporating impacts into federal decisions

There are certain decision-making and analytical realities associated with the scientific nature of climate change and the state of knowledge. These realities can be summarized as principles. First and foremost is the need to view policies with incremental and non-incremental emissions changes differently given current capabilities. Next is a set of common principles for utilizing impacts information in policies with either incremental or non-incremental emissions implications.

- *Treat incremental and non-incremental policies differently.* Given differences in biophysical and economic responses and feedbacks, different analytical approaches are appropriate for policies with small and large emissions and climate implications. Current capabilities are acceptable for policies with incremental emissions effects, but are not robust enough to guide climate (non-incremental) policy. New capabilities are needed for non-incremental policies.
- *Internalize global and intergenerational externalities.* Irrespective of the policy mechanism (market or command-and-control), addressing an environmental problem is a question of internalizing economic externalities. Domestic GHG emissions have global effects up to and beyond one hundred years. Therefore, federal decisions need to consider the global and intergenerational effects of changes in GHG emissions. For incremental policies, this implies using global marginal benefit/cost estimates like the SCC (social cost of carbon), while for non-incremental policies, structured modeling is needed to capture global and over century long biophysical and economic feedbacks and interactions.
- *Model the scope of GHGs.* Global and very long-run modeling is needed, which is a dramatic shift in paradigm from standard historical practice for other domestic environmental decisions such air quality. Even modeling of climate change impacts at a local scale requires consideration of alternative climates, which requires modeling or making assumptions about global economic responses, policy responses, and emissions changes. For instance, to estimate the benefits of U.S. based emissions reductions to the U.S., you need to estimate net changes in global emissions.
- *Contend with uncertainty beyond typical levels.* Given the global and temporal scope, decisions must contend with uncertainties larger than those associated with most other environmental decisions. As a result, ranges of impacts estimates are appropriate and prudent. Uncertainty analysis will also be valuable for ranking policies and for quantifying changes in risk (and valuing those changes) for risk management. However, given unquantifiable and difficult to quantify uncertainties, sensitivity analysis will continue to be important for assessing potential outcomes. In particular,

scenarios are critical, as they allow for consideration of more difficult to quantify alternative biophysical and economic futures. For incremental policies, this implies consideration of ranges of marginal values as well as expected values, while for non-incremental policies, it implies broad sensitivity and uncertainty analysis in order to more fully consider potential risks associated with variability, thresholds, extreme weather, and catastrophic events and move beyond central or best guess assessment.

- *Characterize uncertainty and value risk.* Ultimately, managing climate change is a question of managing risk, and characterizations of risk are essential—both in terms of the likelihood and magnitude of outcomes and consideration of the value of changes in risk. While knowing precise impact distributions is unlikely, robust statements are possible about changes in distributions, such as shifting distributions right or left and making them more or less compact with larger shifts in the right tail. Also, evaluation of risk attitudes is important as they will affect the magnitude of the suggested response. Decision-making under uncertainty requires an explicit or implicit societal valuation of risk. For incremental analysis, a risk premium can be estimated and included in SCC estimates, while for non-incremental analyses, greater (lower) risk aversion will suggest a stronger (weaker) reaction in hedging against the risks.
- *Account for the extraordinarily long investment horizon.* Changes in GHG emissions are investments with returns well beyond the time horizon captured in current markets. Discount rates of 3 percent and lower are appropriate for the quantification of climate change impacts over the scientifically relevant timeframe. Discount rates in this range are consistent with the very long investment horizon and the corresponding uncertainty. It is also reasonable for discount rates to change over time with changes in economic growth and/or explicit consideration of uncertainty.
- *Use non-monetary impacts information.* Monetization of impacts is challenging given uncertainties and the fact that many impacts are non-market effects (e.g., environmental services, and existence and option values for species and ecosystems) and are not captured through market responses, as, for example, changes in heating and cooling demand would be. Quantitative estimates of biophysical impacts (e.g., changes in ecosystems) are therefore especially important, and can be readily used in a risk management approach to facilitate decisions about unacceptable risk. For incremental policies, this implies recognizing the deficiencies in current monetary marginal value estimates both in the development and use of estimates. For non-incremental policies, it implies consideration of both non-monetary and monetary quantified information for assessing risks, identifying acceptable risk thresholds, and evaluating opportunities for avoiding risk.
- *Use qualitative (proxy) impacts information.* Qualitative information can be meaningful and valuable to decisions and can complement and supplement monetized benefits estimates by providing a more expansive characterization of changes to climate risks.

For instance, projected changes in climate variables, such as average temperatures and sea level rise, can serve as meaningful proxies for changes in the risk of all potential impacts. This would include impacts that can be monetized, as well as those that have not been monetized but can be quantified in physical terms (e.g., water availability), and those that have not yet been quantified (e.g., forest disturbance) or are extremely difficult to quantify (e.g., catastrophic events such as collapse of large ice sheets and subsequent substantial sea level rise). Proxy impacts information can inform incremental and non-incremental decisions in a similar fashion to non-monetary information.

Components for an analytical framework

How can we provide better impacts information for decision-making? A framework is needed that recognizes the state of the literature and the substantial and persistent uncertainties associated with climate change. The framework should also be designed to support the multitude of policy questions. The information requirements for evaluating climate risks and developing response strategies and priorities are vast—with global and local, as well as near- and long-term, information needed for numerous and disparate categories. Similarly, decisions of every type and scale will affect GHG emissions and sequestration regardless of whether they are designed to influence climate or something else, such as air quality, energy independence, or forest health. This creates a need for consistent consideration of the implications on GHG emissions across decisions.

