MACRO-ENERGY MODELS: LOOKING BACK AND LOOKING FORWARD

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Macro-Energy Systems Workshop

Precourt Institute for Energy

Stanford University

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The conference is part of an effort to launch a "New Discipline" for Macro-Energy Systems.

Macro-Energy Systems: Large scale energy systems and the energy transition

"Humanity is faced with the need for two massive, interrelated energy transitions, and there is considerable uncertainty about the best way to undertake them. A transition to low- and no-carbon energy technologies underpins all realistic climate solutions. Simultaneously, the reach of modern energy services must grow substantially to reach more than a billion people who currently do not have access. Solving these intertwined challenges will require changes of an unprecedented scale occurring over multiple decades, and a substantial number of researchers are working to understand and advise these transitions. We believe that these efforts could be aided by cultivating a community of scholars—a new discipline—that focuses on the large-scale, systems-level, long-term aspects of sustainable energy planning. We call this discipline ''macro-energy systems.'' (Levi et al., 2019)

The experience with energy models for policy provides good and bad lessons to help guide this endeavor. The personal perspective here sketches an incomplete outline to motivate the effort.

Looking Back

1. Early days before the oil embargo of 1973.
2. Arab oil embargo and Project Independence.
3. Model transparency.
4. Energy Modeling Forum.

Looking Forward

5. Hard questions.
6. Uncertainty.
7. Opportunities and Challenges.

An early trajectory mixed with serendipity and surprise.

Looking Back

(My) Early days before the oil embargo of 1973.

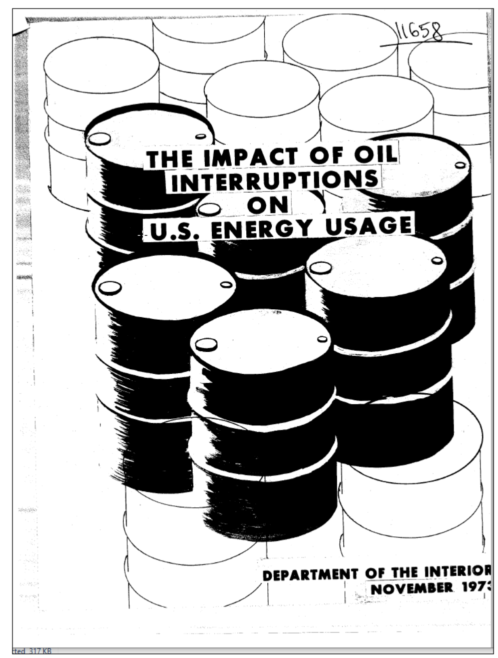
- 1967-1969: Pentagon. “Undergraduate Pilot Training Surge Capacity” study. (with Herbert Winokur of SecDef Systems Analysis)
  - A dispute over the need for additional pilot training bases.
  - A model of dynamic scheduling to account for multiple locations, seasonal flight restrictions, multiple training stages. A linear program.
  - The analysis resolved the dispute in favor of the Air Force proposal.
- 1969-71: UCLA PhD under assignment from Air Force.
  - Dissertation on “large scale” optimization decomposition methods. (Hogan, 1973a) (Hogan, 1973b) (Hogan, 1973c).
  - Dissertation Advisor: Art Geoffrion. “The purpose … is insight, not numbers.” (Geoffrion, 1976)
- 1971-1973: USAF Academy. “The Implications of Paying for What You Get.” (with Eric Hanushek)
  - Well received by the Secretaries of Defense (Elliot Richardson, James Schlesinger).
  - Not well received by the Air Force.

The Arab Oil Embargo of October 1973 was a surprise that changed many things.

Looking Back

Arab Oil Embargo.

- 1973: Department of Interior.
  - September: Deputy Assistant Secretary Office: Eric Zausner, with Bart Holaday.
    - Office of Oil and Gas, Bureau of Mines. (Established Organizations in DOI)
    - Office of Energy Data and Analysis. (Dave Wood, Frank Alessio)
    - First impressions.
  - October: Arab Oil Embargo.
    - Conflicting Estimates of the Impact on U.S. oil imports.
    - No modeling tools or computer data bases.
    - Herb Stein, Council of Economic Advisors, on government preparedness.
  - November: The Barrels Report
    - "The Impact of Oil Interruptions on U.S. Energy Usage."
    - The press conference in November. Passing the baton.

