The National Academies of
SCIENCES • ENGINEERING • MEDICINE

VALUING CLIMATE DAMAGES: UPDATING ESTIMATION OF THE SOCIAL COST OF CARBON DIOXIDE

June 14, 2017

Committee members

Maureen Cropper, University of Maryland, Co-chair
Richard Newell, Resources for the Future
Max Auffhammer, University of California, Berkeley
Robert Kopp, Rutgers University
Billy Pizer, Duke University
Richard Schmalensee, Massachusetts Institute for Technology

Technical Consultant

Casey J. Wichman, Resources for the Future

Study Director

Jennifer Heimberg, The National Academies of Sciences, Engineering, and Medicine

Division of Behavioral and Social Sciences and Education
Board on Environmental Change and Society

COMMITTEE ON ASSESSING APPROACHES TO UPDATING THE SOCIAL COST OF CARBON

MAUREEN L. CROPPER (Co-chair)	University of Maryland
RICHARD G. NEWELL (Co-chair)	Resources for the Future
MYLES ALLEN	University of Oxford
MAXIMILIAN AUFFHAMMER	University of California, Berkeley
CHRIS E. FOREST	The Pennsylvania State University
INEZ Y. FUNG	University of California, Berkeley
JAMES HAMMITT	Harvard University
HENRY D. JACOBY	Massachusetts Institute of Technology
ROBERT KOPP	Rutgers University
WILLIAM PIZER	Duke University
STEVEN K. ROSE	Electric Power Research Institute
RICHARD SCHMALENSEE	Massachusetts Institute of Technology
JOHN P. WEYANT	Stanford University

JENNIFER HEIMBERG, Study Director

CASEY J. WICHMAN, Technical Consultant, Resources for the Future

MARY GHITELMAN, Senior Program Assistant

Study origin and description

The Interagency Working Group (IWG) on the social cost of carbon (SC-CO_2) requested this study to assist in future revisions of SC-CO_2 estimates.

Phase 1 - completed in January 2016 – focused narrowly on whether to update the equilibrium climate sensitivity and the presentation of uncertainty.

Phase 2 - committee examined potential approaches for a more comprehensive update to SC-CO_2 estimates to *ensure the estimates reflect the best available science.*

Phase 2 task specifics

Committee to focus on:

1. Assessing the available science and how it impacts choice of integrated assessment models and damage functions;
2. climate science modeling assumptions;
3. socioeconomic and emissions scenarios;
4. presentation of uncertainty; and
5. discounting.

Making recommendations on approaches to future updates of the SC-CO_2 estimates, as well as research recommendations

*Committee was not asked to estimate a value for the SC-CO_2

Background Information on the SC-CO_2

What is the social cost of carbon?

Social cost of carbon (SC-CO_2): the cost to society of adding 1-metric ton of CO_2 to the atmosphere in a particular year (in US dollars)

Measures the monetized value of the additional CO_2 (including both negative and positive impacts).

This includes, but is not limited to:

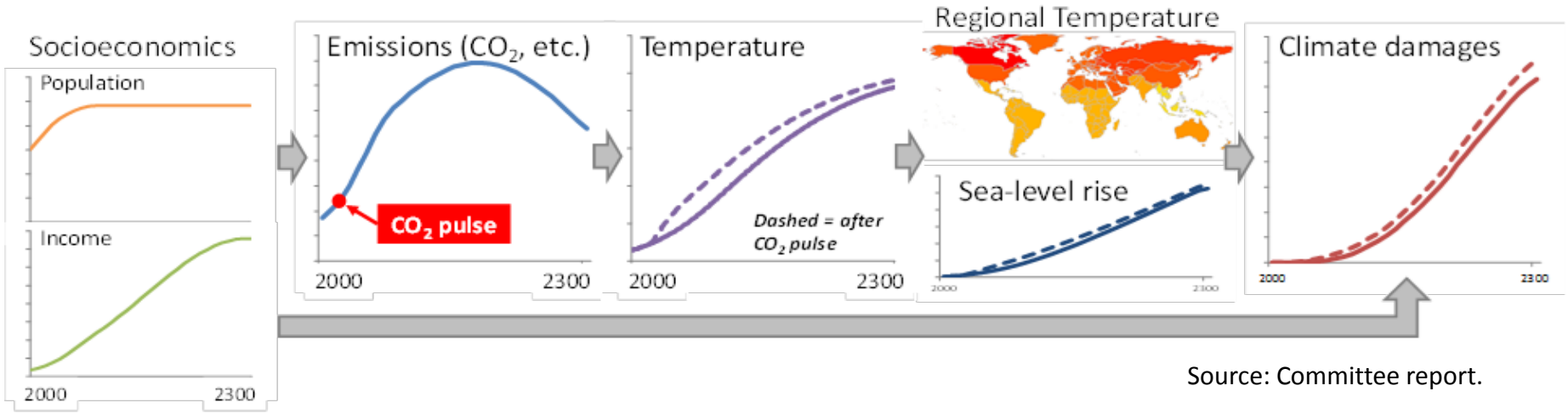
- Changes in net agricultural productivity
- Energy use
- Human health
- Property damage from increased flood risk
- Other impacts