With these things in mind, we suggest the following basic components for an analytical framework for impacts:

For non-incremental emissions decisions

- *Structured modeling.* More structural, integrated assessment frameworks are needed than that currently used in SCC modeling. These frameworks need to capture biophysical and economic interactions and feedbacks across regions, sectors, and time. Such frameworks do not yet exist. A framework like this can also inform and be complemented by location and sector specific analyses.
- *Consistency.* Consideration of and consistency across all three dimensions—climate, ecosystem, and socioeconomic—is needed for robust assessment of impacts within and across sectors and regions. This was a central motivation for the approach for new integrated scenarios from the scientific community (Moss et al., 2008). Consistency is also needed to meaningfully estimate avoided impacts, i.e., the change in impacts between a reference and alternative future. This should be a priority research area. Consistency will substantially improve the quality and comparability of alternative

impacts futures and provide stronger ties to mitigation options, as well as facilitate joint mitigation-adaptation decision-making.[52]

- *Multiple models and scales.* It is unreasonable to think that a single model will ever be able to answer policy questions relevant to every spatial and temporal scale of concern with climate change. Multiple models are needed that provide insights about global, regional, and local effects—near- and long-term. Assembling a consistent and coherent picture of so many scales is a substantial task that will require common assumptions and significant development coordination. In a framework such as this, more aggregate models would be calibrated to finer resolution models, and the aggregate models would provide broader market, biophysical, and temporal context to the finer resolution models.
- *Risk management application.* Given uncertainties, an iterative risk management approach is practical. Policy-makers can define a level of "acceptable" risk, with respect to some metric—e.g., emissions reduction pathway, atmospheric concentration level, radiative forcing, temperature change, or specific set of impacts—with the expectation of learning from today's actions and in the future revising the course accordingly. Risk management can accommodate economic, non-economic (e.g., biophysical), and non-scientific (e.g., equity, political) inputs.[53]
- *Strategic analysis application.* The net benefits of domestic mitigation and adaption will depend on the actions of other countries. Strategic analysis of international responses to domestic policies and proposals is prudent not only for internationally negotiated actions, but for domestic decisions which can be a signal to other countries and thereby affect domestic direct and indirect benefits, i.e., those respectively felt directly in US jurisdictions and indirectly through economic and biophysical feedbacks and US public and private value for international interests.

For incremental emissions decisions

- *Global values.* It is appropriate to use ranges of global marginal values in addition to expected values in determining or assessing the implications of policies with incremental effects on global GHG emissions. Global present value estimates should be used in order to internalize the externalities and guide incremental policies towards an efficient effect on the climate public good.[54]

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[52] Consistency will help inform how we decide on the portfolio of adaptation and mitigation strategies for near-term impacts that are inevitable and long-term impacts that could be avoided through mitigation.

[53] In parallel, it would be valuable to estimate societal risk tolerance (i.e., the curvature of the utility function) for use in assessing risky outcomes. See the paper by Yohe in this volume for a detailed discussion of iterative risk management.

[54] Both the United Kingdom and the European Commission are following the economic principles in their use of the global social cost of carbon (SCC) for valuing the benefits of GHG emission reductions in regulatory impact assessments and cost-benefit analyses (Watkiss et al, 2006). The United Kingdom is now using what they refer to as a shadow price of carbon (SPC) which is based off of climate stabilization trajectory (UK Defra, 2007). However,

- *Reference projection.* For now, the values could be conservatively computed off of baseline projections (i.e., absent potential future climate policies). Estimates off of baseline projections, versus aspirational climate policy pathways, are more consistent with current non-climate policy decisions that have marginal global GHG emissions implications. Baseline SCCs would also be consistent with climate change policy proposals since baseline SCCs more efficiently internalize the climate change risks that the government wishes to avoid or hedge against with the proposed climate policy. If global emissions, socioeconomic, and biophysical trajectories are significantly modified by future climate policy, the estimates of marginal values can be revised. Specifically, a trajectory of revised marginal values can be computed for the corresponding global emissions pathway.
- *Uncertainties and deficiencies.* These need to be considered in using marginal value estimates. They can be dealt with by considering alternative values, including high end values that can be reasonably considered given the expected negative bias in current estimates and risk management motives.
- *Future improvements.* Over time, estimates can be improved with updated information and additional impacts as new detailed sector and region specific research emerges. Methodologically, expected value estimates should be developed that account for uncertainty and risk preferences, and that consider thresholds and variability. Estimates over time and for non-CO_2 GHGs are also needed.

In addition to the development priorities already mentioned, new research is needed to more fully characterize the uncertainty space for climate responses and potential impacts and to identify which uncertainties can and cannot be quantified. Recall that current climate and stabilization modeling has primarily captured model uncertainty. It is important to also recognize that the key uncertainties will vary by policy question and the analytical platform. There are different uncertainties at different scales and for different tools, where uncertainties at one scale can confound the utility of information at another scale. Identifying these is critical to producing meaningful information.

Federal decision-makers will continue to need to make decisions that have intentional or unintentional consequences for future climate change risks. The nature of the public good and the state of knowledge will force these decisions to be made under substantial uncertainty, and the issues associated with this reality will have to be continually confronted.

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conceptually, an SPC would undervalue the impact of today's policies with incremental global emissions effects that are marginal to the current non-stabilization trajectory.

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