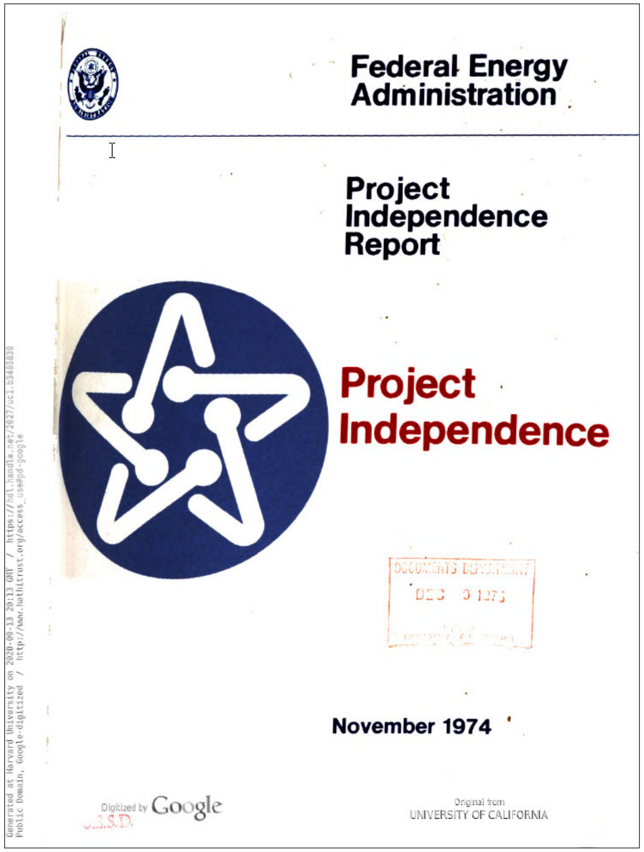


The Arab Oil Embargo response morphed quickly into "Project Independence."

Looking Back

Project Independence.

- November 7, 1973: President Nixon Launches "Project Independence".
  - "Let us unite in committing the resources of this Nation to a major new endeavor, an endeavor that in this Bicentennial Era we can appropriately call 'Project Independence.' Let us set as our national goal, in the spirit of Apollo, with the determination of the Manhattan Project, that by the end of this decade we will have developed the potential to meet our own energy needs without depending on any foreign energy sources. Let us pledge that by 1980, under Project Independence, we shall be able to meet America's energy needs from America's own energy resources."
  - Eric Zausner later summarized: "The task was to redefine two terms: 'Independence' and '1980'.
- Project Independence Report. (Federal Energy Administration, 1974)



Project Independence depended on mobilizing people and material across the U.S. Government.

Looking Back

Project Independence Report.

The complete list of working group members required ten single spaced pages.

A representative sample:

Eric Zausner, Bart Holaday, Bruce Pasternack.

Alvin Cook, Alvin Weinberg, Bart House, Bonita J. Mampe, Darius Gaskins, David H. Nissen, David O. Wood, David Oliver, Donald Eldridge, Ed Krapels, Eric Hirst, Eugene J. Reiser, Hillard Huntington, Hoff Stauffer, James Sweeney, John D. Pearson, John Fallon, Mark E. Rodekohr, Maxine Savitz, Melinda G. Rackoff, Michael H. Wagner, Mike Tayyabkham, Pat Huber, Peter Borre, Ralph E. Miller, Robert Eynon, Stephen Chapel, Susan H. Shaw, Thomas Tietenberg, W. Charles Mylander III, William Hogan, William Stitt.

