The Social Cost of Carbon for Regulatory Impact Analyses

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Interagency Working Group on Social Cost of Carbon

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Energy and Climate Change
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

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The Social Cost of Carbon

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year.

That is, it is the increase in aggregate income that would make society just as well off as a one unit decrease in greenhouse gas emissions in a particular year.

$$SCC_t \equiv \frac{dY_t}{dE_t} = -\frac{\partial W_t / \partial E_t}{\partial W_t / \partial Y_t}$$

It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

SCC Values for use in Regulatory Analyses

- The interagency group selected four SCC values for use in regulatory analyses.
- Benefits from reduced emissions can be estimated by multiplying changes in emissions in any year by the SCC value for that year.
- The net present value of the benefits can be calculated by multiplying each of the future benefits by an appropriate discount factor and summing across all affected years.

Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

	Discount Rate			
	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

SCC Values used in Previous RIAs

- 2008 proposed CAFE standards (DOT)
  - A domestic SCC value of $7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions, with a range of $0-$14 for sensitivity analysis, increasing at a rate of 2.4 percent per year.
- 2008 Energy Conservation Program (DOE)
  - A SCC range of $0 to $20 per ton CO_2 for 2007 emission reductions (in 2007 dollars), with the value increases at 2.4 percent per year.
- 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases (EPA)
  - Global mean SCC of $68 and $40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).
- 2009 interagency assessment "interim" SCC estimates from the existing literature
  - Five interim values: global SCC estimates for 2007 (in 2006 dollars) of $55, $33, $19, $10, and $5 per ton of CO_2, increasing at 3 percent annually.
  - Used by DOE, DOT, and EPA in several proposed and final rules.

Integrated Assessment Models (IAMs)

- Combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework.
  - emissions are translated into changes in atmospheric greenhouse concentrations
  - atmospheric concentrations are translated into changes in temperature
  - changes in temperature are translated into economic damages.

- Emissions projections used in the models are based on specified socio-economic (GDP and population) pathways.

- IAMs transform the stream of economic damages over time into a single value using an appropriate discount factor.

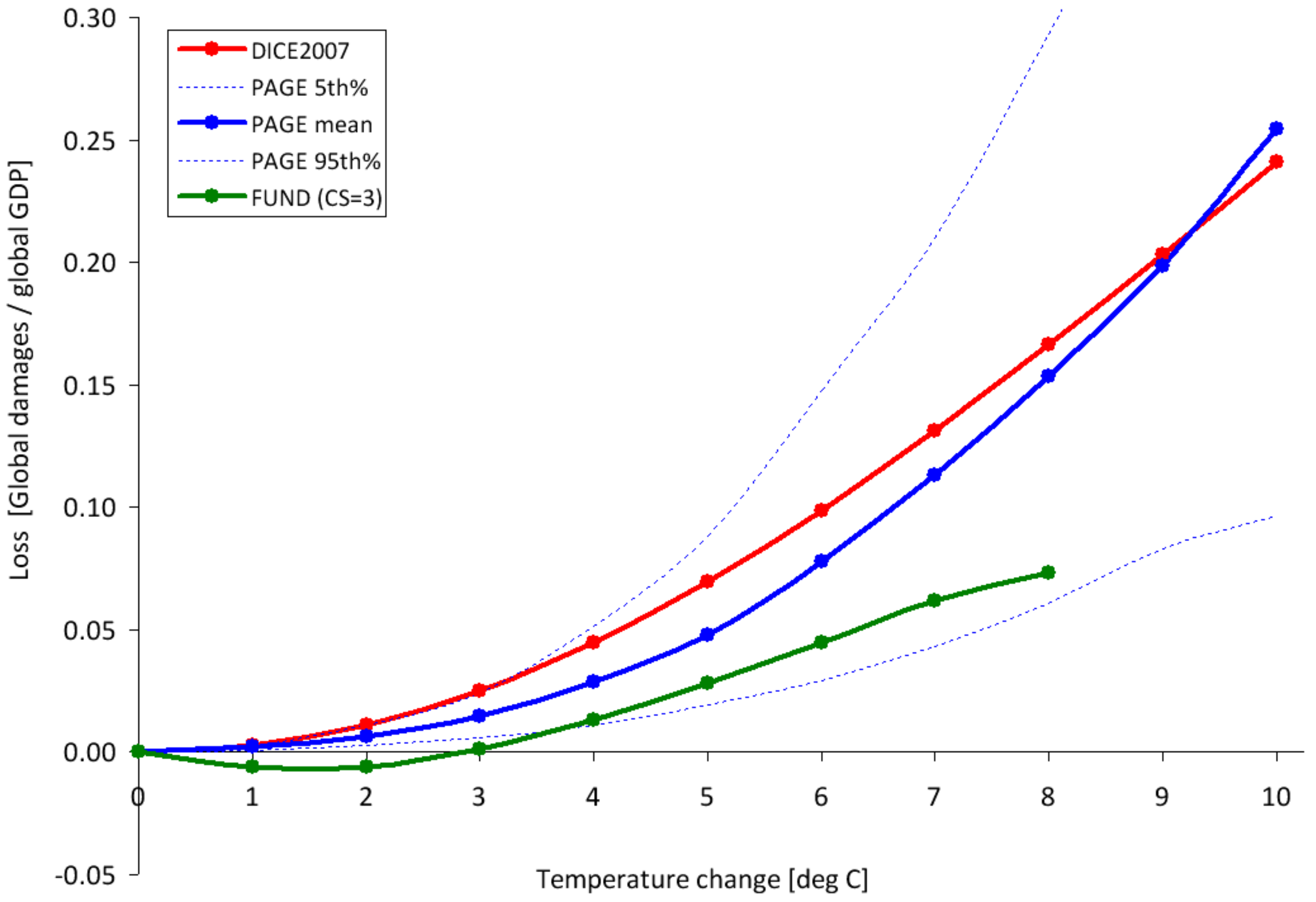
- They vary by level of complexity
  - The IAMs used in the interagency process (DICE, PAGE, and FUND) use stylized, reduced-form equations, which lack the more detailed representation of the underlying climatic and economic systems.
  - Other IAMs (GCAM, MERGE) may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages.

