



engineering and public policy

Preparing Technical Leaders to Address Policy Issues
that Involve Science and Technology.



An Overview of >25 years of HDGC, CDMC and CEDM

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First a word of thanks

While the work we will discuss today has been supported by a variety of sources including EPRI, DOE and others, the most important has been NSF core support to HDGC, CDMC and CEDM.

HDGC: SES-9022738; SES-9209783; BCS-9218045

CDMC: SES-0345798; DMS-9523602; SBR-9521914

CEDM: SES-0949710

For this we are most grateful!

Our work on climate...

...grew out of work on the problem of acid rain.

Twenty-five years ago the growth of concern about the environmental impacts of the long-range transport of sulfur and nitrogen air pollution and associated acid precipitation prompted the development of a family of integrated assessment models designed to help decision-makers frame the issues and think about the policy response.

Three quite different...

...types of models were developed. In Europe, where there was no significant controversy over whether acid rain was a problem, the RAINS model was created and used to allocate emission reductions commitments across different EU member states (Alcamo et al, 1990).

In the U.S. the situation was quite different. Reluctant to take any regulatory action, the Regan Administration argued that the topic required further study and launched the National Acid Precipitation Assessment Program (NAPAP).

Two U.S. Modeling Efforts

In addition to mounting a variety of scientific field studies federal support was provided for the development of two integrated assessment models.

The first was undertaken by a group of U.S. DOE National Labs, each of which developed highly detailed science based sub-models with the idea that later they would be combined to produce an integrated tool for decision support. In the end they were never adequately integrated to provide such a capability.

A second, anchored at Carnegie Mellon and coordinated by Ed Rubin, was built in the Demos/Analytica[®] environment and was a single integrated model focused on characterizing the uncertainties.

The ADAM model

The resulting model was called ADAM (Acid Deposition Assessment Model). All of the key parameter uncertainties were represented as full probability distributions. (Rubin et al. 1990; Rubin et al. 1992). Analysis performed with the ADAM model concluded that, despite the various uncertainties, a U.S. acid rain control program had clear environmental benefits.

Rubin et al. (1990) estimated that for the Adirondack Park in upstate New York "...an additional 50 lakes ... would be expected to recover [and be able to support trout] as a result of [the proposed] 10 Mt/yr emissions reduction. For Boundary Waters [in northern Minnesota], an increase of six lakes supporting trout would be expected."

Rubin, E.S., C.N. Boyd, M.J. Small, R.J. Marnicio, and M. Henrion (1990). "Atmospheric Deposition Assessment Model: Applications to Regional Aquatic Acidification in Eastern North America," Chapter 14 p. 253-284 in, *Impact Models to Assess Regional Acidification*, J. Kamari (Ed.), Kluwer Academic Publishers, 310pp.

Atmospheric Deposition Assessment Model: Applications to Regional Aquatic Acidification in Eastern North America

E.S. Rubin, M.J. Small, C.N. Boyd, R.J. Marnicio, and M. Henrion

14.1. Introduction

US research efforts on the problem of "acid rain" are directed at improving current scientific understanding in critical areas, including sources of precursor emissions; the transport and transformation of pollutants in the atmosphere; the deposition of acidic species; and the chemical and biological effects of acid deposition on aquatic systems, materials, forests, and crops (NAPAP, 1986). The general goals of this research are to characterize the current situation and to develop analytical "models" for predicting the future response of systems to changes in key parameters.

Methods to link the various components of the problem so that the results of scientific research may be better related to the needs of policymakers also are being developed (Balson and North, 1982; Center for Energy and Environmental Studies, 1984; Alcamo et al., 1987). The goal of such "assessment" methods is to provide information useful for decisions about the need for - or consequences of - policy measures to abate acid deposition. A systematic characterization of uncertainties is an important part of assessment methods development.

The analysis presented here focuses on the effect of future emissions on regional aquatic acidification in eastern North America. Specifically, we wish to estimate the degree to which further acidification of lakes, and the consequent loss of fish life, might be expected in the absence of an acid rain control program,

Given our experience with ADAM...

...we began to argue that similar flexible integrated assessment models, that focused on uncertainty, would be valuable in the context of climate.

EDWARD S. RUBIN
LESTER B. LAVE
M. GRANGER MORGAN

Keeping Climate Research Relevant

The federal government must avoid repeating the mistakes it made in studying acid rain.

Recent post-mortems of the National Acid Precipitation Assessment Program (NAPAP) confirmed what Congress and other key parties to the acid rain debate already knew: that the 10-year, half-billion-dollar interagency program to guide U.S. policy on acid rain control proved largely irrelevant to the effort to forge the new Clean Air Act last fall. Although NAPAP won praise for its scientific accomplishments, the program failed in its primary mission—to provide policy-relevant information in a timely manner. Now, government attempts to deal with the more difficult and far-reaching environmental issues associated with global warming appear to be headed down the same ill-fated path.

Global climate change has become the most important environmental issue on the world agenda. The

potentially enormous human and ecological implications of global warming—rising sea levels, altered precipitation patterns, and damage to natural ecosystems—have generated concern. But the equally large uncertainties about the timing and magnitude of possible effects, coupled with questions about the costs and impacts of possible abatement measures, have thus far kept policymakers from agreeing on what to do.

European nations, especially the Scandinavian countries, have called for immediate, large-scale reductions in emissions of carbon dioxide and other “greenhouse” gases. The Bush administration has rejected such initiatives as hasty and wasteful of resources needed for more pressing matters. Until the global climate problem is better understood, the administration contends, the United States should not be stampeded into taking actions that could have ruinous consequences for the economy. The administration does, however, subscribe to the need for more research, boasting a billion-dollar annual federal research program.

Although the government’s decision to commit resources to research on global climate change is laudable, the structure of the program and the research

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WINTER 1991-92 47

Issues in Science and Technology, VIII(2), 47-55, Winter 1991-92.

Uncertainties of climate change

SIR — To resolve the uncertainties enveloping global climate change, the United States and, to a lesser extent, Europe have embarked on an extensive research effort. We believe that these research programmes will do little to provide a solid scientific foundation for policy decisions in the next decade.

Marginal improvements in current models, or additional runs of the global circulation models, will not resolve the fundamental uncertainties paralysing international negotiations. Research is at present focused on predicting the extent of climate change, a question that is unlikely to be resolved for at least another decade. More likely to be resolved and of greater importance in determining policy are the cost of abatement and the effects of climate change. In our view, scientific research is destined to remain largely irrelevant to political decisions about global climate change as it is not designed to produce answers when needed by policy makers.

These problems were the downfall of the decade long, half-billion-dollar National Acid Precipitation Assessment Project (NAPAP). Its important scientific findings had virtually no effect on policy and legislation. Research on the greenhouse effect is following the same path. If science is to be relevant to social decisions about global climate change, the programme’s management and focus must be changed. The focus should be on informing policy decisions over the next decade or two, not on abstract research. Fundamental research is needed, but the agenda must be structured to answer crucial policy questions, not simply to advance knowledge.