What is the SC-CO_2 used for?

The SC-CO_2 is used to quantify the benefits of CO_2 emission reductions in regulatory impact analysis of federal regulations

- Executive Orders since 1981 have required quantifying the benefits and costs of federal regulations.
- A 2008 court ruling mandated the valuation of CO_2 emission reductions in federal regulations.
- Since then the SC-CO_2 has been used in dozens of regulatory impact analyses.

The 4 steps of SC-CO_2 estimation



Source: Committee report.

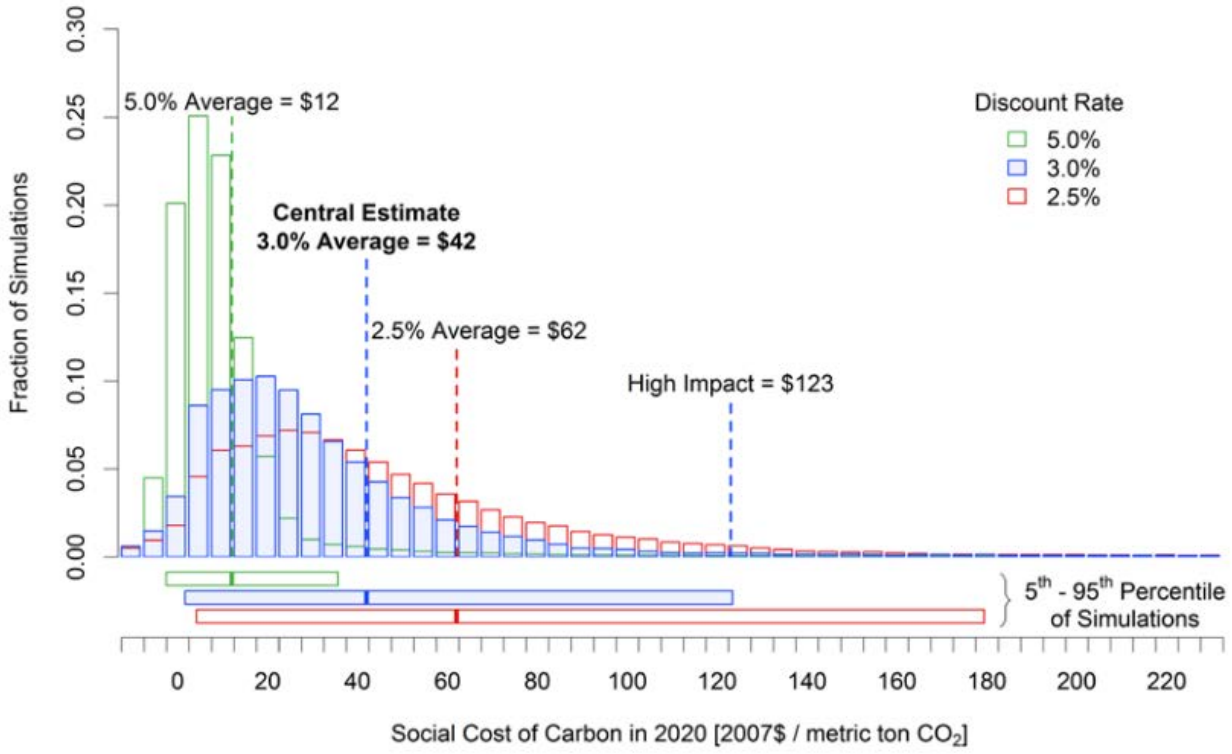
1. Projections of future population & GDP generate a CO_2 emissions path
2. CO_2 emissions path leads to predictions of mean global temperature change
3. Temperature change leads to damages, which are monetized and aggregated
4. Damages persist for many decades: discounting is used to sum them into a single present value

This 4-step procedure is done with both baseline emissions and with a small additional amount (a pulse) of CO_2 emissions in a particular year.