Three Models used in the Interagency Process

- DICE (Dynamic Integrated Climate and Economy)
- FUND (climate Framework for Uncertainty, Negotiation, and Distribution)
- PAGE (Policy Analysis of the Greenhouse Effect)

Damage Functions

Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models



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Omitted Impacts

Impacts currently modeled in FUND	Examples of impacts omitted from current FUND modeling*
• Agricultural production • Forestry production • Water resources • Energy consumption for space cooling & 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

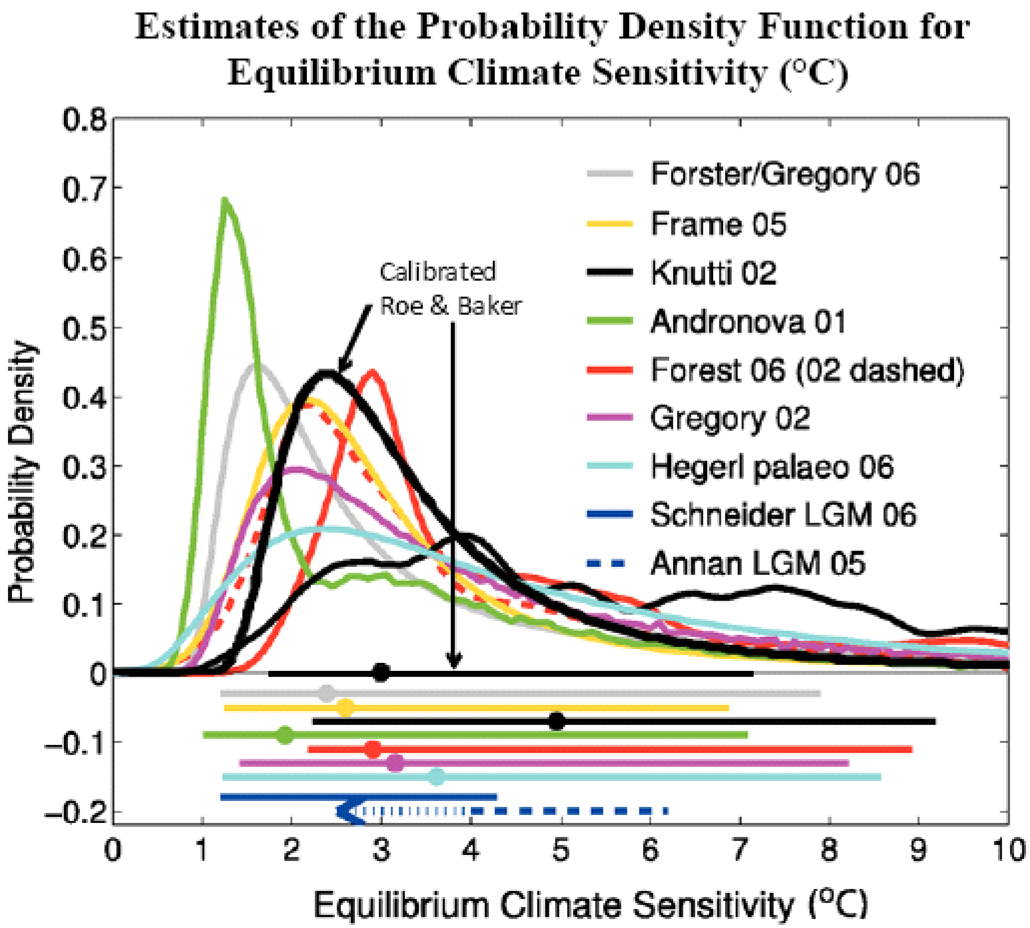
* A comprehensive review of included and omitted impact categories in current marginal benefits modeling is planned.