The United States is spending \$1,200 million on climate change research this year, but only 25 per cent of these resources are focused on the core issues. Even these programmes were generally designed to answer other questions. If scientific research is to inform political decisions, administrators need to exercise tough control. An integrated assessment is needed to identify the priority research and coordinate individual projects.

In our judgement, several independent assessments should be undertaken in parallel. Integrated assessments can spot the critical gaps in the current research agenda, discover research that isn’t on target or is wasteful, and detect the mismatches between the inputs that each group is expecting and the outputs that will be produced by other researchers. Global climate change is too important to repeat the same mistakes that crippled the \$500-million NAPAP programme.

LESTER B. LAVE
HADI DOWLATABADI
GREGORY J. McRAE
M. GRANGER MORGAN
EDWARD S. RUBIN

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Pittsburgh, Pennsylvania 15213, USA*

Nature, 355, 1992 January 16.

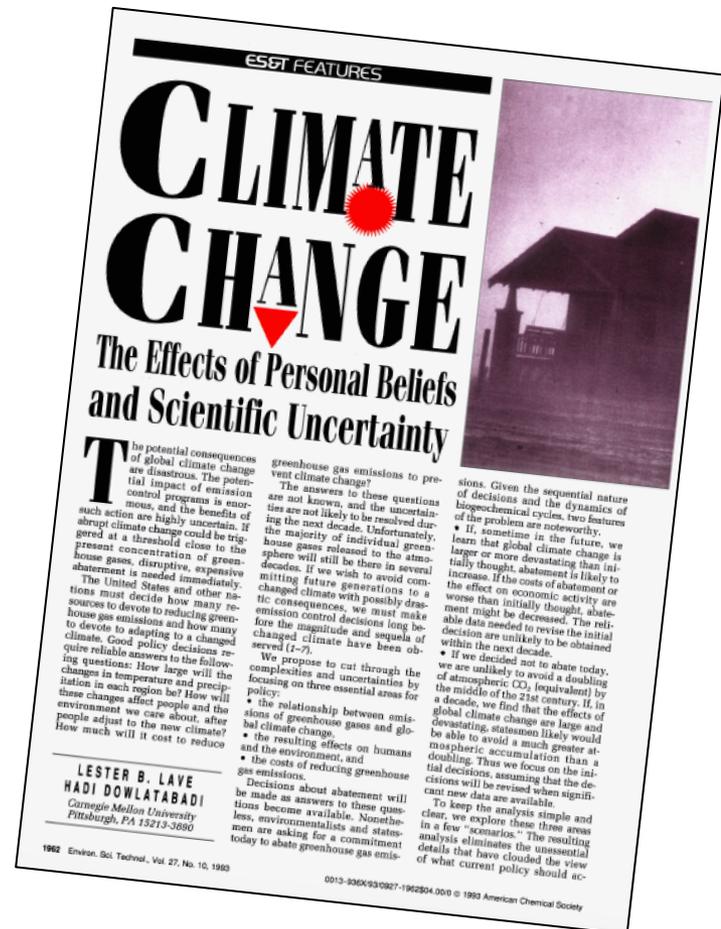
We wrote a successful NSF Center Proposal..



...and created the Center for Study of the Human Dimensions of Global Change. We recruited Hadi Dowlatabadi to serve as Executive Director.

We embarked on building a series of integrated assessment models. Later Hadi will talk a bit about insights from ICAM-1 2 and 3. Here I will say just a few words about ICAM-0.

Lave, L.B. and H. Dowlatabadi (1993). "Climate Change: The Effects Of Personal Beliefs and Scientific Uncertainty," *ES&T*, 27(10), pp. 1962-1972.



ICAM-0

Lave and Dowlatabadi performed a simple parametric analysis in which they assumed several levels of:

- climate change in the year 2040,
- impact on U.S. GDP from that change,
- cost to abate CO₂ emissions.

In the main paper they reported on nine hypothetical decisions makers ranging from someone they termed "Dr. Pangloss" (all is for the best in this best of all possible worlds) to Dr. Doom (we are toast) and applied two different decision rules (expected value and minimize the maximum possible damage) and assessed the cost for each case. Of course they also performed a sensitivity analysis.

Lave and Dowlatabadi concluded:

At least for the next decade, the prior judgments that decision makers bring to the problem, the decision rules they employ (e.g., expected value *versus* minimizing maximum loss), could be far more important in controlling...policy conclusions...than the results of scientific discoveries over that period.
(Lave and Dowlatabadi, 1993)

Sad to say, despite more than two decades of new science and analysis, in my view this conclusion remains true today!

Under HDGC...



...we embarked on a series of detailed studies of various aspects of the climate problem and its impacts. Results from many of these studies then fed in to the development of ICAM-1, 2 and 3.

Three other lines of work:

At ~13:30

- M. Granger Morgan and David Keith, "Subjective Judgments by Climate Experts," *Environmental Science & Technology*, 29(10), 468A-476A, October 1995.

A few words now

- M. Granger Morgan, Milind Kandlikar, James Risbey, and Hadi Dowlatabadi, Editorial - "Why Conventional Tools for Policy Analysis Are Often Inadequate for Problems of Global Change," *Climatic Change*, 41, 271-281, 1999.

At ~15:40

- David W. Keith and Hadi Dowlatabadi "A serious look at Geoengineering" *EOS*, 73(27), 289-293, 1992.

Limits to the conventional tools of policy analysis

The deeper we got into doing integrated assessment of the climate problem, the more concerned we became that too many of the standard analytic tools, that we and others were using, simply were not appropriate.

WHY CONVENTIONAL TOOLS FOR POLICY ANALYSIS ARE OFTEN INADEQUATE FOR PROBLEMS OF GLOBAL CHANGE

An Editorial Essay

The past three decades have witnessed an explosive growth in the development and use of tools for quantitative policy analysis. As policy analysts have turned to the consideration of climate and other problems of global change, they have found it natural to employ such now standard tools as utility theory, benefit-cost analysis, statistical decision theory, multi-attribute utility theory, and contingent valuation. However, many issues in global change involve temporal, spatial and socio-political scales that are significantly broader than those encountered in most traditional policy analyses. In such cases, the uncritical application of conventional tools can violate the assumptions on which they are based, produce silly or mis-erupted over value of life estimates in Chapter 6 of Working Group III in the report of the Intergovernmental Panel on Climate Change (Masood, 1995; Masood and Ocbert, 1995; Pearce et al., 1996).

The source of difficulty is illustrated in Figure 1. Most tools of modern quantitative policy analysis were developed to address problems that lie near the origin in this space. As one moves outward from the origin, more and more of the underlying assumptions upon which conventional tools are based begin to break down. Because many problems in global change lie far from the origin on all three dimensions, one can expect that the straightforward application of standard ideas and methods will often fail.