SC-CO_2 is the per-ton difference in present value of damages due to the pulse.

IWG estimation of the SC-CO_2

- The IWG used three integrated assessment models (SC-IAMs) from the peer-reviewed literature (DICE, FUND, and PAGE),
- five socioeconomic-emissions scenarios,
- a probability distribution for the equilibrium climate sensitivity, and
- three different constant discount rates (2.5%, 3.0%, 5.0%).



Source: 2016 IWG Technical Support Document

The Committee's Conclusions and Recommendations

Organization of the final Phase 2 report*

Ch. 1: Introduction

Ch. 2: Overview of the proposed SC-CO_2 modeling framework

Ch. 3-6: Specific recommendations for each of the 4 key modeling steps in the near term (2-3 years) and the longer term

- Socioeconomic module
- Climate module
- Damages module
- Discounting module

Ch. 7: Directions for future research

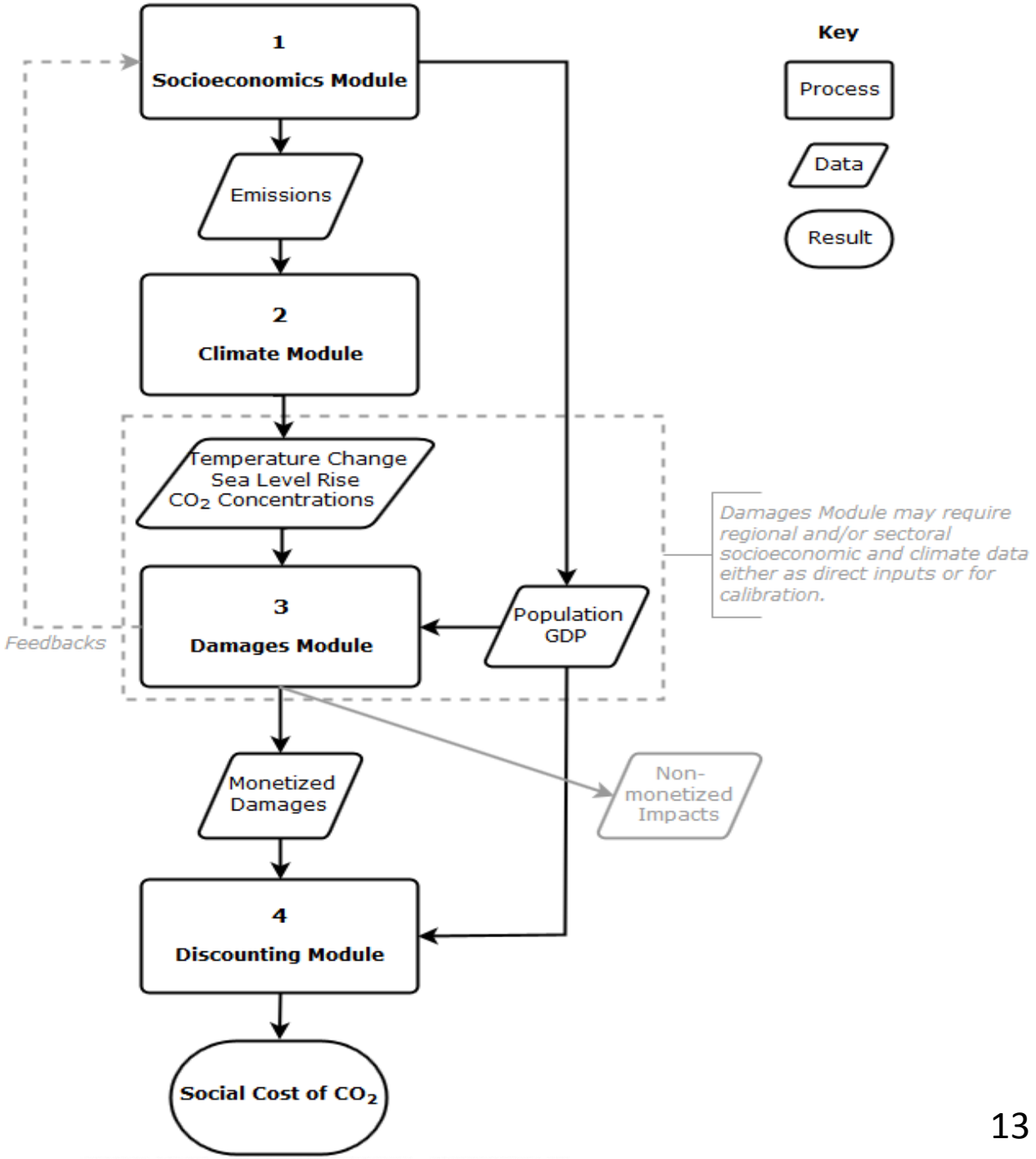
*Available at NAP.edu (search for "Valuing Climate Damages")