Climate Sensitivity

- The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing.
  - Defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)).
  - Includes the response over the short to medium term, but does not include long-term feedback effects which might occur over many hundreds to thousands of years.

- IPCC assessment
  - Likely (>66%) to be in the range 2°C to 4.5°C
  - Most likely value is 3°C
  - Very likely (>90%) to be larger than 1.5°C
  - Values substantially higher than 4.5°C cannot be excluded

The Calibrated Roe and Baker Distribution of Equilibrium Climate Sensitivity



Socioeconomic and Emissions Projections

- It is important to consider several input parameters in tandem: GDP, population, CO2 emissions, and non-CO2 radiative forcing.

- The interagency workgroup relied on EMF-22
  - Uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets.
  - They are recent, peer-reviewed, published, and publicly available.
  - Preferable to the IPCC SRES (developed in 1997) due to their age.

- Five trajectories
  - The business-as-usual (BAU) trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. Associated with CO2 (only) concentrations ranging from 612 to 889 ppm in 2100.
  - The fifth scenario representing an emissions pathway that achieves stabilization at 550 ppm CO2e, based on the averaged GDP, population, and emission trajectories from the four models. This is consistent with widespread action by countries to mitigate GHG emissions, but could result from technological advances

2100-2300 Extrapolations

1. Population growth rate declines linearly, reaching zero in the year 2200.

2. GDP per capita growth rate declines linearly, reaching zero in the year 2300.

3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.

4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.

5. Non-CO_2 radiative forcing remains constant after 2100.

Discount Rates Used In RIAs

- The discount rate has a large influence on the current value of future damages, but there is no consensus on what rates to use.

- Federal rules typically employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4.

- However, Circular A-4 also states:

  "If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent."

The Ramsey Equation

- Under a Ramsey equation framework, the analyst applies either positive or normative judgments in selecting values
  - η (coefficient of relative risk aversion or elasticity of marginal utility of consumption)
  - ρ (pure rate of time preference)
- Combined with g (growth rate of per-capita consumption)
- The interest rate at which future monetized damages are discounted

$$\rho + \eta \odot g$$

Uncertainty in the discount rate

- If there is a persistent element of uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time.
- Consequently, lower discount rates tend to dominate over the very long term.
- Newell and Pizer (2003) model average certainty-equivalent rates using mean-reverting and random walk interest rate dynamics

Discount rates used by the Interagency group

To estimate SCC, we use three discount rates to span a range of certainty-equivalent constant discount rates:

- **2.5 % per year**: selected to incorporate concern that interest rates are highly uncertain over time.
- **3% per year:** selected because it is consistent with estimates in the economics literature and Circular A-4 guidance for the consumption rate of interest.
- **5 % per year**: selected to represent the possibility climate damages are positively correlated with market returns.