PROJECT INDEPENDENCE WORKING GROUP MEMBERS

LEGEND

AEC - Atomic Energy Commission
AMS - American Management Systems
CEQ - Council on Environmental Quality
CIA - Central Intelligence Agency
DOA - Department of Agriculture
DOC - Department of Commerce
DOI - Department of Interior
DOL - Department of Labor
DOT - Department of Transportation
EPA - Environmental Protection Agency
FEA - Federal Energy Administration
FPC - Federal Power Commission
GSA - General Services Administration
HUD - Housing and Urban Development
ICC - Interstate Commerce Commission
MARAD - Maritime Administration
NASA - National Aeronautics and Space Administration
NBS - National Bureau of Standards
NOAA - National Oceanographic and Atmospheric Administration
NSF - National Science Foundation
OMB - Office of Management and Budget
OSW - Office of Saline Water
TVA - Tennessee Valley Authority
USDA - Department of Agriculture

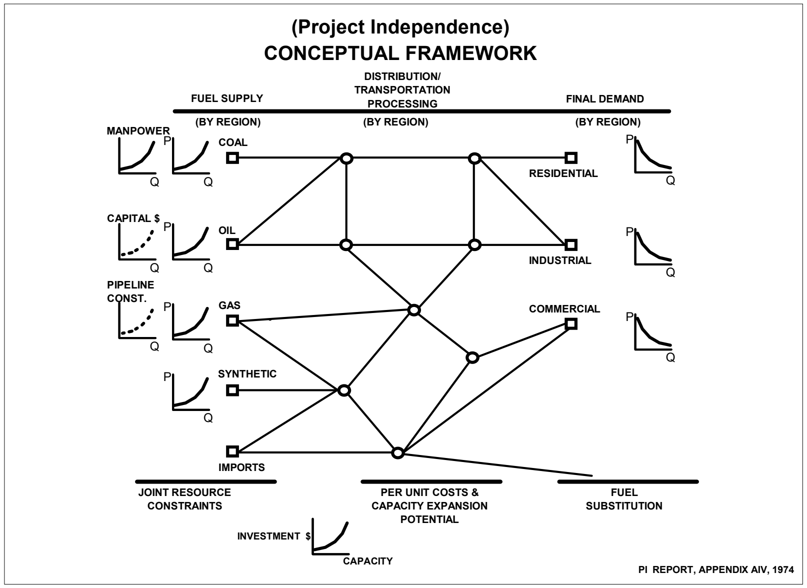
The analytical effort focused on providing supply and demand curves, technology parameters and constraints, and environmental information for an integrating model applied for 1980 and 1985.

Looking Back

Project Independence Report.

- Project Independence Evaluation System (PIES). (Hogan, 1975)
    - Multiple Products.
    - Multiple Regions.
    - Conversion Technologies.
    - Econometric Demand Models.
    - Resource and Environmental Constraints.
    - Software Challenges.
    - Equilibrium Modeling.

    "To a large extent, the PIES model and the associated PIES algorithm have provided impetus for the growth of the field of finite dimensional variational inequality and nonlinear complementarity problems." (Harker & Pang, 1990)



- Repeated Application for Different Questions.
    - Oil Price Scenarios and Import Substitution.
    - Environmental Regulation.

The expanded use of formal models raised many questions about the "black box" and the control of information.

Looking Back

Model Transparency.

- PIES Applications and Reviews.
  - The PIES model was applied to many different questions and received close attention from Congress. The emphasis was on "why" questions about energy policy.
  - There were several formal reviews and critiques by independent groups. (Hausman, 1975) (General Accounting Office, 1976)
  - The model was further developed, refined and applied under the Energy Information Administration in the Department of Energy. (Hogan, Sweeney, & Wagner, 1978) (Murphy & Shaw, 1995)
- Limits to Growth. (Meadows, Meadows, Randers, & Behrens, 1972)
  - The famous publication by the Club of Rome was part of the background environment.
  - Apocalyptic and wrong; but transparent.
  - Nordhaus critique depended on model transparency. (Nordhaus, 1973) (Nordhaus, 1992b)
- Martin Greenberger and Models in the Policy Process. (Greenberger, Crenson, & Crissey, 1976) (Greenberger & Richels, 1979) (Greenberger, 1983)

The focus on model transparency translated into the continuing efforts of the Energy Modeling Forum.

Looking Back

Energy Modeling Forum.

- 1976 EPRI initiative developed by Martin Greenberger.
  - Engineering and Economic Systems at Stanford University.
  - Goal to improve models for the policy process.