An integrated, modular framework (Conc. 2-1, 2-2, Rec. 2-1)

"Unbundle" the process of SC-CO_2 estimation into 4 modular steps that are integrated with one another.

- Each module would be developed based on expertise within the relevant disciplines and to reflect the state of scientific knowledge relevant to that part of the analysis .
- Provides a transparent articulation of the inputs, outputs, uncertainties, and linkages among the different steps.
- Can improve control over characterization of uncertainty within the steps and through an integrated framework for propagating uncertainty through the estimation process.

An integrated, modular approach for estimating the SC-CO_2 (Fig 2-1)



Over-arching criteria for SC-CO_2 estimation (Rec. 2-2)

- **Scientific basis:** Modules should be consistent with scientific knowledge in the current, peer-reviewed literature.
- **Uncertainty characterization:** Key uncertainties—including functional form, parameter assumptions, and data inputs—should be adequately represented. Uncertainties not quantified should be identified.
- **Transparency:** Documentation should allow people to understand and assess the modules, including which features are evidence-based or judgment-based. Model code should be available to researchers.

Domestic and global SC-CO_2

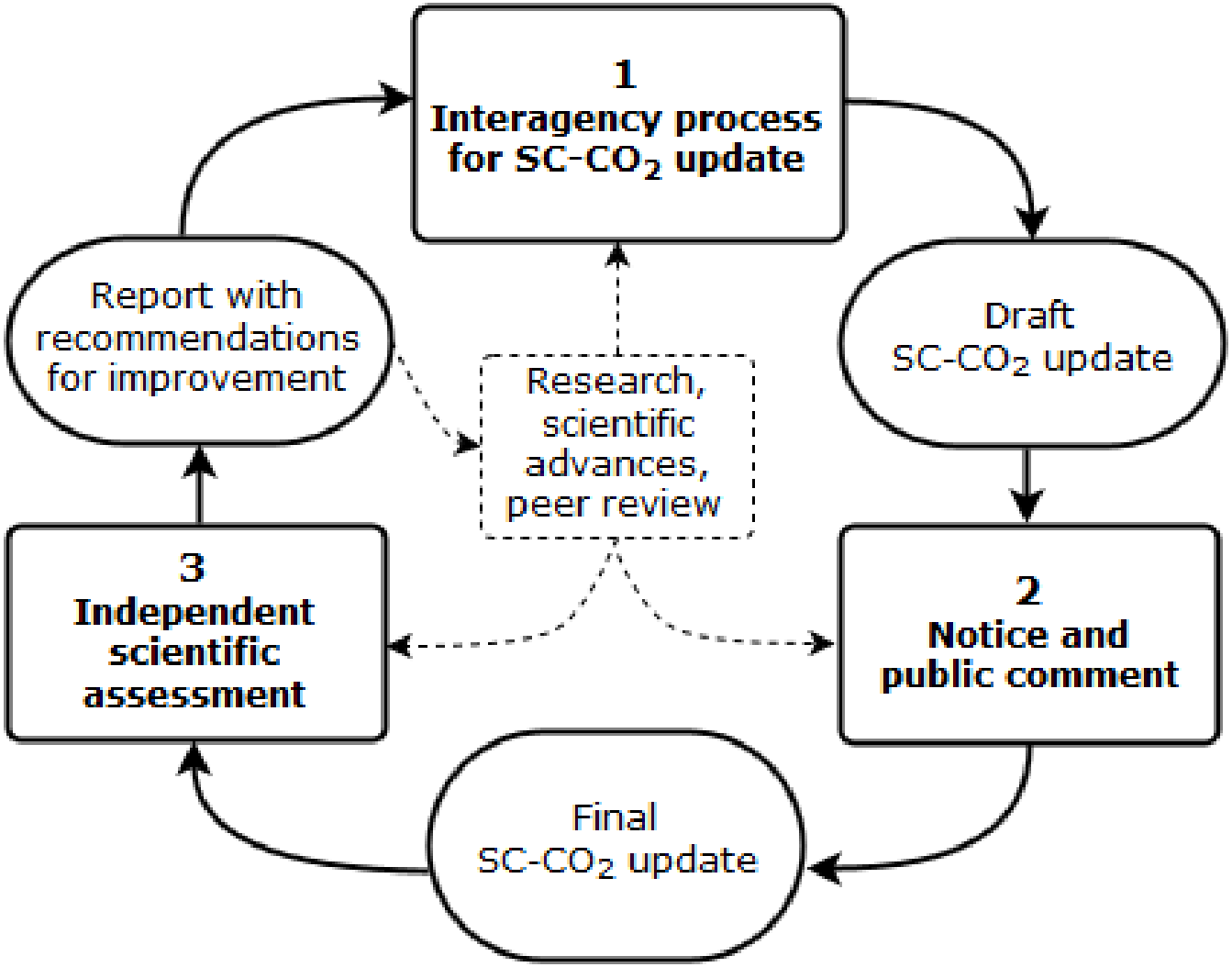
- **IWG has focused on estimating a global SC-CO_2, as has the peer-reviewed literature**
  - CO_2 impacts are global, regardless of where emissions occur.
  - Climate impacts in other countries may affect the United States (e.g., global migration, economic and/or political destabilization).
  - US emission reductions encourage reciprocal actions by other countries.
- **Difficulties in computing a US-only estimate (Conc. 2-4)**
  - Important to consider what constitutes domestic impact in the context of a global pollutant that has international implications that affect the US.
  - Need an SC-CO_2 framework that adequately captures these interactions.
  - Existing SC-IAM methodologies do not model all relevant interactions among regions.
  - In estimating a domestic SC-CO_2 need to consider potential implications of climate impacts on other countries and actions by other countries.