1. Assumptions of Conventional Analysis

The best way to understand those limitations is to examine the basic assumptions on which most conventional policy analysis tools are based. In the discussion that follows we address six: (1) the assumption that there is a single public-sector decision maker who faces a single problem in the context of a single polity; (2) the assumption that the impacts involved are of manageable size and can be valued at the margin; (3) the assumption that values that are known, static, and exogenously determined, and that the decision maker should select a policy by maximizing expected utility; (4) the assumption that time preference is accurately described by conventional exponential discounting of future costs and benefits; (5) the assumption that uncertainty is modest and manageable; and, (6) the assumption that for most questions of interest, the system under study can reasonably be treated as

 *Climatic Change* 41: 271-281, 1999.

One simple example...

...when folks in working Group III of the IPCC's 2nd assessment used different VSLs to value impacts from climate change in different countries, and then added them up to get a global economic costs, enormous controversy ensued (Pearce, 1995).

Given that the developed world (with high VSLs) had produced most of the emissions that cause climate change, using low VSLs to assess damages in the heavily impacted developing world, obviously raised serious questions of international equity!

(Folks have since tried to using equity weights, labor equivalents, etc.)

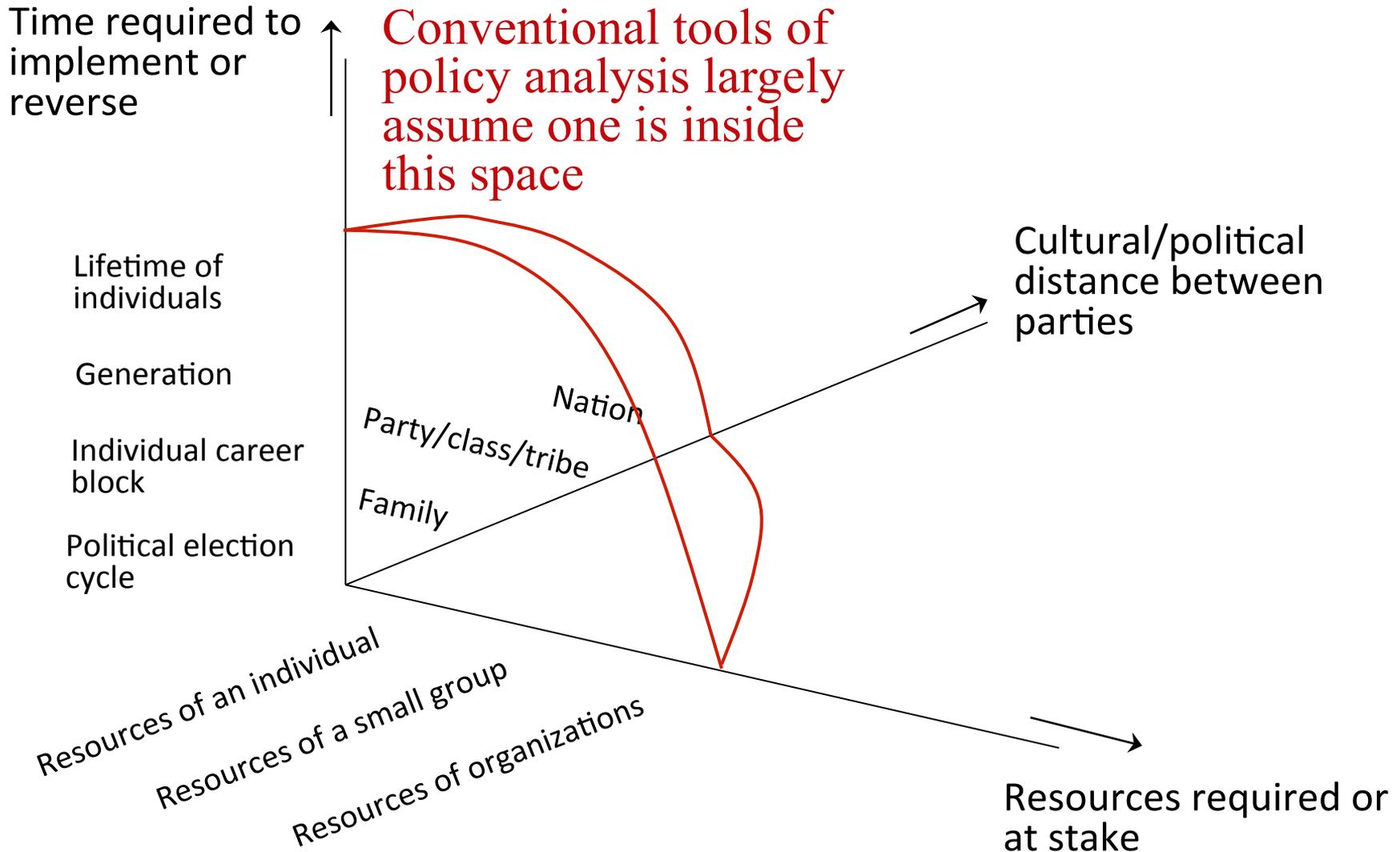
Pearce, F (1971). "Price of Life Sends Temperatures Soaring," *New Scientist*, 146, p5.

Most policy analysis done ...

