Integrated Assessment of Climate Change-
Past, Present, and Future:
a Back to Basics Perspective

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on Climate and Development
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Outline

- Objectives of integrated assessment
- State of the art in IAM circa 1995
- State of the art in IAM circa 2015
- Current/future directions in IAM in 2016+
  - Equity & sustainable development
  - Integrated CC impacts
  - Uncertainty about uncertainty
- Concluding thoughts

Background

- Objectives of Integrated Assessment?
  - Understand complex geophysical-socioeconomic systems
  - To set research priorities and analyze policy interventions
- Why integrate?
  - To develop understanding, insights and information not available through disciplinary research
- Why model?
  - To keep track of what is going on
  - Some parts of a modeling system may be more formal than others
- Why first principles?
  - To insure the framework has solid foundations
  - The more complex the model the easier it is to mess up

Basic Concepts of Integrated Assessment

- Ocean/Atmosphere/Atmospheric Chemistry
  - Conservation of momentum
  - Conservation of mass
  - Conservation of energy
  - Chemical Reactions
- Eco-systems
  - Photo-synthesis
  - Conservation of mass
  - Conservation of energy
  - Bio-Geo-Physical-Chemical Processes
- Socio-economic System
  - Birth and Death
  - Resource allocation, optimization and market equilibrium
  - Technology change and choice
  - Investment and Growth
- Plus a lot of uncertainty stuff discussed later

Central Question(s)

Question

What is a good model? scenario? way to deal with uncertainty? Approach to model assessment?

Answer

It depends on the question being asked.

A Few Modeler Perspectives We Would Like to Avoid Here

- Its not in my model, so it is not important
- It is in my model, but it is not important in my model, so it is not important in the real world
- The real world has produced different outcomes than my model has projected, so the real world must be seriously incorrect
- How dare you question my(our) intellectual dominance

State of the Art in 1995

- Early C/B and integrated impacts models
- Cost effectiveness analyses with both types
- Targets (emissions, concentration, temps.) and time tables
- Tolerable windows (of climate and impacts) ideas
- Early uncertainty analyses

IPCC SAR: WG3 - Chapter 10
<Spin-off from Chapter 8 (Hourcade)>

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Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results

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Lead Authors:
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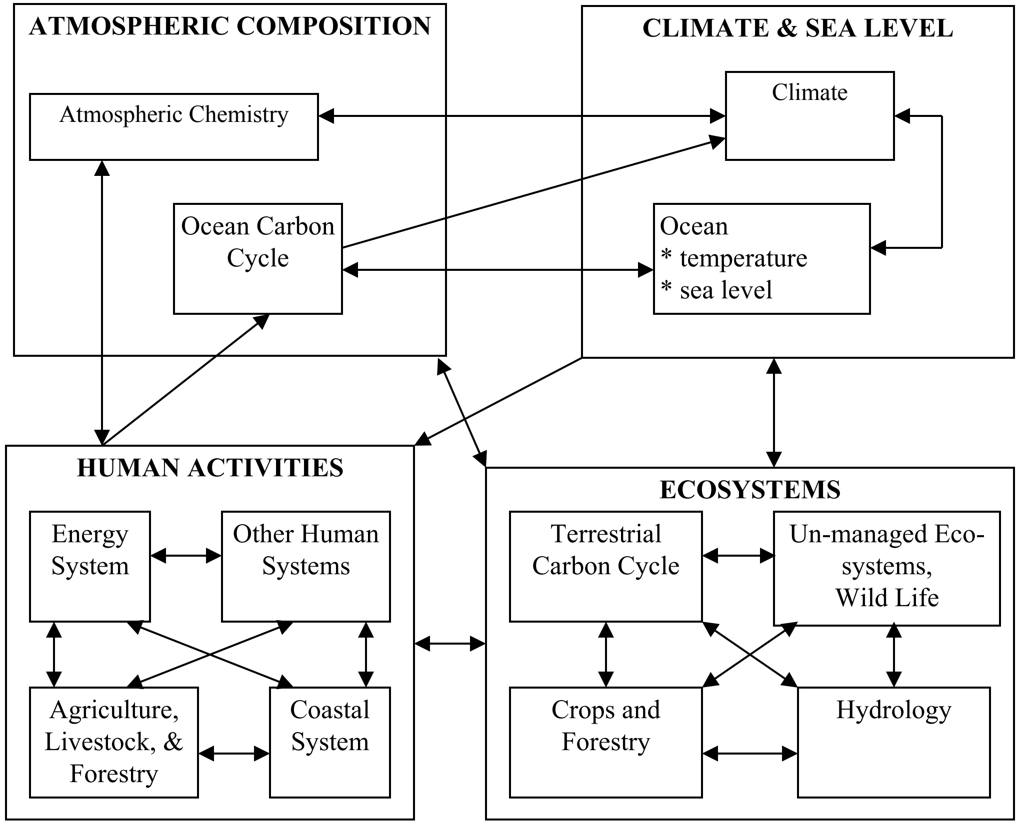
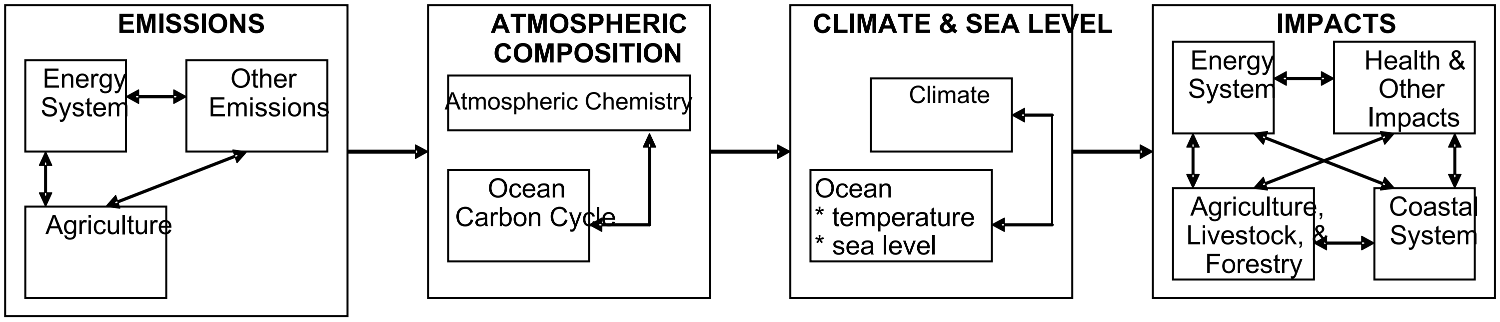
Are We Integrated



…or Still End-to-End ?



Two Kinds of Integrated Assessment Models

- Policy Optimization Models
  - Focused on Finding Optimal Level of Emissions
  - Usually Include Impacts at the Aggregate Level
- Policy Evaluation Models
  - Focused on Simulating Effects of Policies
  - Usually More Detailed Impacts
  - Can be Run Backwards - Tolerable Windows Approach

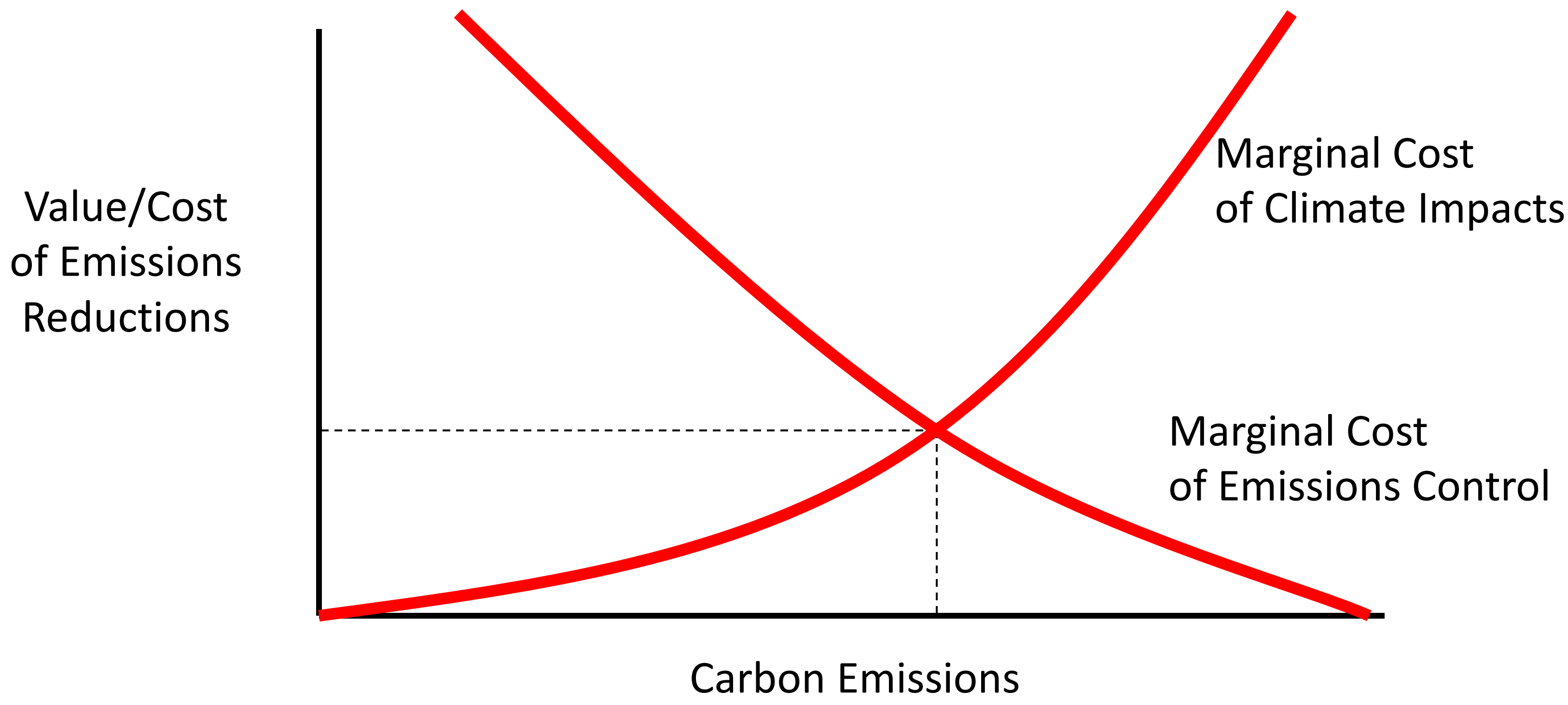
Includes 22 “IAMs” about half of each type of model