A regularized process to update SC-CO_2 estimates (Rec. 2-4)

- An update cycle of roughly **5 years balances the need to respond to evolving research with the need for a thorough and predictable process.**
- The IWG should establish a **three-step process** for updating the SC-CO_2 estimates.

1. Estimates should be revised drawing on internal and external technical expertise and incorporating scientific peer review.
2. Draft revisions to the SC-CO_2 methods and estimates should be subject to public notice and comment.
3. The government's approach to estimating the SC-CO_2 should be reviewed by an independent scientific assessment panel to identify improvements in future updates and research needs.

Regularized process for SC-CO_2 updates (Fig. 2-2)



Near-term and Longer-term Updates

Near-term Updates

Recommendations that would be feasible to implement in the next 2 to 3 years:

- **Socioeconomic module** should use statistical methods and expert elicitation for projecting distributions of GDP, population growth and emissions into the future
- **Climate module** should employ a simple Earth system model that satisfies well-defined diagnostic tests
- **Damages module** should improve and update existing damage functions drawing on recent scientific literature
- **Discounting module** should incorporate the relationship between discount rates and economic growth to account for uncertainty over long time periods

Longer-term Updates

- Longer-term steps for the development and improvement of each module are outlined along with characteristics that each future module should have.
- Feedbacks between the modules and interactions within each module should also be incorporated in the longer term.

The Socioeconomic Module

The Problem

- Need to project population, GDP, and emissions with/without CO_2 pulse; impact of pulse likely to vary with state of economy, environment
- A very hard problem:
  - CO_2 long-lived; certainly need more than a century
  - Need regional, perhaps sectoral detail for damages
  - Complex uncertainty: technologies, mitigation policies, regional/sectoral shares
  - Feedbacks: climate damages → economy, environment…

The IWG Approach

- Relied on 5 EMF scenarios for projections to 2100; mechanically extended to 2300
- Four BAU scenarios, one with serious mitigation – a good representation of uncertainty?
- Extension to 2300 apparently necessary to get most discounted damages; mechanical scenario extension method developed by IWG, not defended
- Scenarios generally too aggregated for damage analysis

Proposed Near-Term Update (Rec. 3-2)