  "EMF seeks to improve the use of energy and environmental policy models for making important corporate and government decisions. Three major goals guide this effort: Harness the collective capabilities of multiple models to improve the understanding of important energy and associated environmental problems, explain the strengths and limitations of competing approaches to the problem, and provide guidance for future research efforts. … EMF was established at Stanford in 1976 to bring together leading experts and decisionmakers from government, industry, universities, and other research organizations to study important energy and environmental issues. For each study, the Forum organizes a working group to develop the study design, analyze and compare each model's results and discuss key conclusions. … A major research university provides the Forum with a non-partisan platform for objective discussion of important issues. EMF participants offer alternative views based upon their research and experience. The studies do not try to forge a consensus but instead highlight why experts may disagree." (EMF 2020 Web page)

The first report of the EMF applied methods for comparing models with common inputs, and explaining any resulting differences in outputs.

Looking Back

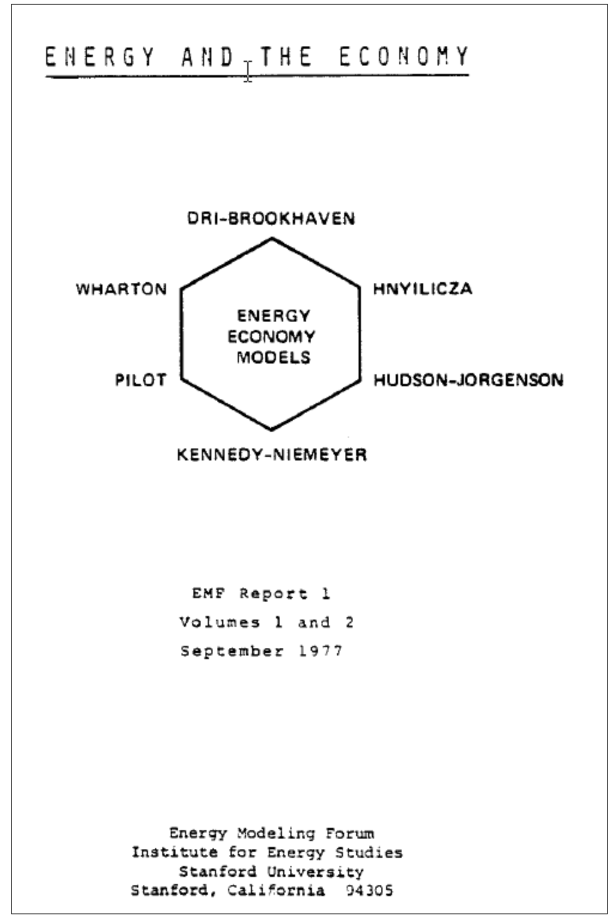
Energy Modeling Forum.

- EMF 1: Energy and the Economy. (Energy Modeling Forum, 1977)

  "Higher energy prices or reduced energy utilization need not produce proportional reductions in aggregate economic output. There is a potential for substituting capital and labor for energy and the contribution of energy to the economy, relative to these factors, is small. … The models require assumptions about future population or labor force growth and the rate of technological change which, other things equal, determine the growth path of the GNP."

- EMF 36: Carbon Pricing After Paris. (EMF Web Page, 2020)

  "The EMF 36 study investigates how the Paris Agreement on greenhouse gas emission reductions can be reached through climate policy measures by means of more stringent carbon pricing. … The fundamental objective is to provide robust insights into policy options trading off key dimensions of a sustainable climate future, i.e. environmental effectiveness, overall economic performance and the incidence of regulatory measures."

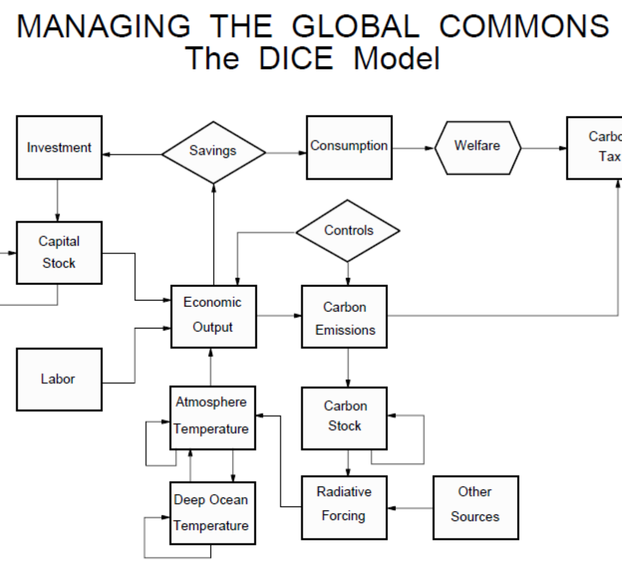


The Dynamic Integrated Climate Economy (DICE) model is an exceptional example of parsimonious balance of detail and tractability.