Table 10.1. *Integrated assessment models*

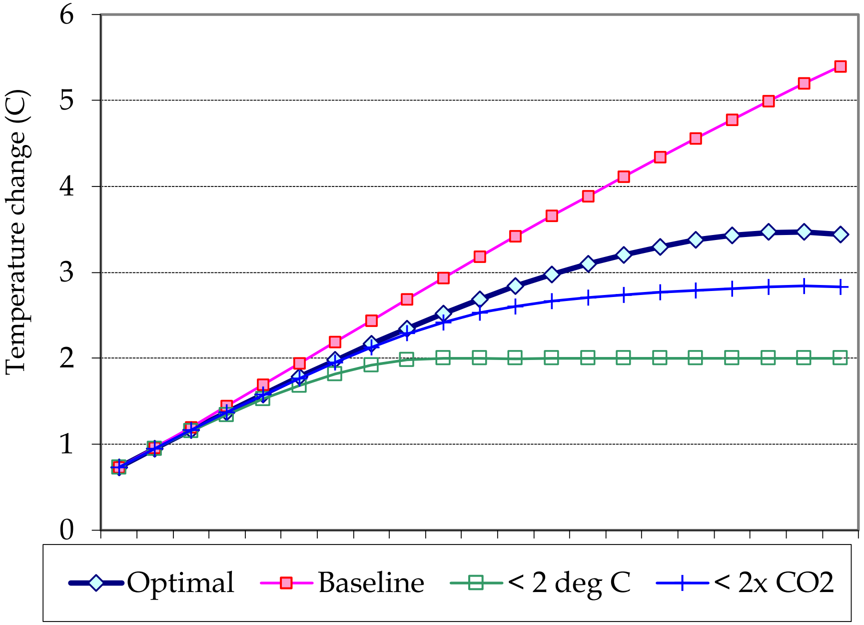
Model	Modellers
AS/ExM (Adaptive Strategies/Exploratory Model)	R. Lempert, S. Popper (Rand); M. Schlesinger (U. of Illinois)
AIM (Asian-Pacific Integrated Model)	T. Morita, M. Kainuma (National Inst. for Environmental Studies, Japan); Y. Matsuoka (Kyoto U.)
CETA (Carbon Emissions Trajectory Assessment)	S. Peck (Electric Power Research Institute) T. Teisberg (Teisberg Assoc.)
Connecticut (also known as the Yohe model)	G. Yohe (Wesleyan University)
CRAPS (Climate Research And Policy Synthesis model)	J. Hammitt (Harvard U.); A. Jain, D. Wuebbles (U. of Illinois)
CSERGE (Centre for Social and Economic Research on the Global Environment)	D. Maddison (University College of London)
DICE (Dynamic Integrated Climate and Economy model)	W. Nordhaus (Yale U.)
FUND (The Climate Framework for Uncertainty, Negotiation, and Distribution)	R.S.J. Tol (Vrije Universiteit Amsterdam)
DIAM (Dynamics of Inertia and Adaptability Model)	M. Grubb (Royal Institute of International Affairs), M.H. Dong, T. Chapuis (Centre Internationale de recherche sur l'environnement et développement)
ICAM-2 (Integrated Climate Assessment Model)	H. Dowlatabadi, G. Morgan (Carnegie-Mellon U.)
IIASA (International Institute for Applied Systems Analysis)	L. Schrattenholzer, Arnulf Grubler (IIASA)
IMAGE 2.0 (Integrated Model to Assess the Greenhouse Effect)	J. Alcamo, M. Krol (Rijksinstitut voor Volksgezondheid Milieuhygiene, Netherlands)
MARIA (Multiregional Approach for Resource and Industry Allocation)	S. Mori (Sci. U. of Tokyo)
MERGE 2.0 (Model for Evaluating Regional and Global Effects of GHG Reductions Policies)	Alan Manne (Stanford U.), Robert Mendelsohn (Yale U.), R. Richels (Electric Power Research Institute)
MiniCAM (Mini Global Change Assessment Model)	J. Edmonds (Pacific Northwest Lab), R. Richels (Electric Power Research Institute), T. Wigley (University Consortium for Atmospheric Research (UCAR))
MIT (Massachusetts Institute of Technology)	H. Jacoby, R. Prinn, Z. Yang (Massachusetts Institute of Technology)
PAGE (Policy Analysis of the Greenhouse Effect)	C. Hope (Cambridge U.); J. Anderson, P. Wenman (Environmental Resources Management)
PEF (Policy Evaluation Framework)	J. Scheraga, S. Herrod (EPA); R. Stafford, N. Chan (Decision Focus Inc.)
ProCAM (Process Oriented Global Change Assessment Model)	J. Edmonds, H. Pitcher, N. Rosenberg (Pacific Northwest Lab); T. Wigley (UCAR)
RICE (Regional DICE)	W. Nordhaus (Yale U.); Z. Yang (MIT)
SLICE (Stochastic Learning Integrated Climate Economy Model)	C. Kolstad (U. of California, Santa Barbara)
TARGETS (Tool to Assess Regional and Global Environmental and Health Targets for Sustainability)	J. Rotmans, M.B.A. van Asselt, A. Beusen, M.G.J. den Elzen, M. Janssen, H.B.M. Hilderink, A.Y. Hoekstra, H.W. Koster, W.J.M. Martens, L.W. Niessen, B. Strengers, H.J.M. de Vries (Rijksinstitut voor Volksgezondheid en Milieuhygiene, Netherlands)

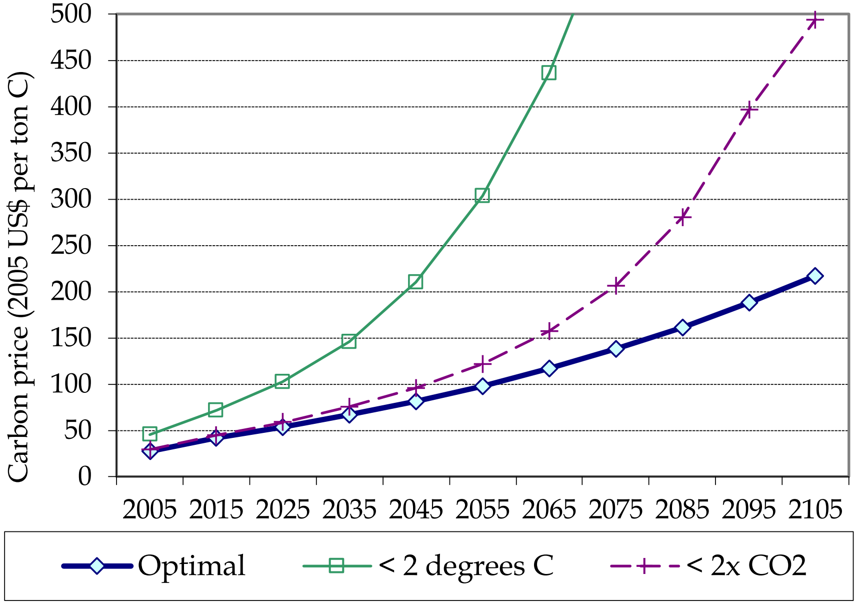
DICE/RICE
Cost/Benefit Modeling Approach

Balancing the Costs of Controlling Carbon Emissions Against the Costs of the Climate impacts They Cause