- Using the identity E ≡ N*(Y/N)*(E/Y), generate a small set of aggregate baselines that can be treated as representative of a plausible pdf
  - Use an appropriate statistical technique to **estimate a probability density of average annual growth rates of global per-capita GDP.**
  - Work with demographers who have produced probabilistic projections through 2100 to create a small number of **population projections beyond 2100** to represent a probability density function.
  - For each population/income scenario, use **expert elicitation** to produce **a small number of emissions trajectories for each forcing agent** of interest.
  - For each N, Y, E scenario, then develop one or more projections of sectoral/regional GDP and regional population using scenario libraries, published regional or national projections, detailed-structure economic models, SC-IAMs, or other sources. Non-stochastic.
- Some shortcomings:
  - No regional/sectoral structure, no trade flows
  - Who are the experts on future mitigation, technology, etc. ? (Unavoidable problem)
  - Regional disaggregation non-stochastic, despite complex real uncertainty (e.g., China)
  - No feedbacks from damages to economy, environment

Longer-term updates (Rec. 3-3)

The IWG should develop a new socioeconomic module that:

- provides internally consistent probabilistic projections as far beyond 2100 as required to capture the vast majority of discounted damages, taking into account the increased uncertainty regarding technology, policies, and social and economic structures in the distant future;
- provides probabilistic regional and sectoral projections consistent with requirements of the damage module;
- captures important feedbacks from the climate and damage modules that affect capital stocks, productivity, and other determinants of socioeconomic and emissions projections;
- is developed in conjunction with the climate and damage modules, to provide coherent propagation of uncertainty through the components of the SC-CO_2 estimation procedure.

This will involve significant research:

- Current models are not designed for centuries-long projections
- Need to go beyond modelers' judgements, include other experts
- Need more work on feedbacks to incorporate main ones; integrate with damages module?
- Need only enough detail for damages, but probably do need trade
- How to do stochastic regional/sectoral disaggregation?

The Climate Module

Climate module:
Near-term update (Rec. 4-1)

IWG should adopt a climate module that captures the relationships between CO_2 emissions, atmospheric CO_2 and global mean surface temperature change over time.

- Module should capture uncertainty in these relationships and project atmospheric CO_2 and mean global temperature over time.
- Module should be assessed on the basis of its response to long-term forcing trajectories and to a pulse of CO_2 emissions.
- The FAIR model provides a proof-of-concept (see Ch. 4).
- The IWG should also adopt a sea level rise component and a surface ocean pH component in the climate module that are consistent with the current peer-reviewed literature. (Rec. 4-3, 4-4)

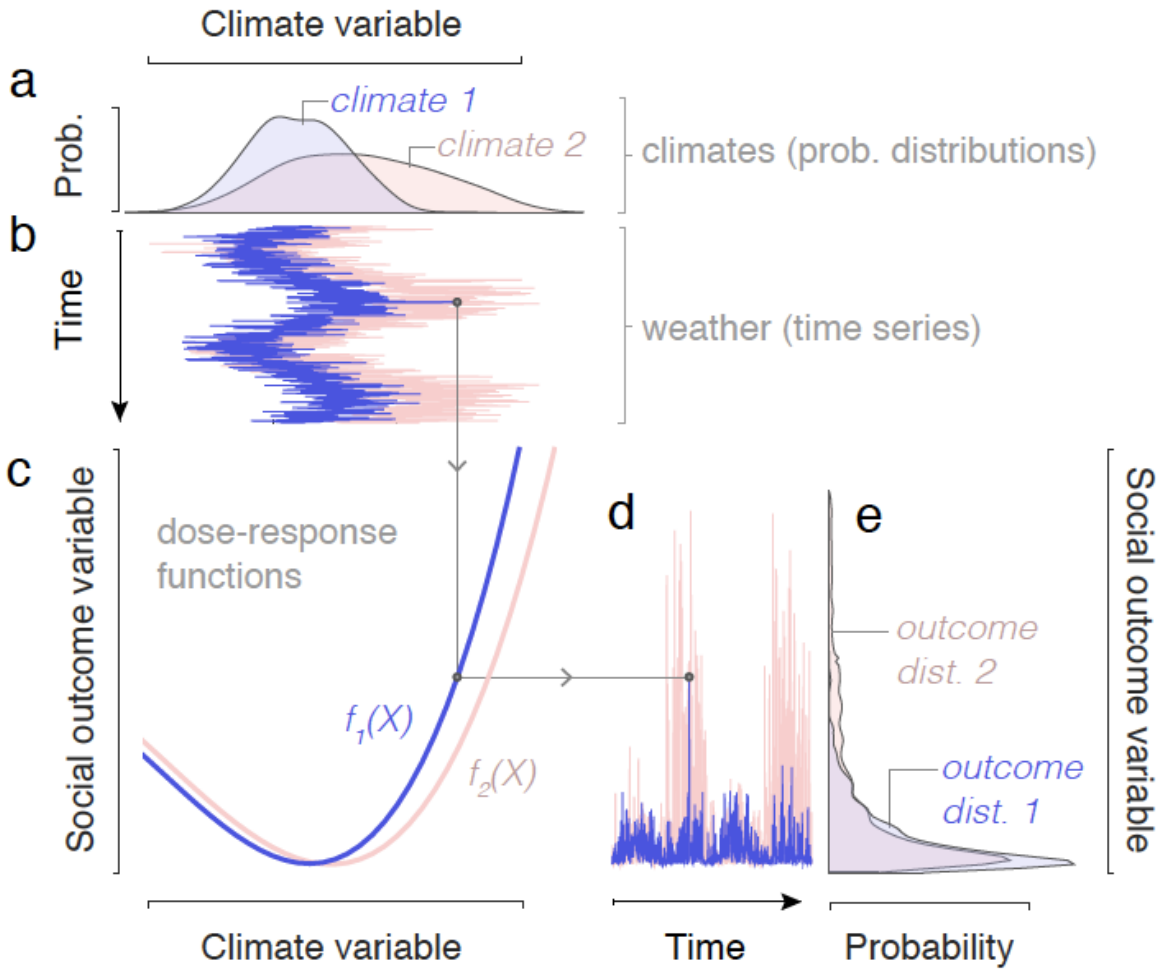
Climate module:
geographic/temporal disaggregation