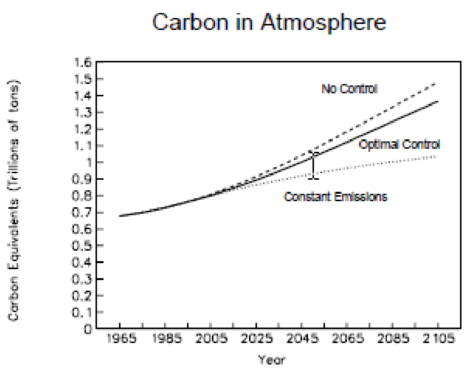
Looking Forward

Hard questions.

- Nordhaus, Climate Change and the Social Cost of Carbon (SCC).
  - DICE (Nordhaus, 1992a)



Note: Adapted from W. Nordhaus, "An Optimal Transition Path for Controlling Greenhouse Gases," SCIENCE, Vol. 258, 20 November 1992, pp. 1315–1319.



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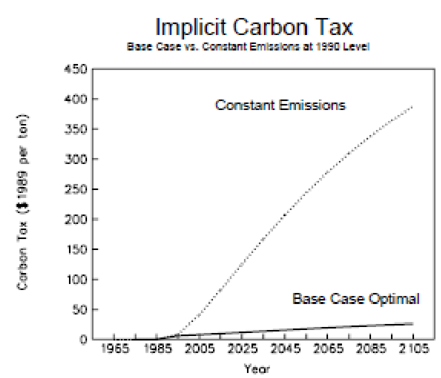


Note: Adapted from W. Nordhaus, "An Optimal Transition Path for Controlling Greenhouse Gases," SCIENCE, Vol. 258, 20 November 1992, pp. 1315–1319.

The many adaptations and extensions of the DICE model, by Nordhaus and others, illustrate the search for insight as well as numbers.

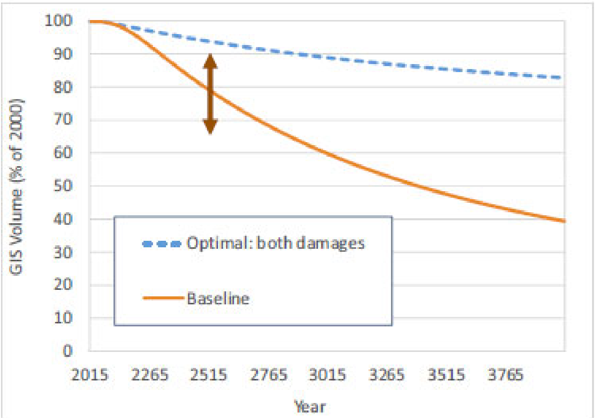
Looking Forward

Hard questions.

- Nordhaus and Climate Change.
  - Greenland Ice Sheet. DICE-GIS. (Nordhaus, 2019)

"…integrated economic–climate models of tipping points and catastrophes have been schematic and have generally not relied on realistic geophysical models."

" … the optimal path shows a slower melt, and the GIS remains above 80% of current volume and is safely above the upper threshold volume … for at least a millennium. … For the lowest discount rates and the higher melt rate, the GIS adds at most 5% to the estimated SCC."