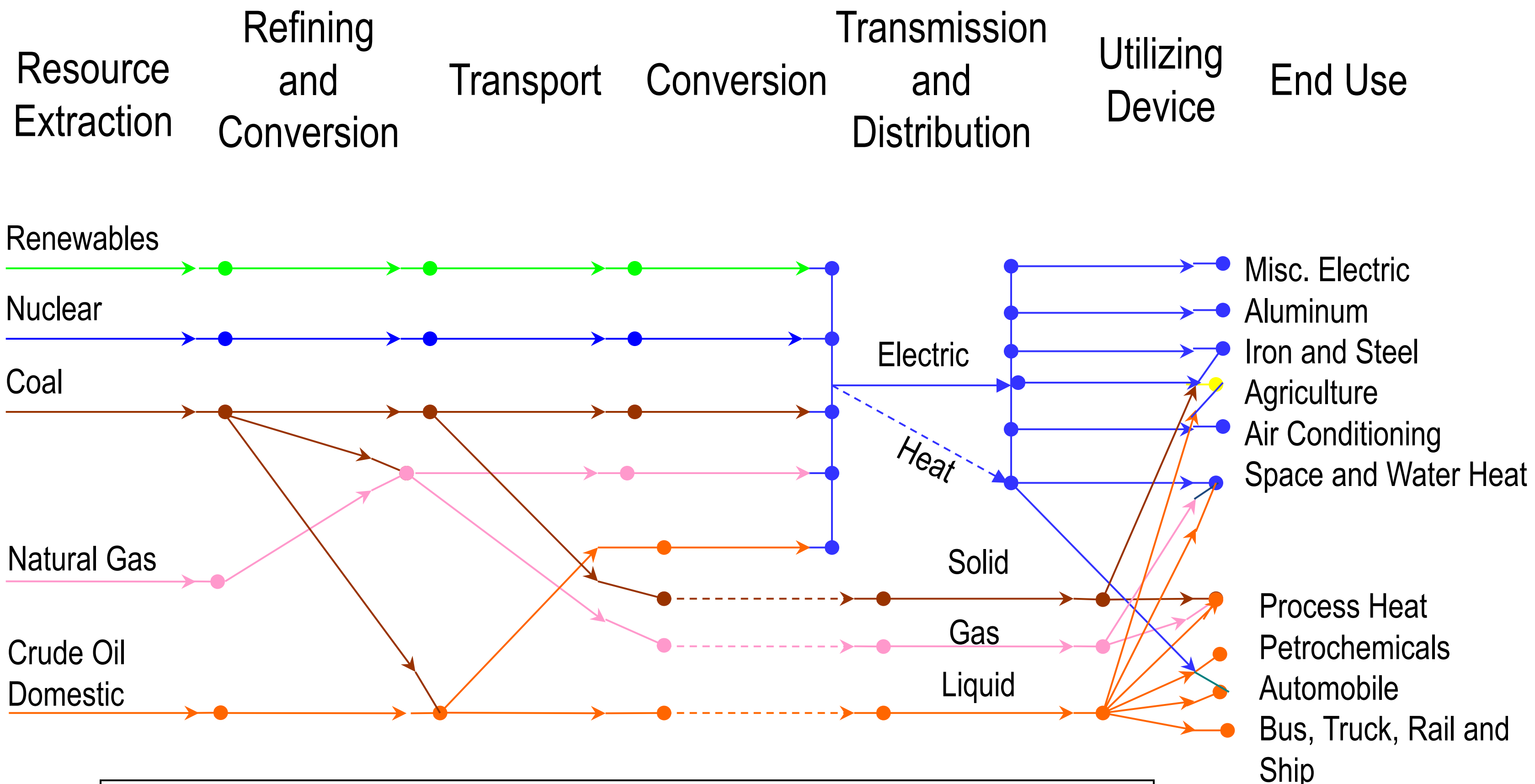


DICE/RICE RESULTS

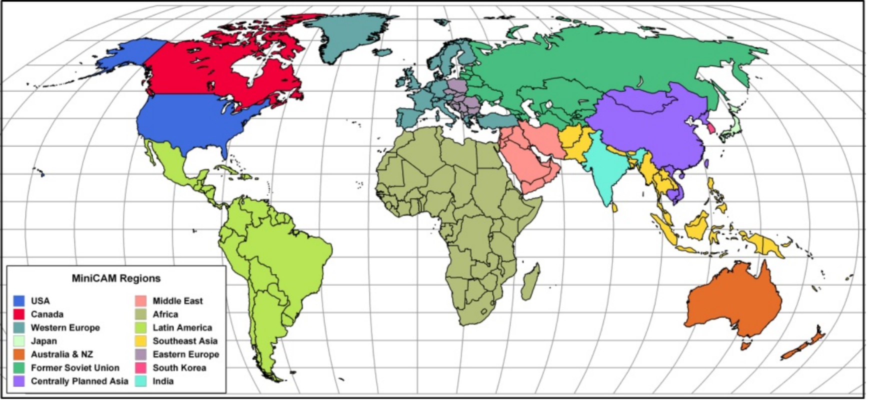




Process Analysis – Part of Core of MERGE and GCAM

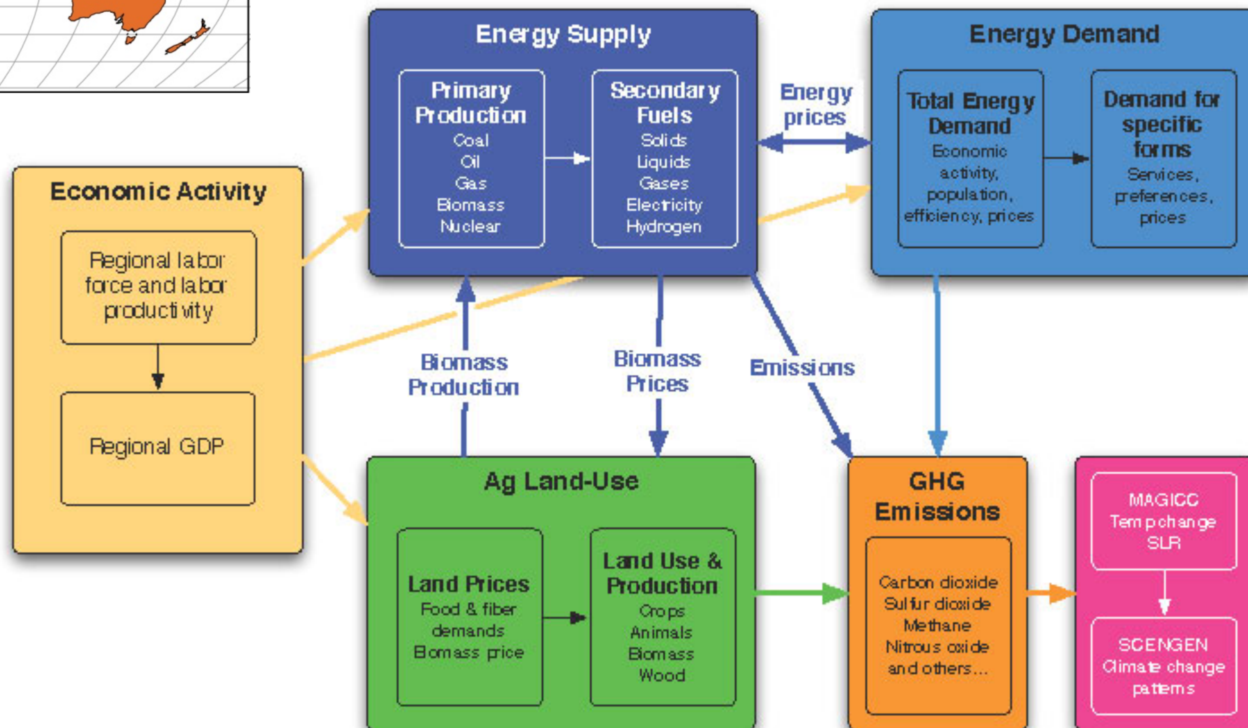


MARKAL
Objective: Minimize Energy System Costs
Constraints: Satisfy Energy Demands
Use Only Available Resources
Convert Energy Forms at Efficiencies of Available Technologies



GCAM-Circa?

- Energy-Agriculture-Economy Market Equilibrium
- 14 Global Regions – Fully Integrated
- Explicit Energy Technologies – All Regions

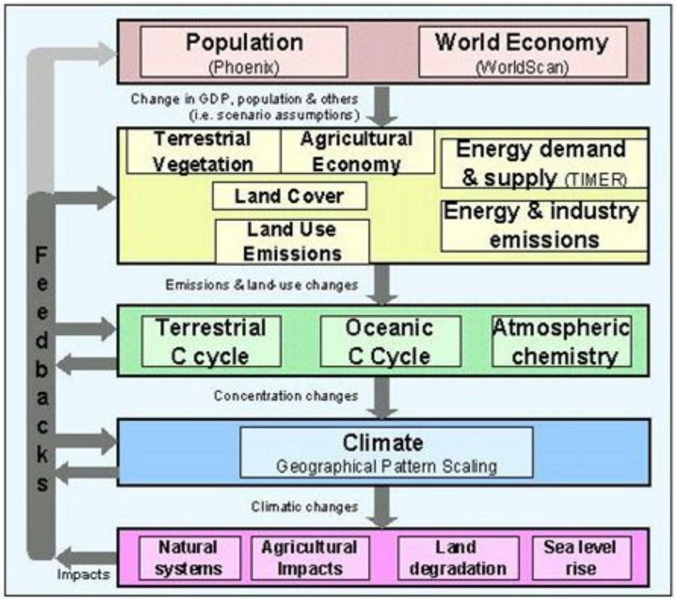


- Fully Integrated Agriculture and Land Use Model
  - 15 Greenhouse Gases and Short-lived Species
  - Typically Runs to 2100 in 15-year time steps

IMAGE-Circa 1995

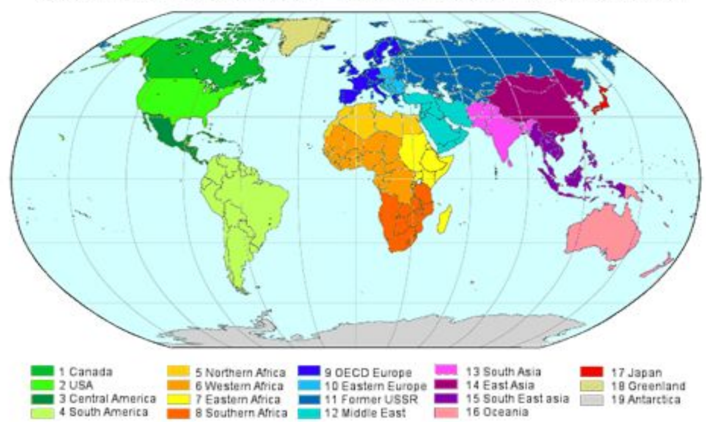
RIVM IMAGE

IMAGE : A dynamic integrated assessment modeling framework for global change



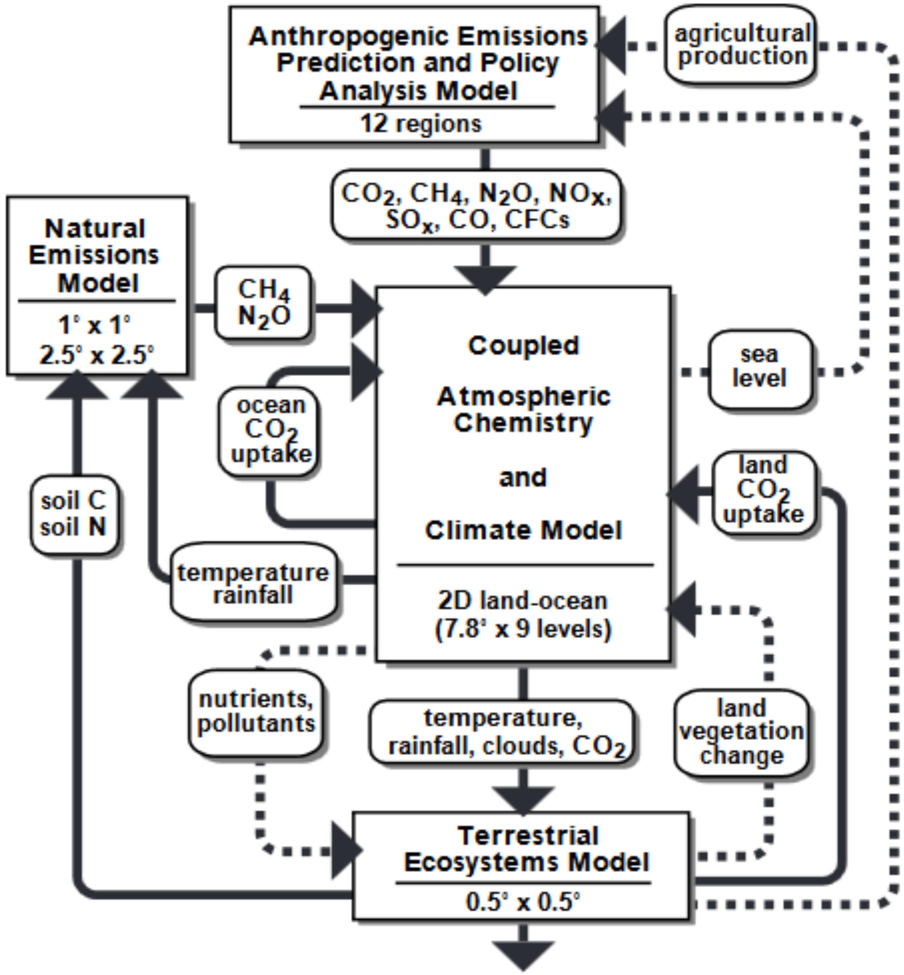
WorldScan(economy model), and PHOENIX (population model) feed the basic information on economic and demographic developments for 17 world regions into three linked subsystems (EIS, TES, and AOS*)