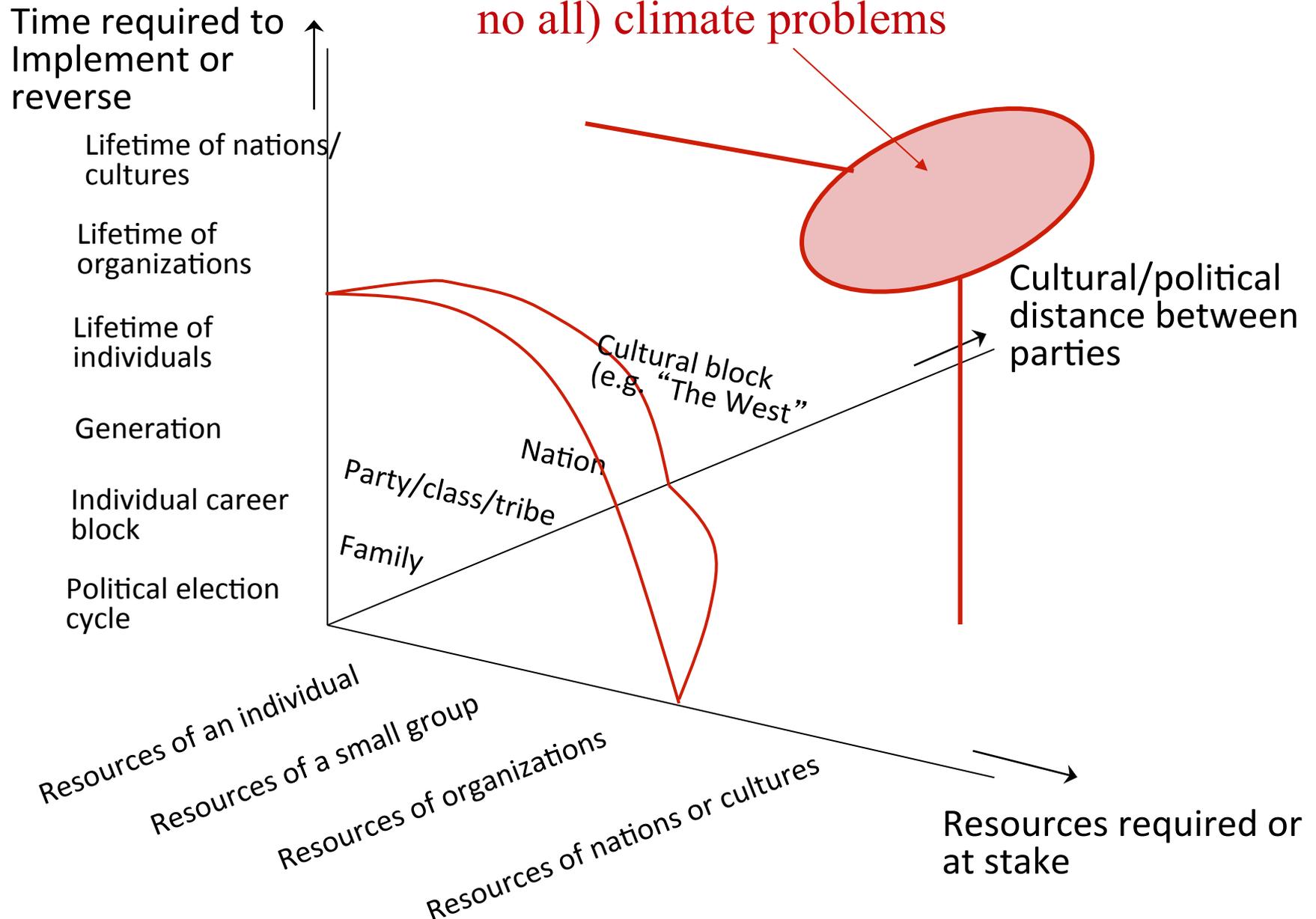
...with conventional tools make one or more of the following assumptions:

1. there is a single (public-sector) decision maker who faces a single problem (in the context of a single polity);
2. values are known (or knowable), and static;
3. the decision maker should select a policy by maximizing expected utility;
4. the impacts involved are of manageable size and can be valued at the margin;
5. time preference is accurately described by conventional exponential discounting of future costs and benefits;
6. the system under study can reasonably be treated as linear;
7. uncertainty is modest and manageable.

The space in which these assumptions are reasonable

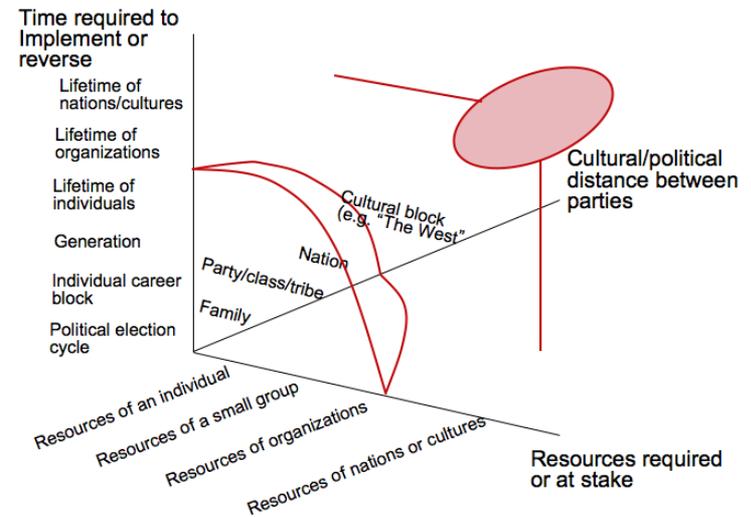


The domain of many (but certainly no all) climate problems



Bottom line:

Before picking up any of the conventional tools of policy analysis (e.g., B-C, decision analysis, MAUT, contingent valuation of non-market goods and events, etc.) and applying them to a climate problem, one really needs to think carefully about where the problem lies in this space. If it lies outside the “conventional zone,” one may need to adopt (or develop) non-conventional analytical methods.



CDMC 2004 to 2011



The Climate Decision Making Center (CDMC) was an NSF supported center anchored in the Department of Engineering and Public Policy at Carnegie Mellon University. Over the course of its operation it involved co-investigators and other collaborators at twelve other institutions:

1. University of British Columbia
2. University of Calgary
3. University of California at Berkeley
4. University of Victoria
5. Stanford University
6. The Wharton School
7. Duke University
8. Oxford University
9. Pacific Risk
10. Potsdam Institute for Climate Impact Research (PIK)
11. University of Michigan
12. Joint Global Change Research Institute (BPNL/U.MD)

Details including lists of the 190 papers and reports published, 10 MS and 18 PhDs graduated etc. can all be found at:

<http://cdmc.epp.cmu.edu>

CDMC 2004 to 2011...(Cont.)

Investigators and students in CDMC worked in four broad areas:

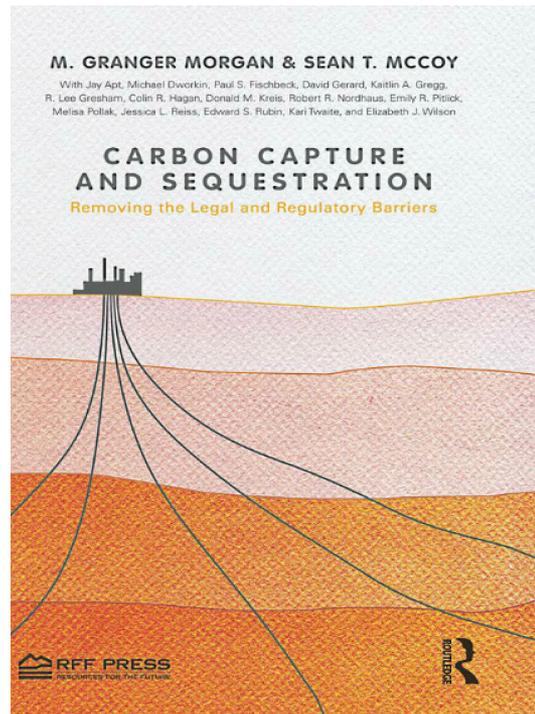
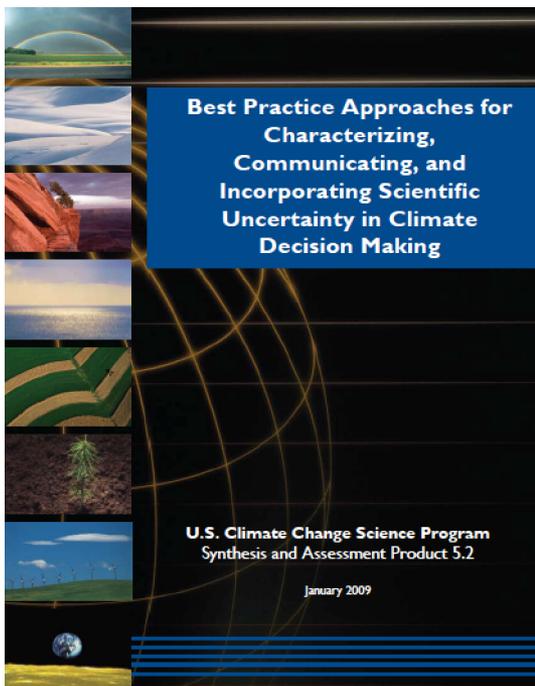
1. Decision Making Under Uncertainty
2. The Climate System
3. The Energy System
4. Impacts and Adaptation

CDMC 2004 to 2011...(Cont.)