Computational steps in the SCC process

1. Use of three integrated assessment models: FUND, DICE, and PAGE
2. Add exogenous inputs:
   - Roe and Baker distribution for climate sensitivity parameter.
   - Five sets of GDP, population, and carbon emissions trajectories based on EMF-22.
   - Constant annual discount rates of 2.5, 3, and 5 percent.
3. Calculate temperature effects and damages in each year from baseline emissions path.
4. Add an additional unit of C emissions in year t.
5. Recalculate temperature effects and damages expected in all years beyond t resulting from adjusted path of emissions.
6. Find difference in damages between the baseline path and the adjusted path.
7. Discount resulting path of marginal damages back to emissions year using set discount rates.
8. Calculate SCC as net present value of discounted path of marginal damages.

Aggregate Results

- This exercise produced 45 separate distributions of the SCC for a given year (3 models, 3 discount rates, and 5 socioeconomic scenarios). 10,000 estimates were produced for each model run.
- Values for 2010, 2020, 2040, and 2050 are calculated by combining all outputs from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.
- The distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate.
- The interagency group selected four SCC values for use in regulatory analyses.
  - Three values are based on the average SCC across models scenarios at the 2.5, 3, and 5 percent discount rates.
  - The fourth value is the 95th percentile at a 3 percent discount rate, representing higher than-expected economic impacts further out in the tails of the distribution.

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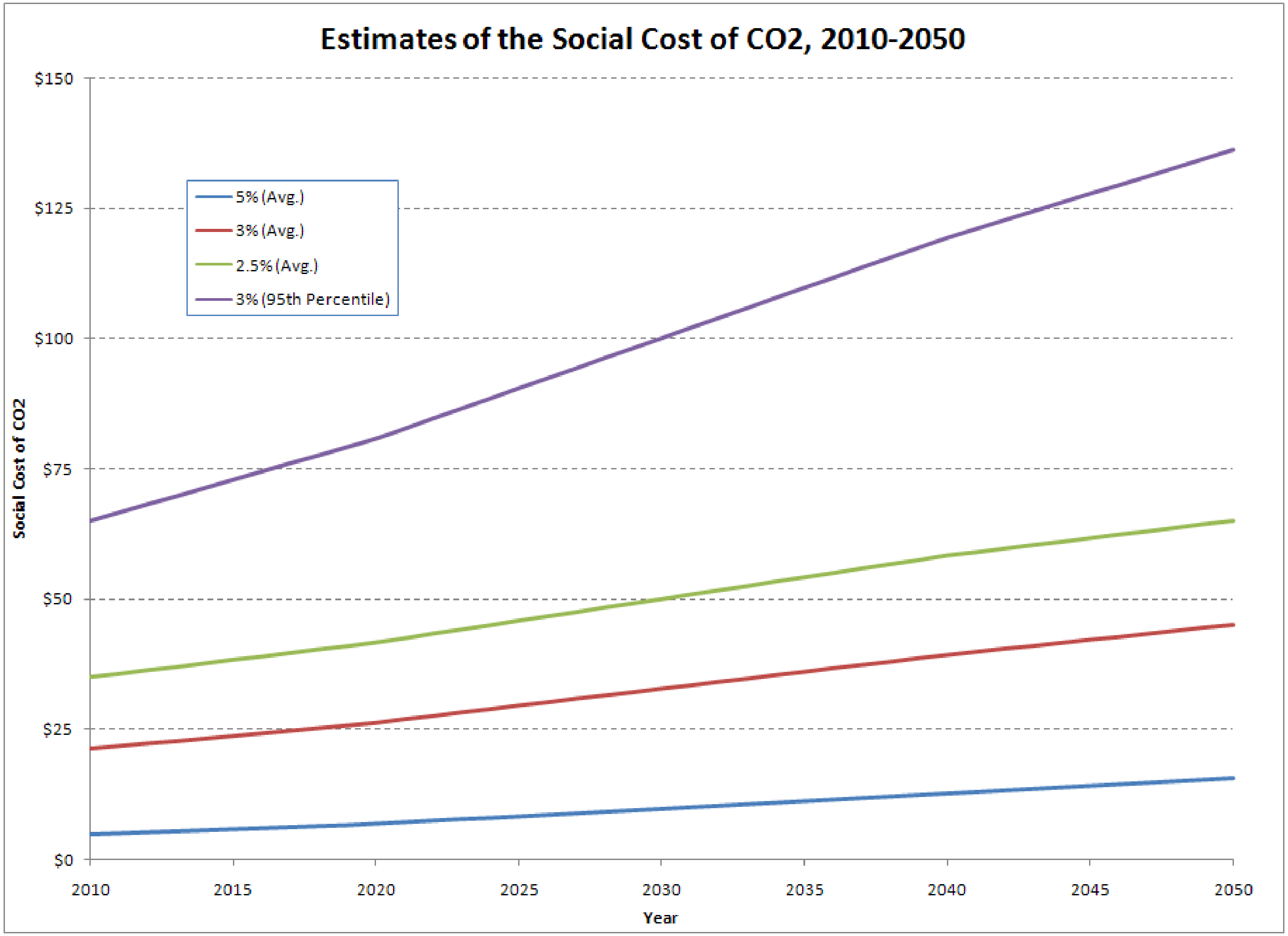
Disaggregated Social Cost of CO2 Values for 2010 (in 2007 dollars)