RIVM Environmental Research -1998 World Regions and Subregions



* EIS(Energy-Industry System), TES(Terrestrial Environment System), AOS (Atmospheric Ocean System)

MIT IGSM Framework-Circa 1995



Prinn, R., Jacoby, H., Sokolov, A. R. Prinn, H. Jacoby, A. Sokolov, C. Wang, X. Xiao, Z. Yang, R. Eckhaus, P. Stone, D. Ellerman, J. Melillo, J. Fitzmaurice, D. Kicklighter, G. Holian, Y. Liu (1999). Climatic Change, 41(3), pp 469-546.

EPPA CGE Structure

Key dimensions of the EPPA model

Production sectors

Non-Energy

1. Agriculture
2. Energy-intensive industries
3. Auto, truck and air transport
4. Rail transport
5. Other industries and services

Energy

6. Crude oil
7. Natural gas
8. Refined oil
9. Coal
10. Electricity, gas and water

Future Supply Technology

11. Carbon liquids backstop [1]
12. Carbon-free electric backstop [2]

Consumer sectors

1. Food and beverages
2. Fuel and power
3. Transport and communicatior
4. Other goods and services

Primary Factors

1. Labor
2. Capital (by vintage)
3. Fixed factor (agricultural land, fossil reserves)

Regions (and abbreviations)

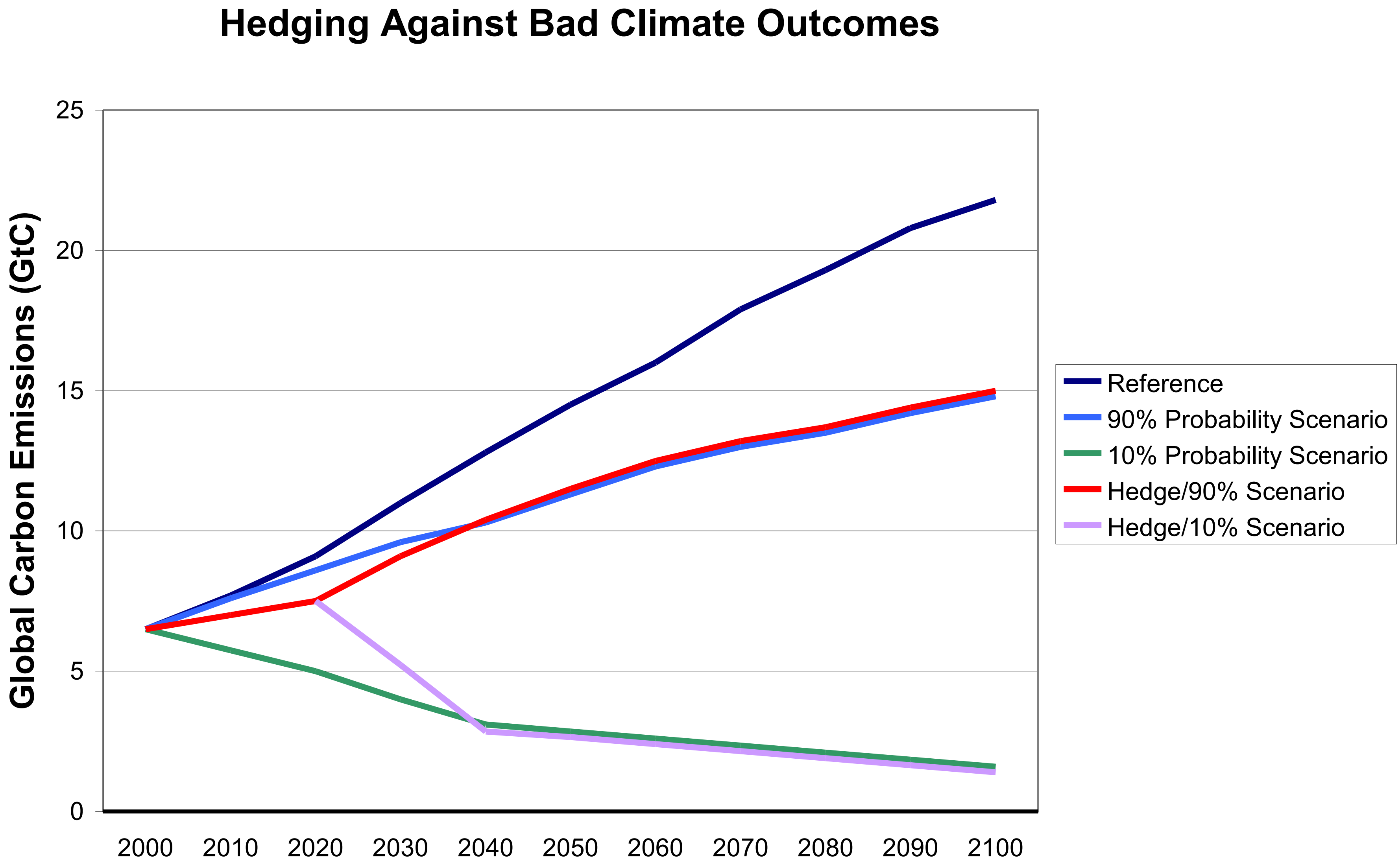
1.	United States	USA
2.	Japan	JPN
3.	European Community	EEC
4.	Other OECD [3]	OOE
5.	Central and Eastern Europe [4]	EET
6.	The former Soviet Union	FSU
7.	Energy-exporting LDCs [5]	EEX
8.	China	CHN
9.	India	IND
10.	Dynamic Asian Economies[6]	DAE
11.	Brazil	BRA
12.	Rest of the World	ROW

Gases (and chemical formuli)

1.	Carbon Dioxide	CO_2
2.	Methane	CH_4
3.	Nitrous Oxide	N_2O
4.	Chlorofluorocarbons	CFC
5.	Nitrogen Oxides	NO_x
6.	Carbon Monoxide	CO
7.	Sulfur Oxides	SOx

[1] Liquid fuel derived from shale.
[2] Carbon-free electricity derived from advanced nuclear, solar, or wind.
[3] Australia, Canada, New Zealand, EFTA (excluding Switzerland and Iceland), and Turkey.
[4] Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Yugoslavia.
[5] OPEC countries as well as other oil-exporting, gas-exporting, and coal-exporting countries (see Burniaux et al., 1992).
[6] Hong Kong, Philippines, Singapore, South Korea, Taiwan, and Thailand.

MERGE (Manne-Richels)
Hedging Experiments



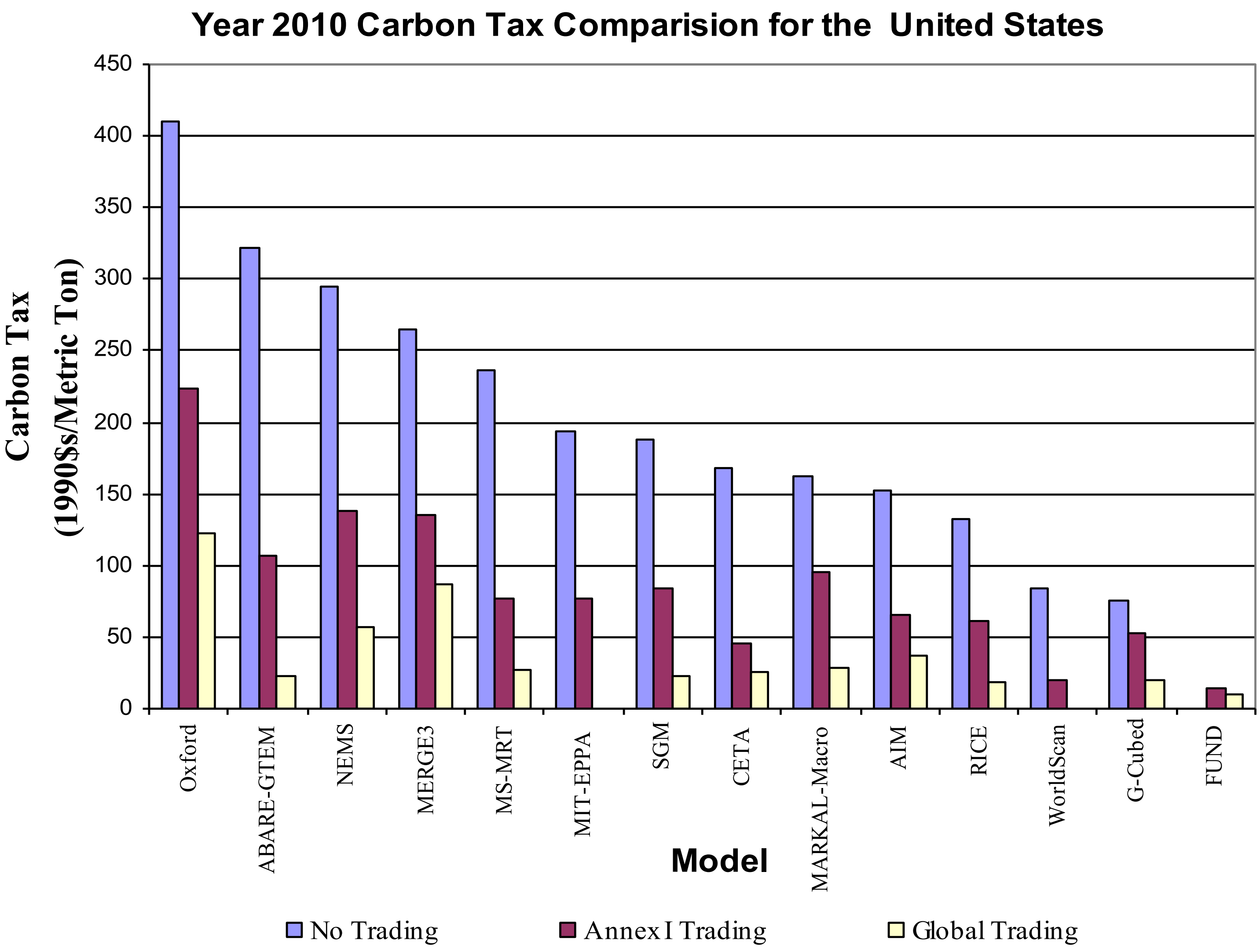
State of the Art in 2015

- More refined CE analyses
  - The four flexibilities: where, when, what, how,…
  - The transition issue – where you go in short run conditions where you can go in the LR
- Impacts oriented
  - More sectoral stressors and refined tolerable windows
  - Starting to appreciate mitigation/adaptation interactions
  - More empirical evidence, especially on impacts side
  - Introduction of regional integrated assessments