Investigators and student in CDMC worked in four broad areas:

1. Decision Making Under Uncertainty
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Other tools and methods developed by CDMC included assessment models for ecosystem managers, application of options and decision theory in the choice of energy system investments, engineering-economic and behavioral analysis of advanced low-carbon energy systems, and a variety of similar work.



(will discuss at ~15:40)

Will discuss at ~13:30

CDMC 2004 to 2011...(Cont.)

Investigators and student in CDMC worked in four broad areas:

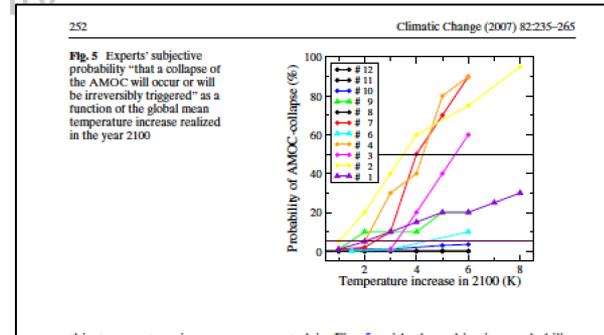
1. Decision Making Under Uncertainty
2. The Climate System
3. The Energy System
4. Impacts and Adaptation

At ~13:30

- Four expert Elicitations
- Three papers on impacts of climate change on the frequency and intensity of tropical cyclones.

At ~15:40

- Several activities on the science and governance of solar radiation management (SRM)



this temperature distributions for the warming of 4 K in consistency, experts would have occurred are for "the probability collapse had been completion because them to clarify. E did not ask us to paper but did not Another minor transient response In order to be consistent strength of the AM show a somewhat 2xCO₂ curves which should probably bars that should b

nature climate change LETTERS
 PUBLISHED ONLINE 18 DECEMBER 2011 | DOI: 10.1038/NCLIMATE1232

Effectiveness of stratospheric solar-radiation management as a function of climate sensitivity

Katharine L. Ricke^{1*}, Daniel J. Rowlands², William J. Ingram^{2,3}, David W. Keith^{4†} and M. Granger Morgan¹

If implementation of proposals to engineer the climate through solar-radiation management (SRM) ever occurs, it is likely to be contingent on climate sensitivity. However, modelling studies examining the effectiveness of SRM as a strategy to offset anthropogenic climate change have used only the standard parameterizations of atmosphere-ocean general circulation models that yield climate sensitivities close to the Coupled Model Intercomparison Project mean. Here, we use a perturbed-physics ensemble modelling experiment to examine how the response of the climate to SRM implemented in the stratosphere (SRM-S) varies under different greenhouse-gas climate sensitivities. When SRM-S is used to compensate for rising atmospheric concentrations of greenhouse gases, its effectiveness in stabilizing regional climates diminishes with increasing climate sensitivity. However, the potential of SRM-S to slow down unmitigated climate change, even regionally, increases with climate sensitivity. On average, in variants of the model with higher sensitivity, SRM-S reduces regional rates of temperature change by more than 90% and rates of precipitation change by more than 50%.

The Royal Society has defined SRM as techniques that "attempt to offset effects of increased greenhouse gas (GHG) concentrations by causing the Earth to absorb less solar radiation". The most plausible large-scale method is to increase the loading of light-scattering aerosols in the stratosphere (SRM-S ref. 1). A number of atmosphere-ocean general circulation model (AOGCM) modelling studies suggest that SRM can compensate for many of the temperature and precipitation changes associated with global warming, even at the regional level², though these regional compensatory effects are not uniform³. Those previous studies have used models in which the climate's equilibrium sensitivity to GHG forcing (henceforth, CS) reflects near-median estimates of CS. However, both observationally constrained and expert-elicited estimates of CS have a substantial "high tail"⁴, and it is arguably more likely that SRM is deployed it will be because CS, and the impacts from climate change, turn out to be higher than current best estimates. Here we examine the effectiveness and side-effects of SRM-S across a range of CS to check if use of the mean CS biases our understanding of SRM.

Evaluating the effectiveness of SRM-S requires first specifying the conditions in which it might be implemented and the effects that would be desired. There are various scenarios under which SRM might be employed. From a conventional policy viewpoint in which SRM is one of a portfolio of strategies alongside mitigation and

Fig. 1 | Time series of temperature and precipitation of the no-SRM, low-SRM and high-SRM scenarios examined, with six flat condition sub-ensembles averaged for each of the 43 IPCC model configurations analysed. (a) Five-year running-mean global-mean near-surface (2.5-m air temperature) and five-year running-mean global-mean precipitation rate. (b) As shown over the length of the 80-model-year simulation.

CDMC 2004 to 2011...(Cont.)

Investigators and student in CDMC worked in four broad areas:

1. Decision Making Under Uncertainty
2. The Climate System
3. The Energy System
4. Impacts and Adaptation

At ~13:30

M. Granger Morgan and David Keith, "Improving the Way We Think About Projecting Future Energy Use and Emissions of Carbon Dioxide," *Climatic Change*, 90(3), 189-215, October 2008.

Aimee Curtright, M. Granger Morgan and David Keith, "Expert Assessment of Future Photovoltaic Technology," *Environmental Science & Technology*, 42(24), 2008.

Inês Azevedo, M. Granger Morgan and Fritz Morgan, "The Transition to Solid-State Lighting," *Proceedings of the IEEE*, 97(3), 481-510, March 2009.

Inês Azevedo, Realistic Potential for Greenhouse Gases Mitigation through Energy Efficiency and Conservation for the US Residential Sector, PhD, Carnegie Mellon, May 2009.

Inês Azevedo, M. Granger Morgan and Lester B. Lave, "Residential and Regional Electricity Consumption in the U.S. and EU: How Much Will Higher Prices Reduce CO2 Emissions?", *The Electricity Journal*, 24, Jan/Feb 2011.