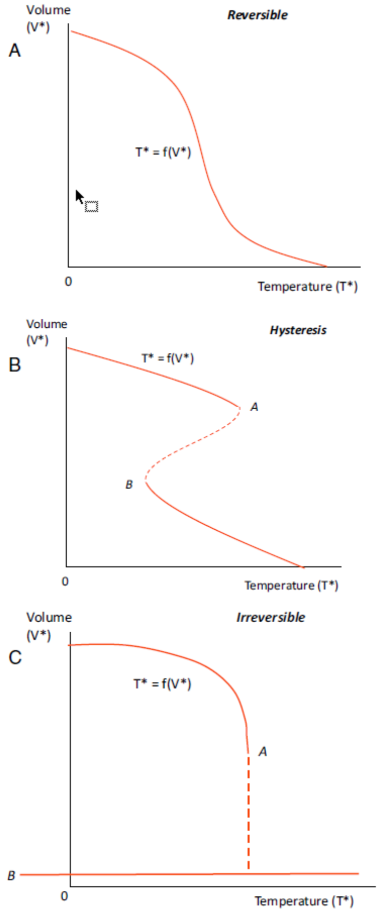


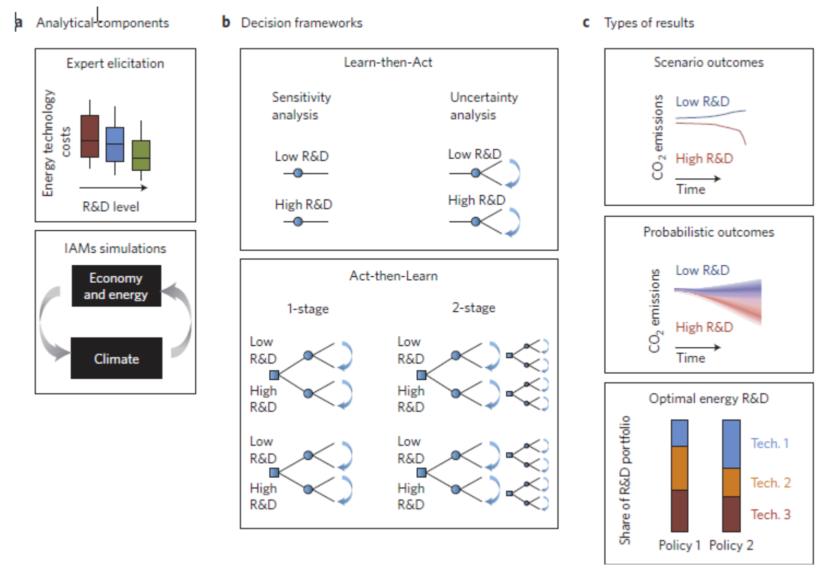
Fig. 1. Alternative specifications of GIS equilibrium. *A* is reversible; *B* displays hysteresis; *C* is effectively irreversible because rebuilding requires ice age conditions.

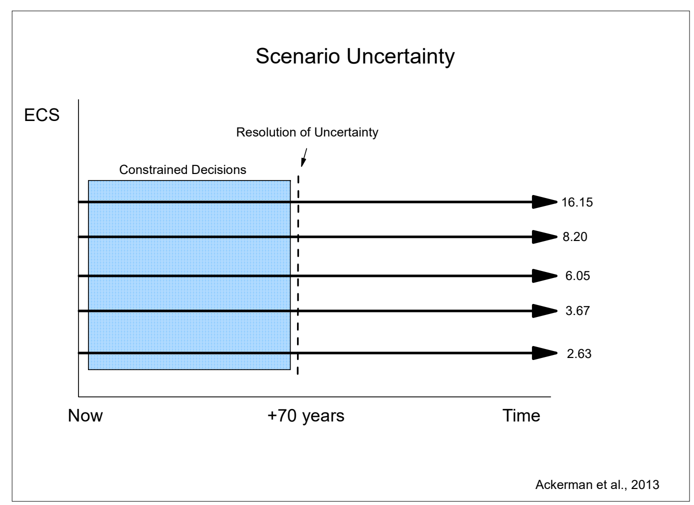
The treatment of uncertainty remains a major challenge.

Looking Forward

Uncertainty.