Four Kinds of Mitigation Policy Flexibilities

1. Where Flexibility
2. When Flexibility
3. How Flexibility
4. What Flexibility

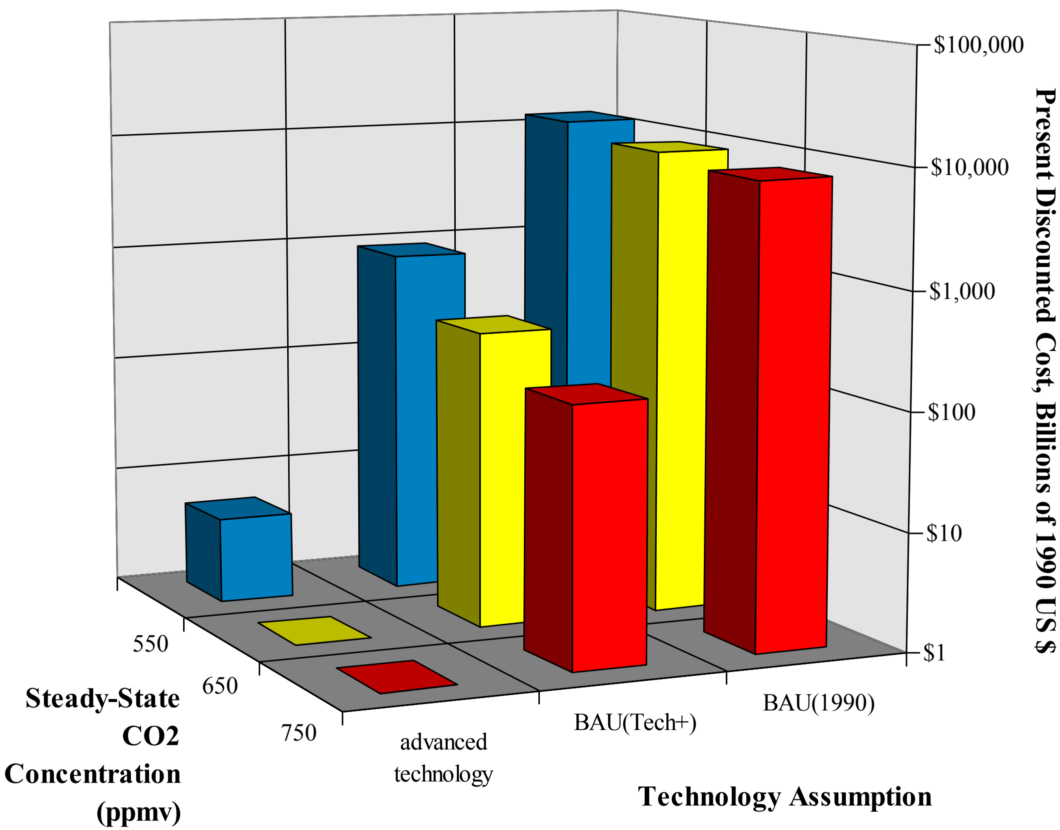
Where Flexibility:
The Cost of Kyoto



How Flexibility:

The VALUE OF DEVELOPING NEW ENERGY TECHNOLOGY

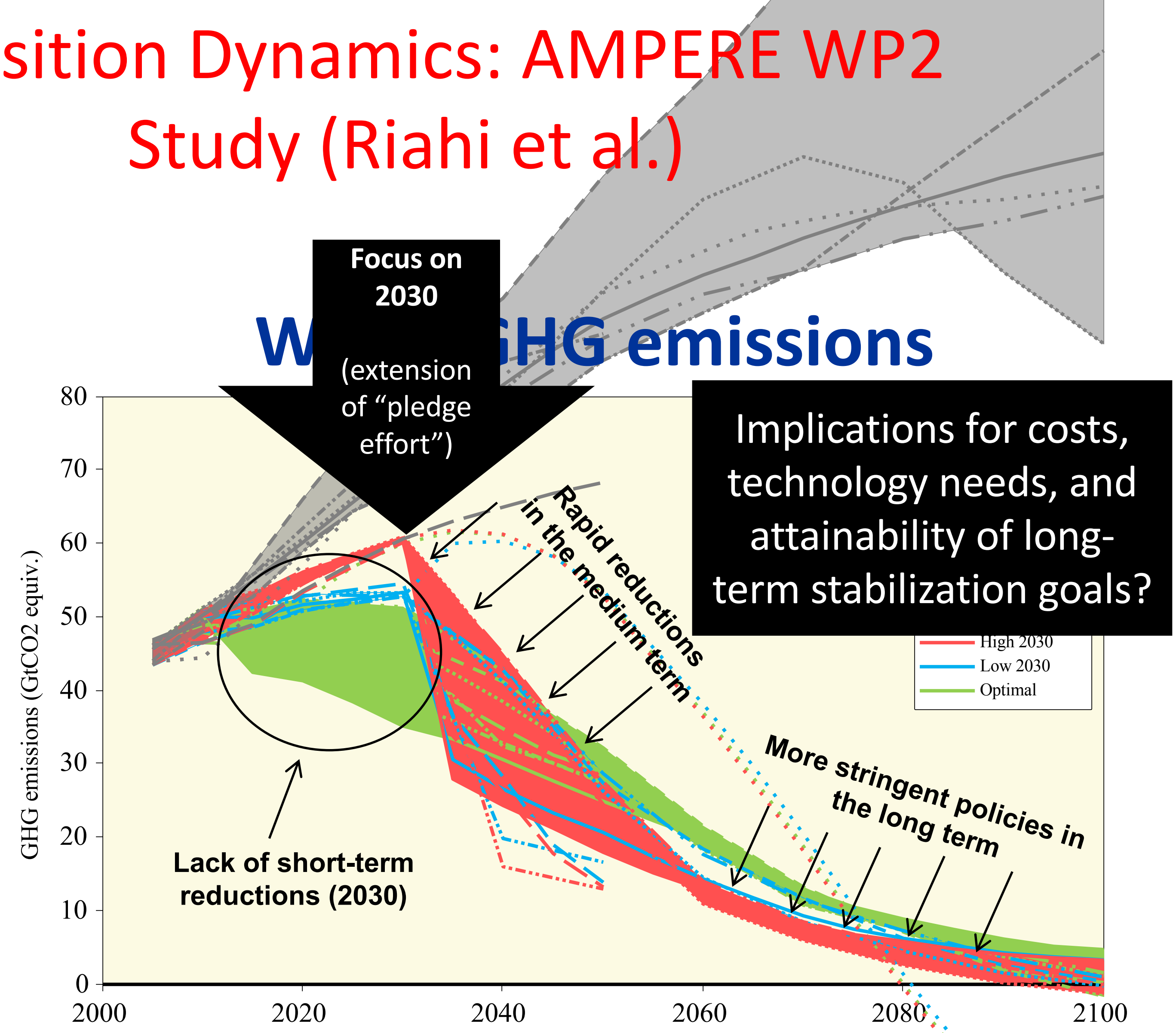
(Present Discounted Costs to Stabilize the Atmosphere)



Minimum Cost Based on Perfect Where & When Flexibility Assumption. Actual Cost Could be An Order of Magnitude Larger.

Battelle Pacific Northwest Laboratories

Transition Dynamics: AMPERE WP2 Study (Riahi et al.)