At ~9:15

In a moment

Lauren A. Fleishman, Wändi Bruine de Buin and M. Granger Morgan, "Informed Public Preferences for Electricity Portfolios with CCS and Other Low-Carbon Technologies," *Risk Analysis*, 30, 1399-1410, 2010.

CDMC 2004 to 2011...(Cont.)

Investigators and student in CDMC worked in four broad areas:

1. Decision Making Under Uncertainty
2. The Climate System
3. The Energy System
4. Impacts and Adaptation

McDaniels, T., H. Dowlatabadi, and S. Stevens, "Multiples Scales and Regulatory Gaps in Environmental Change: The case of salmon aquaculture," *Global Environmental Change*, 15(1), pp. 9-21, 2005.

Gerwing, K. and T. McDaniels, "Listening to the Salmon people: First Nations' objectives for salmon aquaculture decisions," *Society and Natural Resources*, February 2005.

Hamouda, L., K.W. Hipel, D.M. Kilgour, D.J. Noakes, L. Fang, and McDaniels, T., "The Salmon Aquaculture Conflict in British Columbia: A graph model analysis," *Ocean & Coastal Management*, 48, pp. 571-587, 2005.

Hagerman, S.M., H. Dowlatabadi, T.S. Satterfield, and T. McDaniels, "Expert Views on Biodiversity Protection in an Era of Climate Change," *Global Environmental Change*, 20, 192-207, 2010.

Hagerman, S.M., Dowlatabadi, H., Chan, K.M.A. and Satterfield, T.S., "Integrative propositions for adapting conservation policy to the impacts of climate change," *Global Environmental Change*, 20, 351-362, 2010.

Gouge B., F. Ries, C. Reynolds, C. Lim, E. Mazzi, and H. Dowlatabadi, *An Integrated Approach to Transportation Policy in British Columbia: Assessing greenhouse gas reductions opportunities in freight transportation Pacific Institute for Climate Solutions*, Pacific Institute for Climate Solutions, report, 35pp, 2008.

Dowlatabadi, H. and C. Cook, "Climate Risk Management & Institutional Learning," *Integrated Assessment*, 8(1), pp. 151-163, 2008.

Wilson, C. and H. Dowlatabadi, "Models of Decision Making and Residential Energy Use," *Annual Review of Environment and Resources*, 32, pp. 169-203, 2007.

Shepherd, P., J. Tansey, and H. Dowlatabadi, "Context Matters: What shapes adaptation to water stress in the Okanagan," *Climatic Change*, 78(1), pp. 31-62, 2006.

Hanova, J. and H. Dowlatabadi, "Strategic GHG Reductions Through the Use of Ground Source Heat Pump Technology," *Environmental Research Letters*, 2(044001), 8pp, 2007.

Klinsky, S. and H. Dowlatabadi, "Conceptualisations of Justice in Climate Policy," *Climate Policy*, 9, 2009.

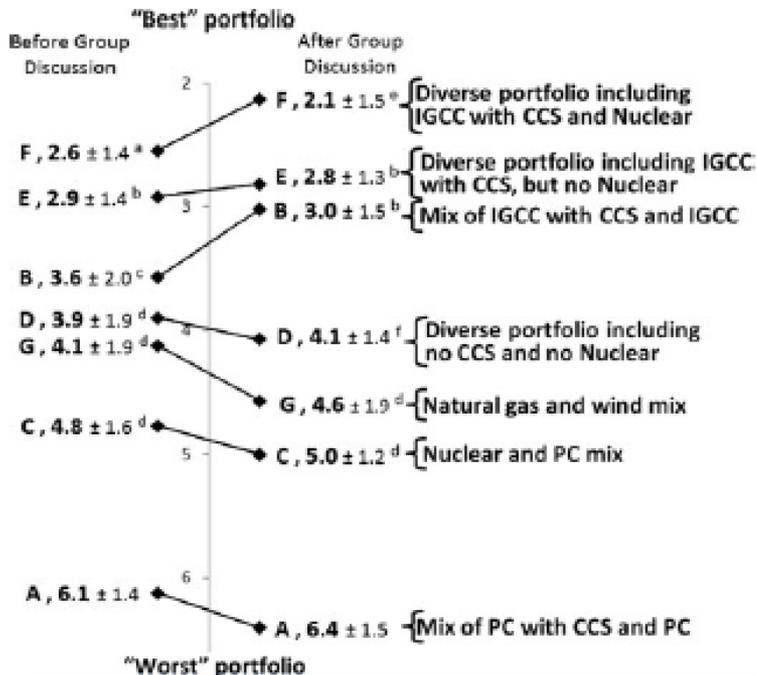
Klinsky, S., "Mapping Emergence: Network analysis of climate change media," *Integrated Assessment*, 7, 2007

Boyle, M. and H. Dowlatabadi, *Building Foundations for Climate Change Adaptation in Nunavut Communities*, Climate Change Impacts and Adaptation Program, Natural Resources Canada, published as technical report Project A1200, 2007.

Hadi Dowlatabadi, "Climate Adaptation in Arctic Canada", project summary prepared February, 2008.

Public Acceptance of CCS

There have been several studies, including one we did, which suggest that members of the U.S. Public may have pretty negative attitudes toward CCS. However, all of these were done asking about CCS in isolation. In her Ph.D. Lauren Fleishman (Mayer) asked groups of Pennsylvania lay people to act as advisors to the Governor on devising low carbon electricity portfolio.



Lauren A. Fleishman, Wändi Bruine de Bruin and M. Granger Morgan, "Informed Public Preferences for Electricity Portfolios with CCS and Other Low-Carbon Technologies," *Risk Analysis*, 30, 1399-1410, 2010.

Lauren A. (Fleishman) Mayer, Wändi Bruine de Bruin and M. Granger Morgan, "Informed Public Choices for Low-Carbon Electricity Portfolios Using a Computer Decision Tool," *Environmental Science and Technology*, 48, 3640-3648, 2014.

Traditional Coal Plants

Option 1: CO₂ is released into air

How it Works: Traditional coal plants burn coal to make steam. The steam is used as fuel in a type of engine, called a "turbine". This turbine runs a generator to make electricity.

When coal is burned, CO₂ is released by the plant. In **Option 1**, this CO₂ escapes into the air because no equipment is added to capture the CO₂.