- To the extent required by the damages module, the IWG will need to regionally disaggregate temperature, precipitation, and other climate variables, and provide a frequency of extremes in addition to mean values. (Rec. 4-5)

- In the near term, linear pattern scaling, although subject to numerous limitations, provides an acceptable approach to estimating some regionally disaggregated variables from global mean temperature and global mean sea level. (Conc. 4-3)

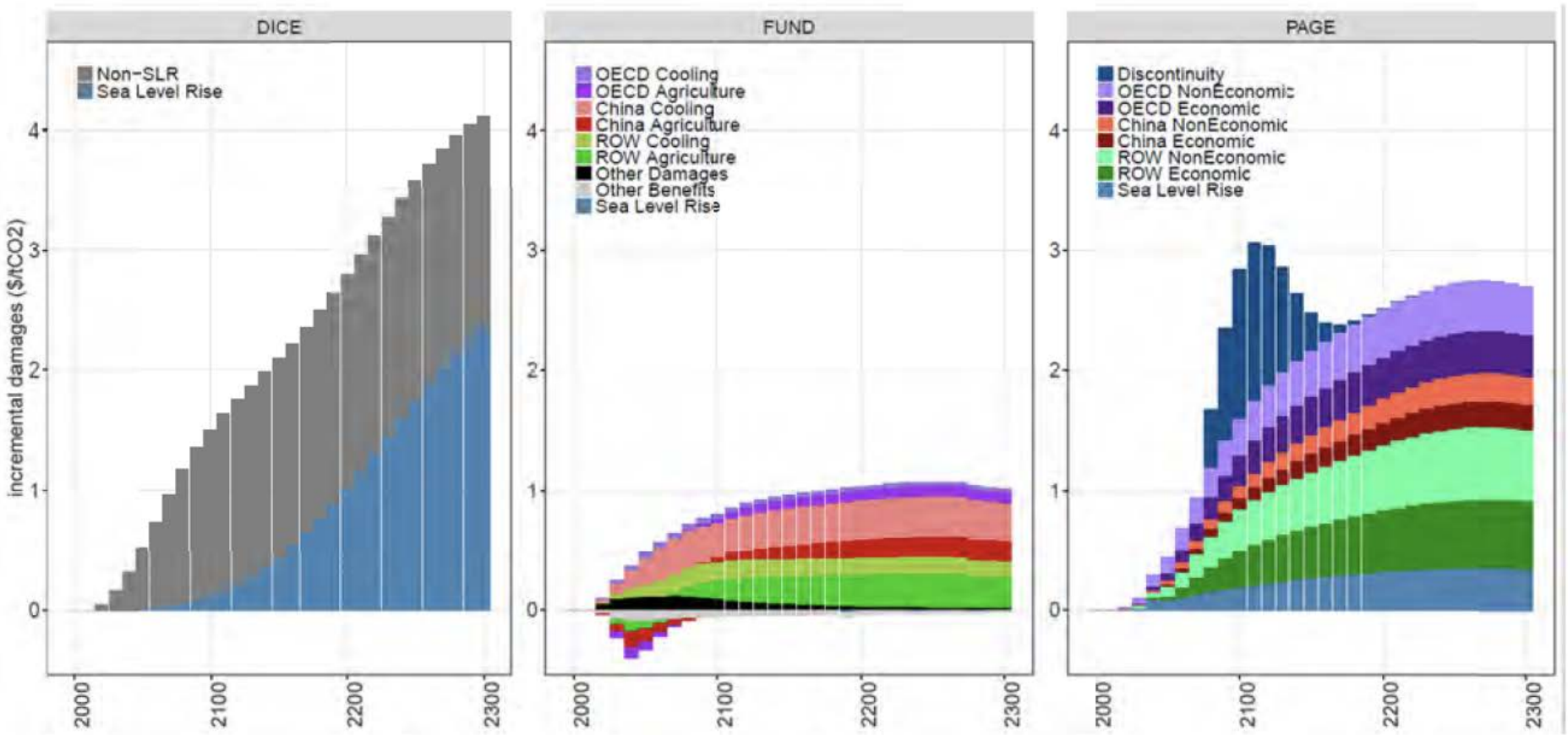
The Damages Module

Recent Explosion of Literature on Damage Function Estimation



Carleton & Hsiang (2016)

Incremental Annual Damages
DICE/FUND



Damages module:
Near-term update (Rec. 5-1)

IWG should develop a damages module using elements from the current SC-IAM damage components and scientific literature.

- Individual sectoral damage functions should be updated as feasible.
- Damage function calibrations should be transparently and quantitatively characterized.
- If multiple damage formulations are used, they should recognize any correlations between formulations.
- A summary should be provided of disaggregated (incremental and total) damage projections underlying SC-CO_2 calculations, including how they scale with temperature, income, and population.

Damages module:
Longer-term updates (Rec. 5-2)

IWG should develop a damages module with the following five features:

1. Disaggregates market and nonmarket climate damages by region and sector, presenting results in monetary and natural units.

2. Includes important interactions and spillovers among regions and sectors, as well as feedbacks to other modules.

3. Considers damages that affect welfare directly or through changes to consumption, capital stocks (physical, human, natural), or other channels.

4. Includes adaptation to climate change and the costs of adaptation.

5. Includes representation of nongradual damages, such as those associated with climatic or socioeconomic thresholds.

The Discounting Module

Discounting module:
Linking to uncertainty in economic growth (Rec. 6-1)