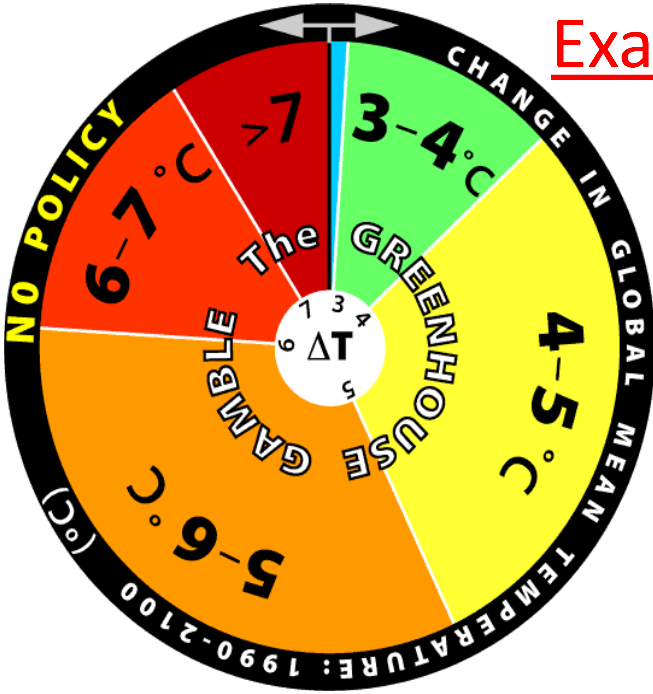


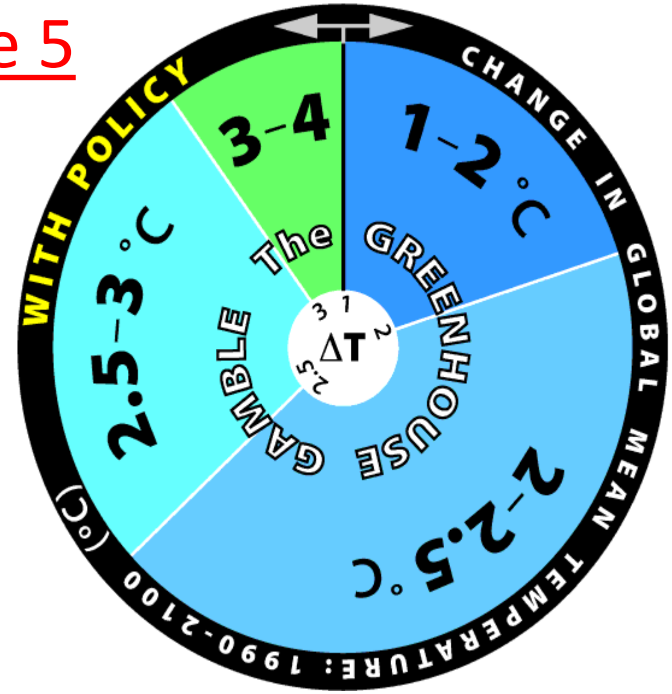
See presentation by Nils Johnson in session on informing near term international policy discussion

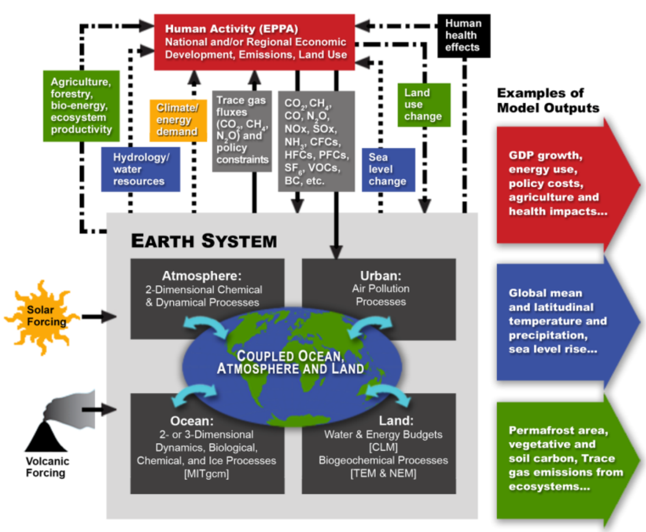
Without policy – emissions and climate response uncertain

With policy – fixed emissions (675 ppm CO2eq), climate response uncertain

Example 5







MIT IGSM

The MIT IGSM included uncertainty in both physical and social science/economics aspects, captured in formal uncertainty analysis to generate probabilistic outcomes, represented here as Greenhouse Gamble wheels.

PNNL MiniCAM Land/Biofuels

SCIENCE VOL 324 29 MAY 2009

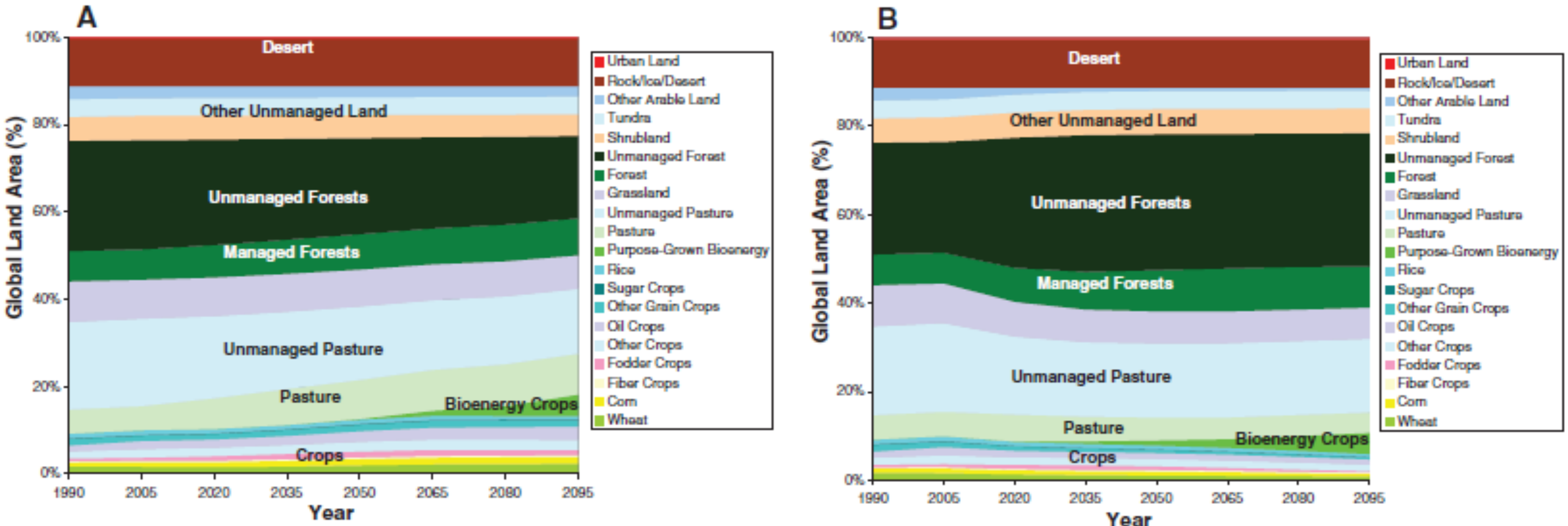
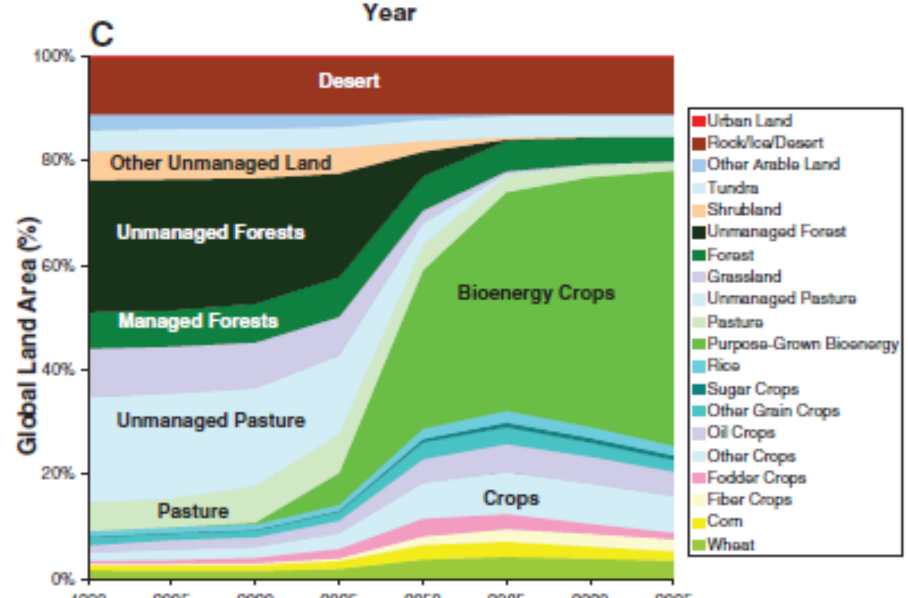


Fig. 2. A comparison of global land use under different scenarios. (**A**) Land use along the reference pathway. (**B**) Land use under a UCT pathway defined to achieve a CO_2 concentration target of 450 ppm, which limits fossil fuel, industrial, and terrestrial carbon emissions with a common carbon tax on emissions. (**C**) Land use along the corresponding FFICT scenario in which only fossil fuel and industrial emissions are controlled to achieve the same 450-ppm CO_2 concentration. In the FFICT scenario, the substantial increase in demand for purpose-grown biomass (four times as much as the reference scenario in Year 2095) intensifies its competition with food and fiber crops for the best cropland, pushing crops and biomass growth beyond traditional croplands and into lands that are inherently less productive. As a result, the relative increase in land required for biomass and other crops exceeds the relative increase in demand.