- Sequential Resolution of Uncertainty: Act-Learn-Act-Learn-Act … . (Anadón, Baker, & Bosetti, 2017)
- Transparent Models.
  - Breeder Reactor. (Manne & Richels, 1978)
  - Oil Stockpiling. (Teisberg, 1981)
  - Climate Change. (Manne & Richels, 1991)
  - Climate Change and Equilibrium Climate Sensitivity (ECS) uncertainty. (Ackerman, Stanton, & Bueno, 2013)



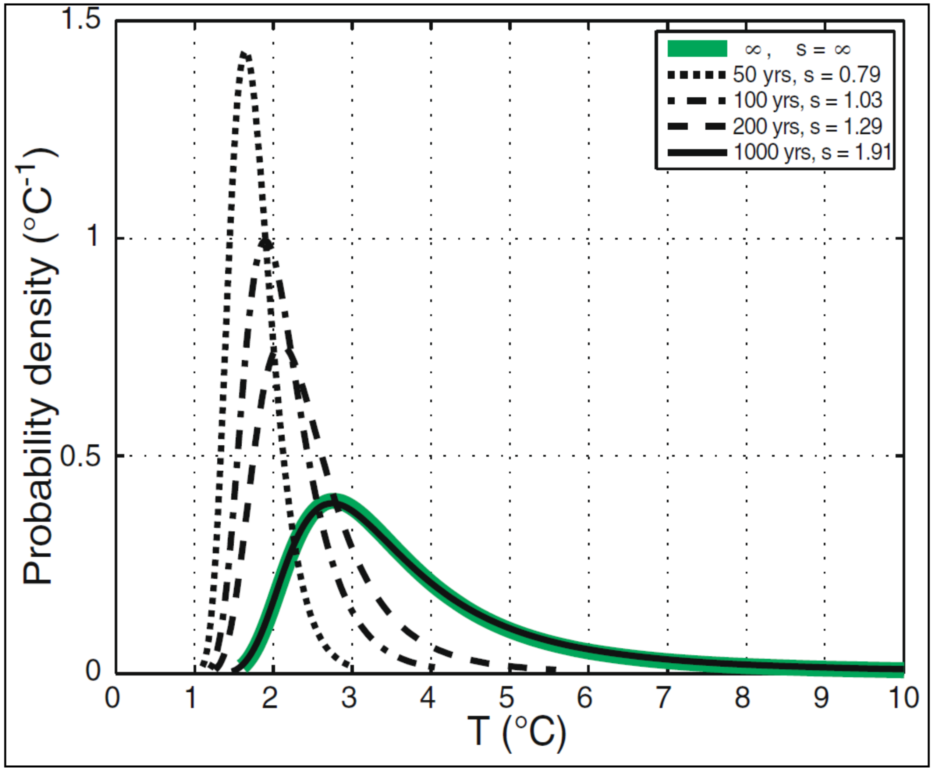


The treatment of uncertainty includes computational, conceptual and communication challenges.

Looking Forward

Uncertainty.

- More Challenging Models.
  - An implementation with full Stochastic Dynamic Programming. (Cai, Lenton, & Lontzek, 2016). "We solve the model with parallel dynamic programming methods on 312,500,000 approximation nodes for the ten-dimensional continuous state space and degree-4 complete Chebyshev polynomials for each of the five discrete state vectors. It takes about 3 h to solve the model for a single set of parameter values on 10,560 cores at the Blue Waters supercomputer."
  - ECS uncertainty: "…there are important physical constraints on the climate system that limit how fast temperatures can rise ….even for a planet that is formally headed to[ward] oblivion, it can take a very long time to get there." (Roe & Bauman, 2013, pp. 649–652)



Opportunities and challenges for Macro-Energy Systems.

> "A transition to low- and no-carbon energy technologies underpins all realistic climate solutions. Simultaneously, the reach of modern energy services must grow substantially to reach more than a billion people who currently do not have access."

- Multiple Models. "Fit for Purpose."
- Model Transparency. Numbers are important, but insight is invaluable.
- Expect Surprises. "… the range of uncertainty is impressive; it is so large that the uncertainty may be the most important feature of the analysis." (Hogan, 1985)
- Balance Costs and Benefits. On an optimal mitigation path, the carbon price is the social cost of carbon. (National Academy of Sciences, 2017) Actions which cost less than this price would be supported. Actions which cost more than the carbon price, would not be supported or would need some additional justification.
- Efficiency, Incentives, Innovation.
- Hard Questions.
    - Horizontal Equity.
    - Intergenerational Equity.
    - Discount Rates.
- Herb Stein's Law. "If something cannot go on forever, it will stop."

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