MORE INFORMATION (ABOUT TRADITIONAL COAL PLANTS)

Cost*	Traditional coal plants make cheaper electricity than advanced coal plants. Yet, it is more expensive to add CO ₂ capture equipment to traditional coal plants.*
CO₂ released*	Traditional coal plants release CO ₂ to the air.*
Other Pollution/Waste*	<ul style="list-style-type: none"> While these plants are much cleaner than in the past, they still release CO₂, nitrogen oxides, sulfur dioxide, mercury and particulates to the air. These pollutants can cause people to have many different health problems.* Traditional coal plants produce a lot of ash that contain hazardous chemicals. Some ash can be recycled, for example, to make concrete. The leftover solid waste is usually put in a landfill near the plant. Traditional coal plants use a lot of water to cool the plant's equipment. The water comes from wells, lakes, rivers or oceans. Some of it will evaporate after use. The rest is returned to its source. Since it's hot, the water may disturb plants and animals living in the water source.
Availability	Experts say that the U.S. has enough coal to meet its needs for at least 100 years.
Reliability	Coal can provide steady and dependable electricity.
Limits of use	Traditional coal plants release a lot of CO ₂ . They cannot make all of the electricity that is needed in PA if we want to reduce CO ₂ . Other types of plants must also be built.
Noise	These plants are about as loud as average street traffic.
Land use and ecology	Coal mining near the surface disturbs the land, plants and animals. It also disrupts and pollutes streams. Underground mining can cause acid water to leak into streams. If the mine collapses, it can also cause the ground to sink or shift.
Safety	These plants are quite safe for operators. Coal mining is dangerous for the miners.
Lifespan	The lifetime of any plant is uncertain. But, a new traditional coal plant built today would likely make electricity for at least 50 years.
Current Use	There are more than 1,000 of these plants working in the U.S. today.

*More cost and pollution information is available in "Cost Comparison" and "Pollution Comparison" sheets in Envelope #3.

Once members of the public in PA understand the full situation they opt for CCS as part of a portfolio.

MAKE YOUR OWN POWER PLANT COMBINATION

BUILD CENTER

Plant Type	Number of Plants	Electricity Produced (TWh)
Biomass-and-Cool	1	3.5 TWh
Coal CO ₂ released	0	0 TWh
Coal CO ₂ captured	0	0 TWh
Coal-to-Gas CO ₂ released	0	0 TWh
Coal-to-Gas CO ₂ captured	2	10 TWh
Energy Efficiency	0	0 TWh
Natural Gas	10	19.5 TWh
Nuclear	3	21 TWh
Solar Cell	0	0 TWh
Wind	13	6.5 TWh

Percent of Electricity Goal

Electricity Produced

60.5 TWh

101% of Goal (40 TWh)

Goal Reached!

CO₂ released

39%

Keep below 50%!

SAVE UP TO THREE COMBINATIONS

REVIEW & SAVE

RESET

Average monthly electric bill of \$77 will increase by:

\$13.71 or 17%

Cost of everything else you buy will increase by:

2%

IMPACTS

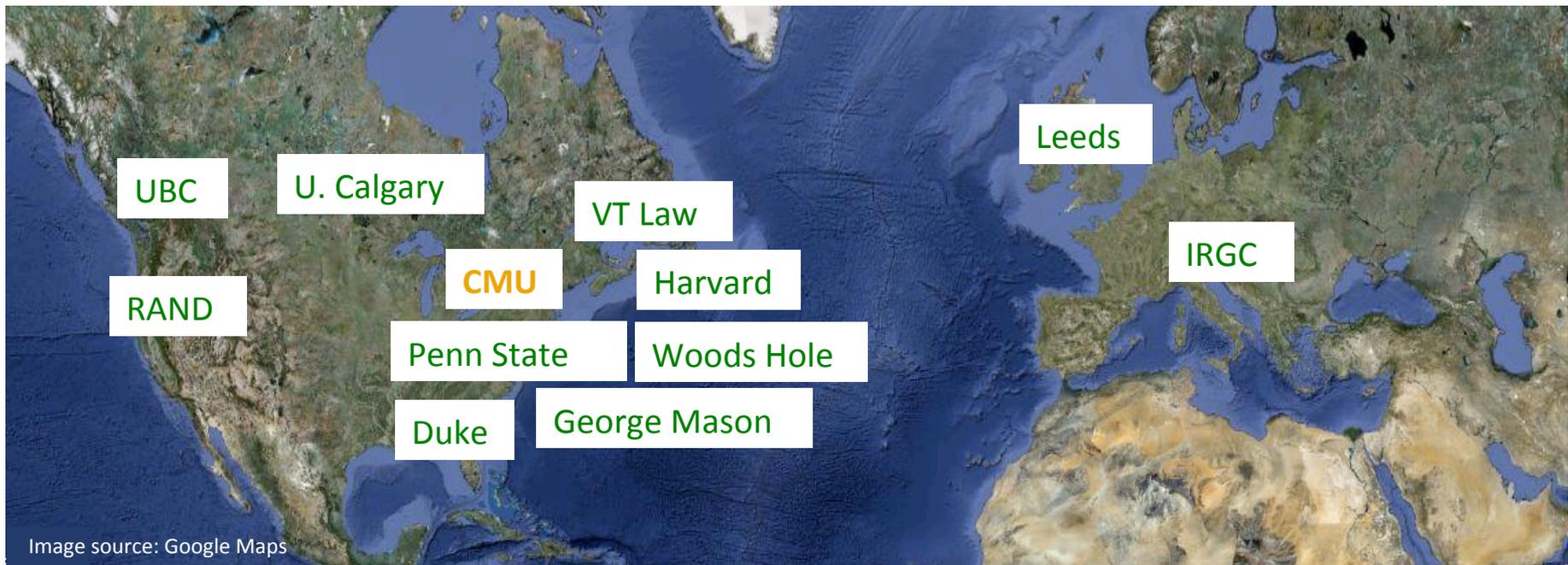
	Original Plan	Your Combination	% Change
Water Use (Olympic Pools/year)	56,000	42,900	-23%
Land Use (Football Fields)	3,400	9,500	179%
Health Costs (\$Millions/year)	\$830	\$100	-88%

CEDM 2010-2020



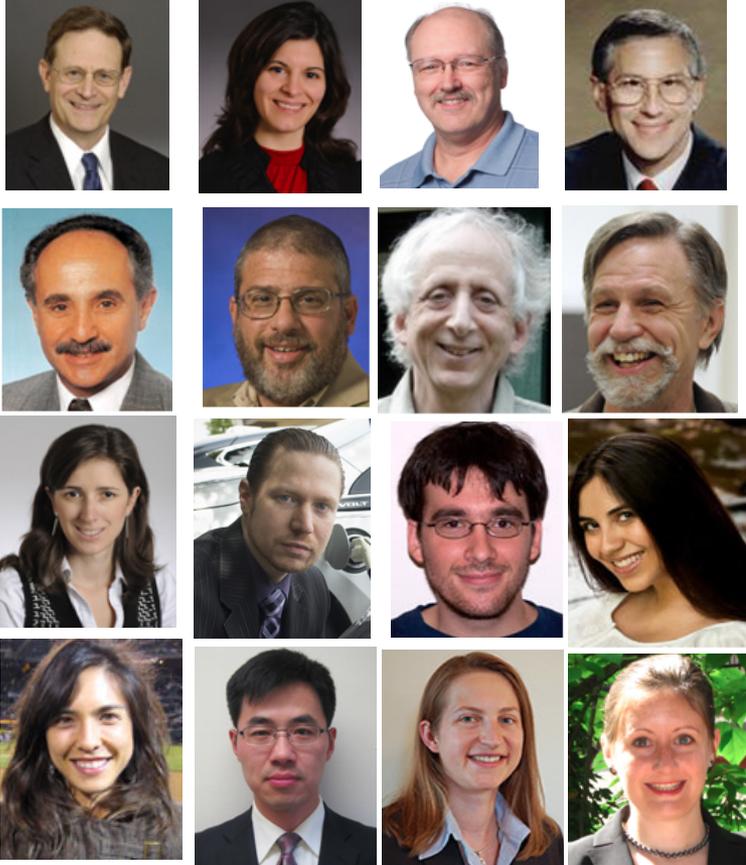
The Center for Climate and Energy Decision Making is our current NSF supported center. It again is anchored in EPP at Carnegie Mellon. Participating institutions have changed a bit over time.