- Current approach uses three constant discount rates:
  - 2.5%: to capture uncertainty in discount rates over time
  - 3.0%: consumption rate of discount (OMB)
  - 5.0%: to capture positive correlation between damages and economic growth
- Discounting module should explicitly recognize the uncertainty surrounding discount rates, its connection to uncertainty in economic growth, and in turn to damages.
- Damages associated with each economic growth rate scenario should be discounted at a rate based on that same economic growth scenario.

Discounting module:
Using the Ramsey formula (Rec. 6-2)

Ramsey formula links the discount rate ***r*** and GDP growth rate ***g***:

$r = \delta + \eta g$: where δ is the rate of time preference and η measures how people value additional increments to income

- The IWG should choose η and δ that are consistent with theory and evidence and produce certainty equivalent discount rates consistent, over the next several decades, with consumption rates of interest.
- The IWG should use three sets of Ramsey parameters (η, δ) , generating a low, central, and high near-term discount rate, and thus three means and ranges of SC-CO_2 estimates.

Summary

- A modular approach should be adopted to allow relevant disciplinary expertise to shape each part of the SC-CO_2 analysis.
  - Output from each module should be presented in probabilistic form to facilitate uncertainty analysis of results.
  - Explicit probability distributions should be derived for socioeconomic inputs (GDP, population, emissions).
  - The climate module should represent temperature change over time and include sea-level rise and ocean pH components.
  - Damage functions should be updated to reflect recent literature.
  - The discounting approach should link discount rates to the uncertain rate of economic growth and, in turn, damages.
- Criteria regarding the scientific basis, characterization of uncertainty, and transparency should be applied.
- A regularized 3-step process should be established for updating the SC-CO_2 roughly every 5 years, informed by ongoing research.