MIT IGSM

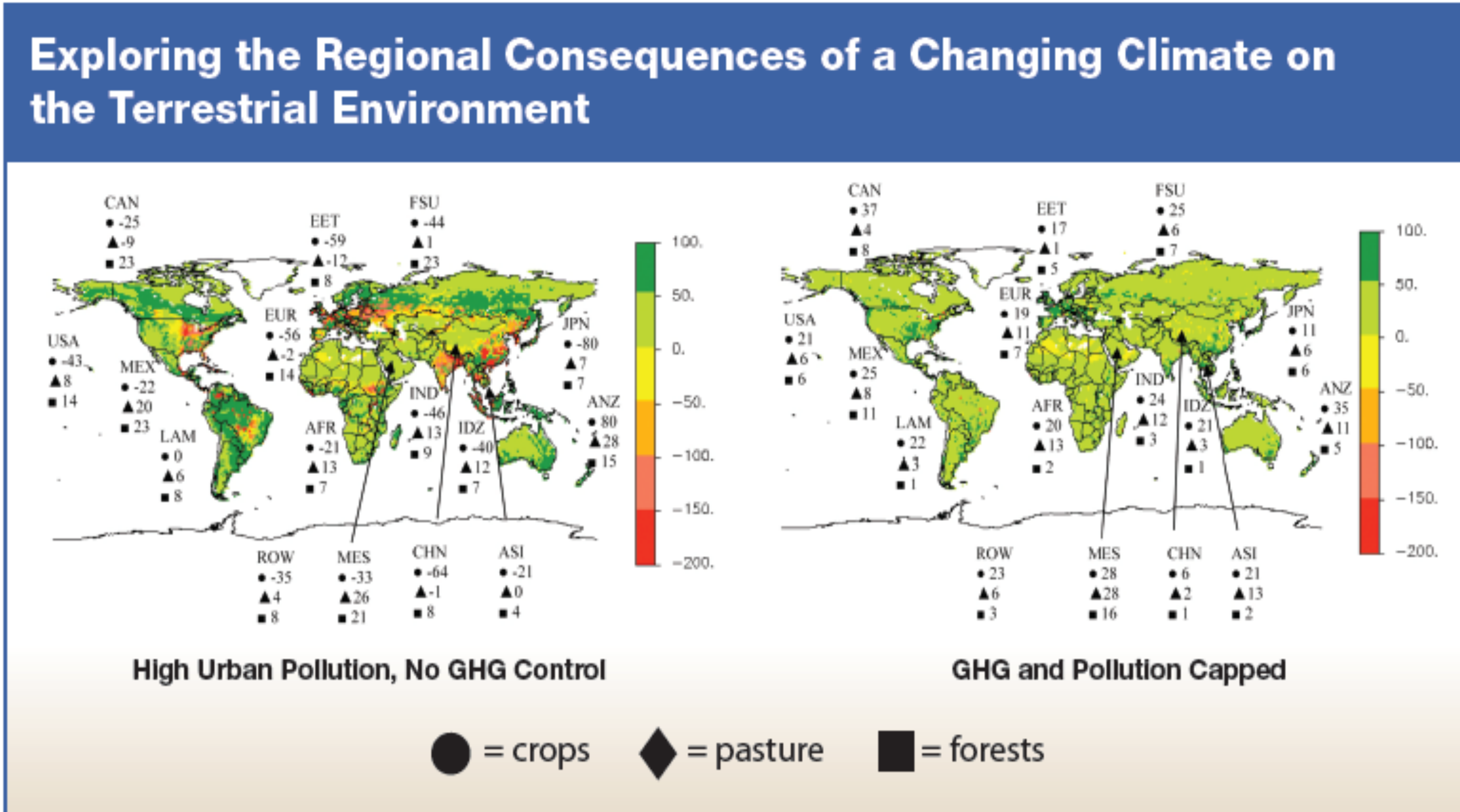
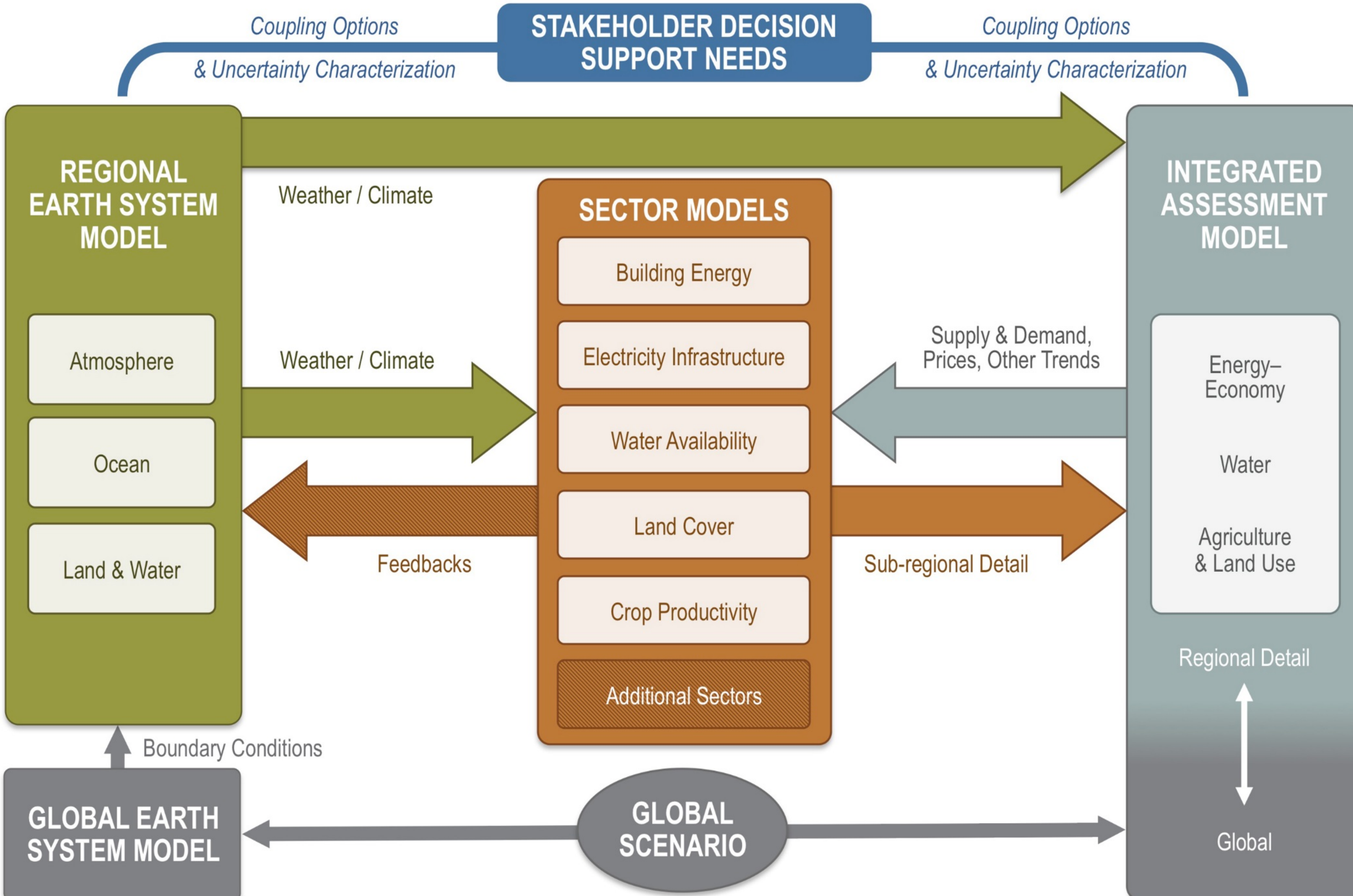


Fig. 3.9. Exploring the Regional Consequences of a Changing Climate on the Terrestrial Environment. Crop, pasture, and forest productivity are influenced significantly by climate change, CO_2 fertilization, and damage from ozone resulting from urban air pollution. For each of the economic regions in MIT's IGSM, the figures show the effects on yield (crops) and net primary productivity (pasture and forestry) between 2000 and 2100 ($gC/m^2/yr$).

Regional IA-PRIMA/RIAM



Kraucunas, et al. (201X)

Some Newer IA Horizons

- Search for decision relevant metrics (growing interest)
  - What to measure, how to measure it, how to deal with tradeoffs
  - Income distribution and equity
  - Sustainable development, energy poverty and energy access
- Integrated impacts (more work, needs focus and strategy)
  - Risk analysis framing of IAV
  - Interactions between sectors & feedbacks to earth system
  - Reconciliation of statistical & physical modeling
- Uncertainty characterization and modeling (still messy)
  - Identification of many different types of uncertainties
  - Disciplinary differences in definitions, framing and methods
  - The question of means versus extremes as the focus

Whither the Poor and Defenseless? A Revealed Preference Study of Climate Change Policy Analyses

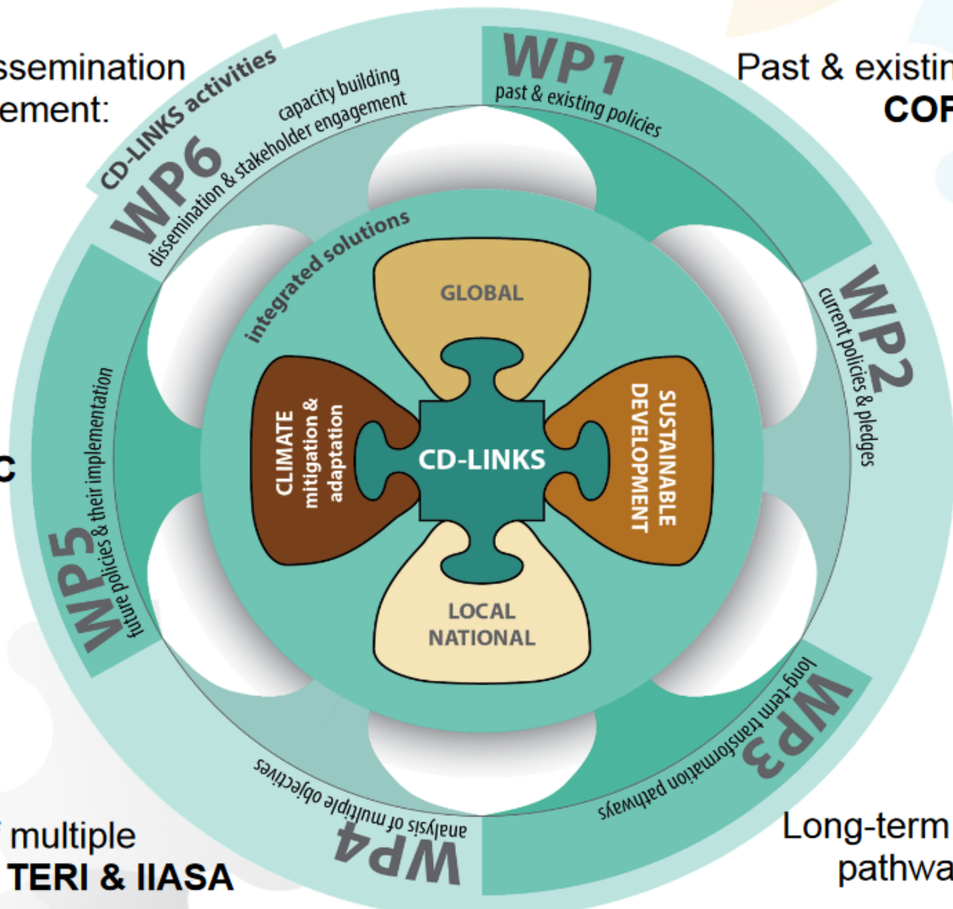
Class of World Citizen	Typical OECD (AEA Member?) Analysis	ROW Analysis
2 Billion People Without Markets	What 2 Billion People?	High Priority: Reduce Their Vulnerability
2 Billion In or Near Poverty with Fragile Markets	They Don't Count for Much!	High Priority: Reduce Their Vulnerability
2 Billion Potential Decaf Latté Drinkers	Half Are Stuck In Transition, But the Rest We Can Help	They Can Take Care of Themselves