Model	Discount rate: Scenario	5% Avg	3% Avg	2.5% Avg	3% 95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

SCC Path 2010-2050



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SCC Growth Rate over Time

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change.

Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	**5%** Avg	**3%** Avg	**2.5%** Avg	**3.0%** 95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

Discounting future SCC Values to the Present

- When the SCC estimate grows over time, future monetized value of emissions reductions in each year must be discounted to present to determine total net present value for use in regulatory analysis.

- Damages from future emissions should be discounted at the same rate as used to calculate SCC estimates.

Limitations of the analysis

- Non-catastrophic damages
- Catastrophic damages
- Extrapolation of damages to high temperatures
- Adaptation and technological change
- Risk aversion
- Tipping points
- Catastrophic effects
- Inter-sectoral and inter-regional interaction
- Imperfect substitutability of environmental amenities

Conference on Modeling Climate Change Impacts and Association Economic Damages (Nov. 18-19, 2010)

Overview of Existing Integrated Assessment Models

- Overview of IAMs
- DICE
- PAGE
- FUND
- GCAM
- IGSM

Near-Term - DOE and EPA Efforts

- Proposed DOE Impacts Knowledge Platform
- Proposed EPA Generalized Modeling Framework

Critical Modeling Issues

- Sectoral and Regional Disaggregation
- Adaptation and Technological Change
- Scenario Development and Socio
- Incorporation of Climate System Uncertainty
- Extrapolation of Damage Estimates to High Temperatures
- Earth System Tipping Points
- Potential Economic Catastrophes
- Nonmarket Impacts

Implications for Climate Policy Analysis and Design

- Implications for Benefit-Cost Analysis
- Implications for Addressing Equity
- Implications for Cost-Effectiveness Analysis
- Implications for Managing Risks

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Conference on Research on Climate Change Impacts and Associated Economic Damages (Jan. 27-28, 2011)

Opening Remarks

•Progress in estimating climate change impacts

•Progress in valuing climate damages

Storms and Other Extreme Weather Events

•Impact of Climate Change on Storms and Other Extreme Weather Events

•Global Damages from Storms and Other Extreme Weather Events

Water Resources

•Hydrological/Water Resource Impacts of Climate Change

•Estimating the Economic Impact of Changes in Water Availability

Human Health

•Climate-Associated Changes in Health Conditions/Diseases and Air Pollution

•Estimating the Economic Value of Health Impacts of Climate Change

Agriculture

•Biophysical Responses of Agro-ecosystems to Climate Change

•Estimating the Economic Impact of Climate Change in the Agricultural Sector

Sea Level Rise

•Sea Level Impacts of Climate Change

•Estimating the Economic Impact of Sea Level Rise

Marine Ecosystems and Resources

•Modeling Climate and Ocean Acidification Impacts on Ocean Biogeochemistry

•Modeling Climate and Acidification Impacts on Fisheries and Aquaculture

•Economic Impact of Climate Change and Ocean Acidification on Fisheries

•Non-market Valuation of Climate and Acidification Impacts on Marine Resources

Terrestrial Ecosystems and Forestry

•Biological Responses of Terrestrial Ecosystems to Climate Change

•Estimating the Economic Impact of Climate Change on Forestry

•Valuing Climate-associated Changes in Terrestrial Ecosystems and Ecosystem Services

Energy Production and Consumption

•U.S. Energy Production and Consumption Impacts of Climate Change

•Impacts of Climate Change on Global Energy Production and Consumption

Socio-economic and Geopolitical Impacts

•Regional Conflict and Climate Change

•Migration Impacts of Climate Change

Panel Discussion: Incorporating Research on Climate Change Impacts into Integrated Assessment Modeling

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