The map shows participating institutions for the first five years.



Investigators Participating during 2010-2015

At Carnegie Mellon:



At UBC:



At VT Law:



At Duke:



At Calgary/Harvard:



At Penn St.:



At WHOI:



Plus several Others at CMU

At Geo. Mason:



At Wharton:



At IRGC:



At RAND:



Now at CMU

At Leeds:



Previously at CMU

You can find most of the papers on the CEDM web site



One slide on a recently completed piece of work that will *not* be covered in any of the talks that follow.

SEMINARS & WORKSHOPS

CEDM Seminar – Sonia Yeh – 4/13/2015 @ Noon

[Read More →](#)

CEDM Seminar – Rob Axtell – 3/30/2015 @ Noon

[Read More →](#)

CEDM Seminar – Gregory Nemet – 3/16/2015 @ Noon

[Read More →](#)

NEWS

CEDM News: CEDM Researchers Analyze the Greenhouse Gas Emissions of Using Natural

[Read More →](#)

CEDM News: CMU study on Electric Vehicles featured in Wired magazine

[Read More →](#)

CEDM News: CEDM Researchers Propose Solutions To Reduction in Revenue from

[Read More →](#)

INTRODUCTION TO CEDM



Decisions in climate and energy involve multiple factors that differ across the variety of decision-makers, time horizons, and uncertainties that are involved. They range from choosing among

the multitude of strategies available to reduce carbon dioxide ... [Read More »](#)

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NAVIGATION

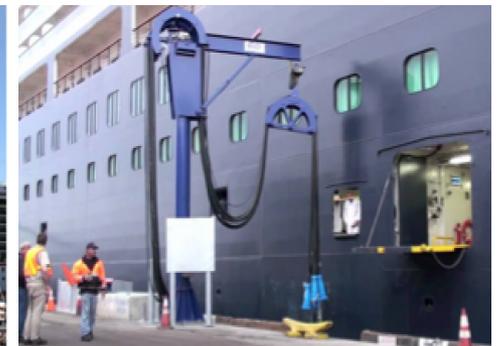
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Reducing CO₂ from airplanes and ocean shipping

- Parth Vaishnav, **Reducing Pollution from Aviation and Ocean Shipping**, EPP PhD defended 2015 April 29.
- Parth Vaishnav, “Greenhouse Gas Emissions from International Transport,” *Issues in Science & Technology*, 2014.
- Parth Vaishnav, “Costs and Benefits of Reducing Fuel Burn and Emissions from Taxiing Aircraft,” *Transportation Research Record: Journal of the Transportation Research Board* 2400, no. -1 (December 1, 2014): 65–77. doi: 10.3141/2400-08.



International Civil Aviation Organization (ICAO) straw man proposal



Investigators planned for 2015-2020

Previous at Carnegie Mellon:



At UBC:



At VT Law:



At Duke:



At RAND:



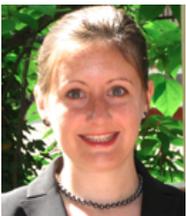
At U Washington:



At UC Davis:



New at
Carnegie Mellon:



At Leeds:



At CATF:



At IRGC:



Previously
at CMU



A few insights on which we will elaborate as the day progresses

Strategies for Abatement and Adaptation

Technology and human behavior must be considered *together*, with issues framed in behaviorally realistic ways, or one may not obtain sensible results.

Policy is far more likely to be the emergent consequence of many distributed decisions than the result of any single global decision. Hence there is much to be said for working “from the bottom up.”

Tools and analysis to support local and regional decisions may be as or more valuable as global assessments.

In assessing strategies for both abatement and adaptation, it is essential to adopt a systems perspective and to “run the numbers.”

Climate Policy:

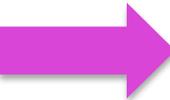
Many conventional tools for policy analysis should to be modified or extended when they are used to assess climate policy and impacts.

Uncertainty is ubiquitous and without an adequate treatment of uncertainty one can be easily lead astray.

Seeking a “globally optimal” climate policy in not a sensible objective.

Muddling our way to climate policy is a good start, but it needs to be combined with some long-term “visioning.”

Plan for the day

- 
- 08:30 – 09:15 Overview of >25 years of HDGC, CDMC and CEDM – Granger Morgan
- 09:15 – 10:00 Uncertainty in energy efficiency, Part 1: technologies, strategies, behavior and policy – Inês Azevedo
- 10:00 – 10:30 Uncertainty in energy efficiency, Part 2: technologies, strategies, behavior and policy – Alex Davis
- 10:45 – 11:15 **Coffee break**
- 11:15 – 11:45 Decision support for implementing the EPA Clean Power Plan Proposed Rule – Jeff Anderson
- 11:45 – 12:30 Marginal emissions factors, health and climate change co-benefits and trade-offs - Inês Azevedo
- 12:30 – 13:30 **Lunch break**
- 13:30 – 13:55 Insights from twenty years of work on expert elicitation and projections – Granger Morgan
- 13:55 – 14:05 Transitioning to a low carbon economy, Part 1: Insights from the RenewElec Project – Granger Morgan
- 14:05 – 14:30 Transitioning to a low carbon economy, Part 2: Insights from ITC and BC’s Climate Policy – Hadi Dowlatabadi
- 14:30 – 15:10 Strategies for supporting investment decisions about large energy infrastructure in the face of regulatory and other uncertainty – Dalia Patiño
- 15:10 – 15:40 **Coffee break**
- 15:40 – 16:00 Reflections on Research and Governance wrt Albedo Modification – Granger Morgan
- 16:00 – 16:45 Insights From Our Experience in Building and Using ICAMs – Hadi Dowlatabadi
- 17:45 – 17:00 Muddling through on climate policy: good, but not good enough to avoid the risk of dead ends – Granger Morgan
- 17:00 – 17:30 Discussion and round table on what investigators in CEDM might best work on in the next several years to be most useful to the IA and energy modeling communities.