European CD-LINKS Project

CD-LINKS work packages

Capacity building, dissemination & stakeholder engagement: **CMCC & IIASA**

Past & existing policies: **COPPE & PIK**



Future policies & their implementation: **CMCC**

Current policies & pledges: **PBL**

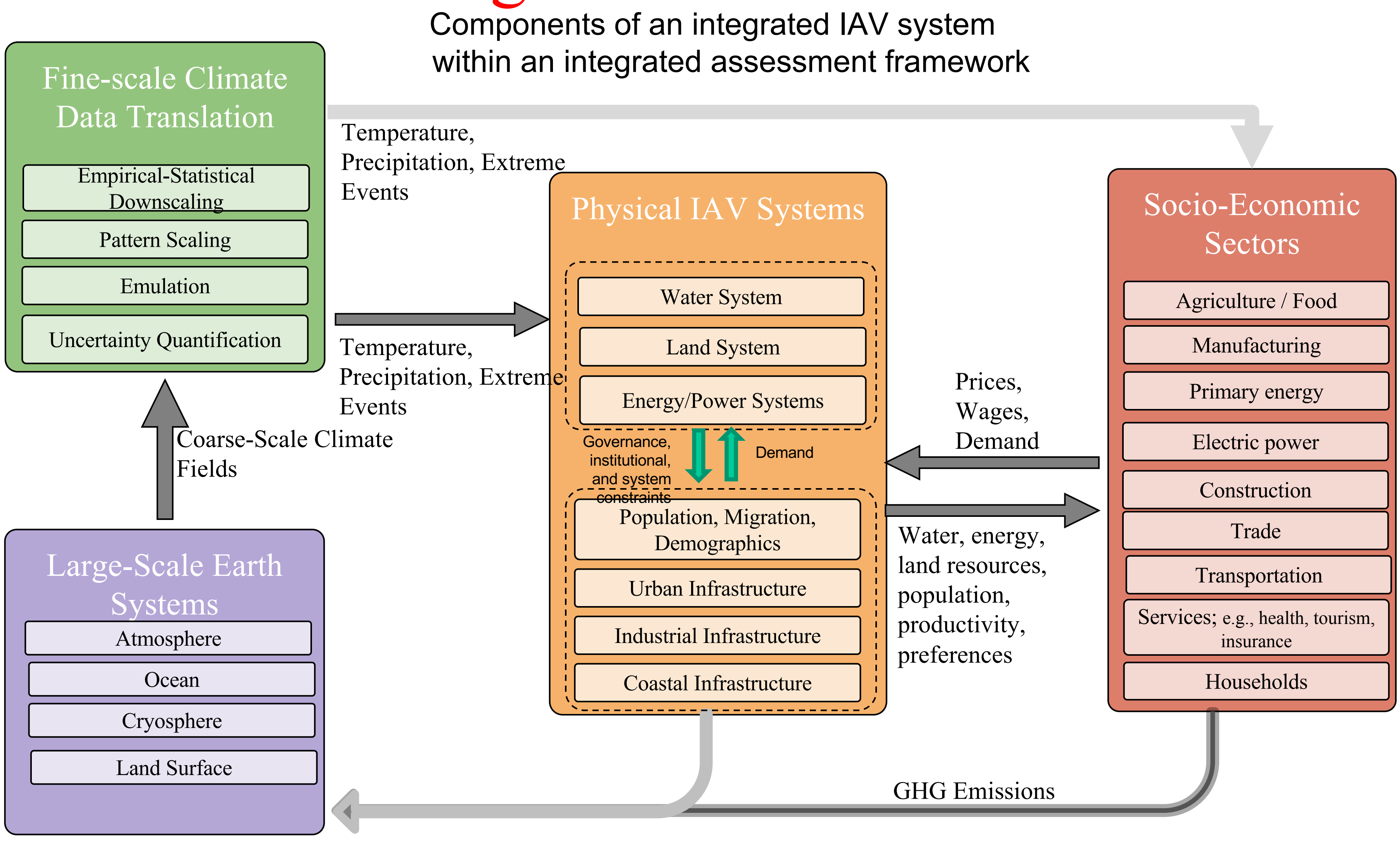
Analysis of multiple objectives: **TERI & IIASA**

Long-term transformation pathways: **PIK & PBL**

Recent Trend Towards Establishing Frameworks for Integrated Impacts Assessment

- Establishing innovative frameworks for developing multi-sector, multi-scale, multi-model approaches for IAV and the nexus of (IAMs, IAVs, and ESMs)
- This framework will provide:
  1. The IAV community with methods and models for including both multi-sector impacts and full earth systems interactions and feedbacks in its work
  2. The IAM community with enhanced capabilities to consider fully linked multi-sector climate change impacts in its work
- Critical importance of linking, coupling, and emulation (DRI Macro example)

Conceptual Representation of Integrated Framework



Fisher-Vanden, et al. (2016)

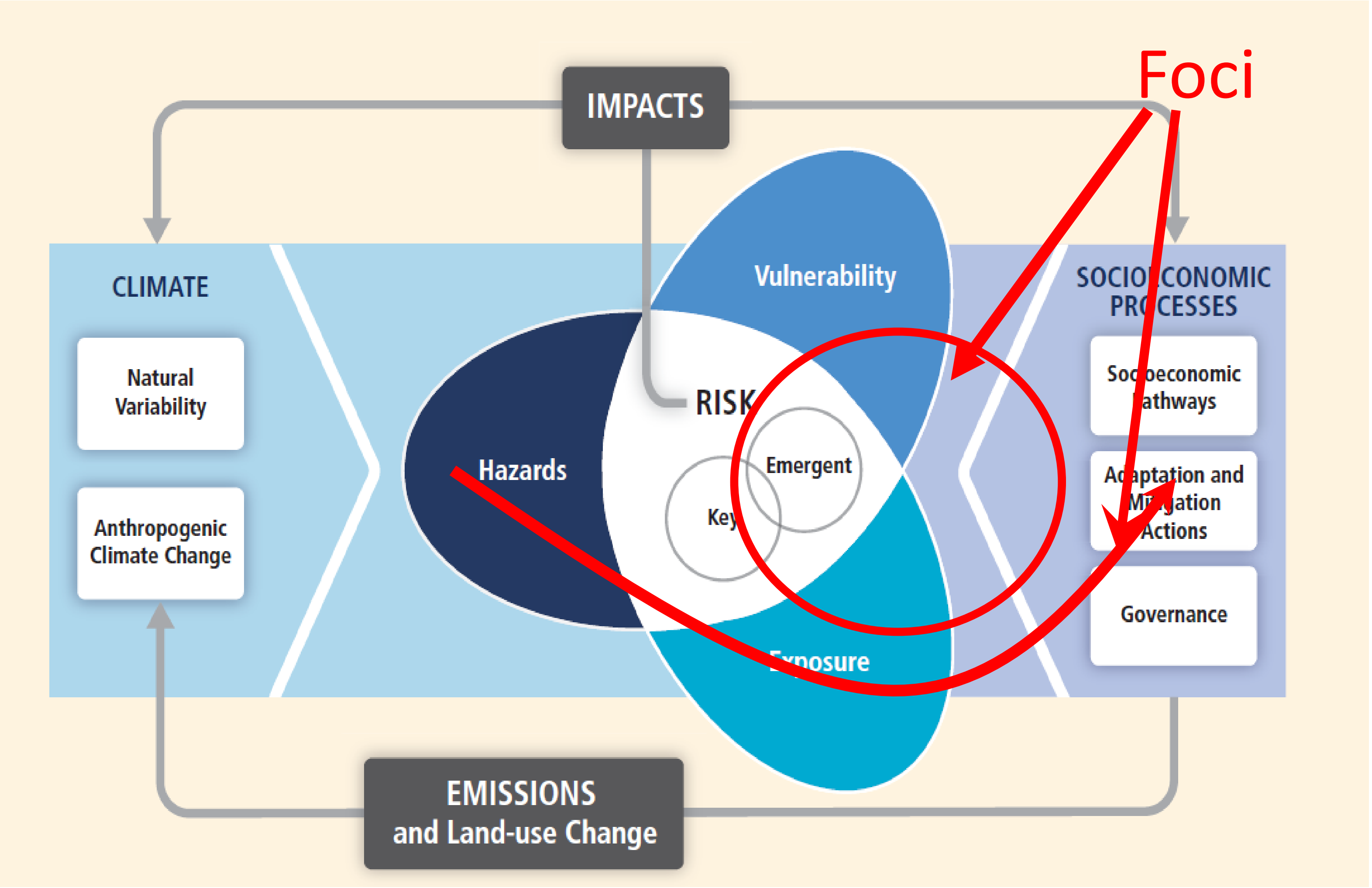
Uncertainty Categories/Concepts

- Climate models
  - Initial condition uncertainty
  - Annual to inter-annual variability uncertainty
  - Input uncertainty
  - Structural uncertainty
  - Parametric uncertainty
- IAMs
  - Some of the above (do we need more?)
  - Some of the below (or not so much?)
  - Foresight by decision makers?
  - Contingent decisions by decision makers
- IAV models
  - Some of the above (do we need more?)
  - Tolerable windows/RPM thinking
  - Risk assessment framing (need risk attitudes)
- In the aggregate this is a bit of a MESS

Approaches to Uncertainty Analysis

- Sensitivity analysis
- Stochastic simulation (MC, MCMC, etc.)
- Probability distribution “tail analyses”
- Decision Making Under Uncertainty
  - Sequential DMUU
  - Decision Analysis
  - Stochastic Control
  - Robust Planning
- ANOVA type methods (Sobols/MoM)

IPCC AR5: WG 2-Chapter 19



ipcc
INTERGOVERNMENTAL PANEL ON climate change

Biggest Overall Challenges

- Data availability and quality, including “big data”
- More serious work on metrics
- Staying true to first principles
- Importance of linkages, emulators, translators
- Uncertainty- consistency, statistics, experts, structural, machine learning

Thank You!

Questions

What is Integrated Assessment of Climate Change Policy?

- Many definitions of IA for many purposes
- Here we call integrated assessment of climate change policy any attempt to bring together the costs and benefits of climate change policies in a systematic manner