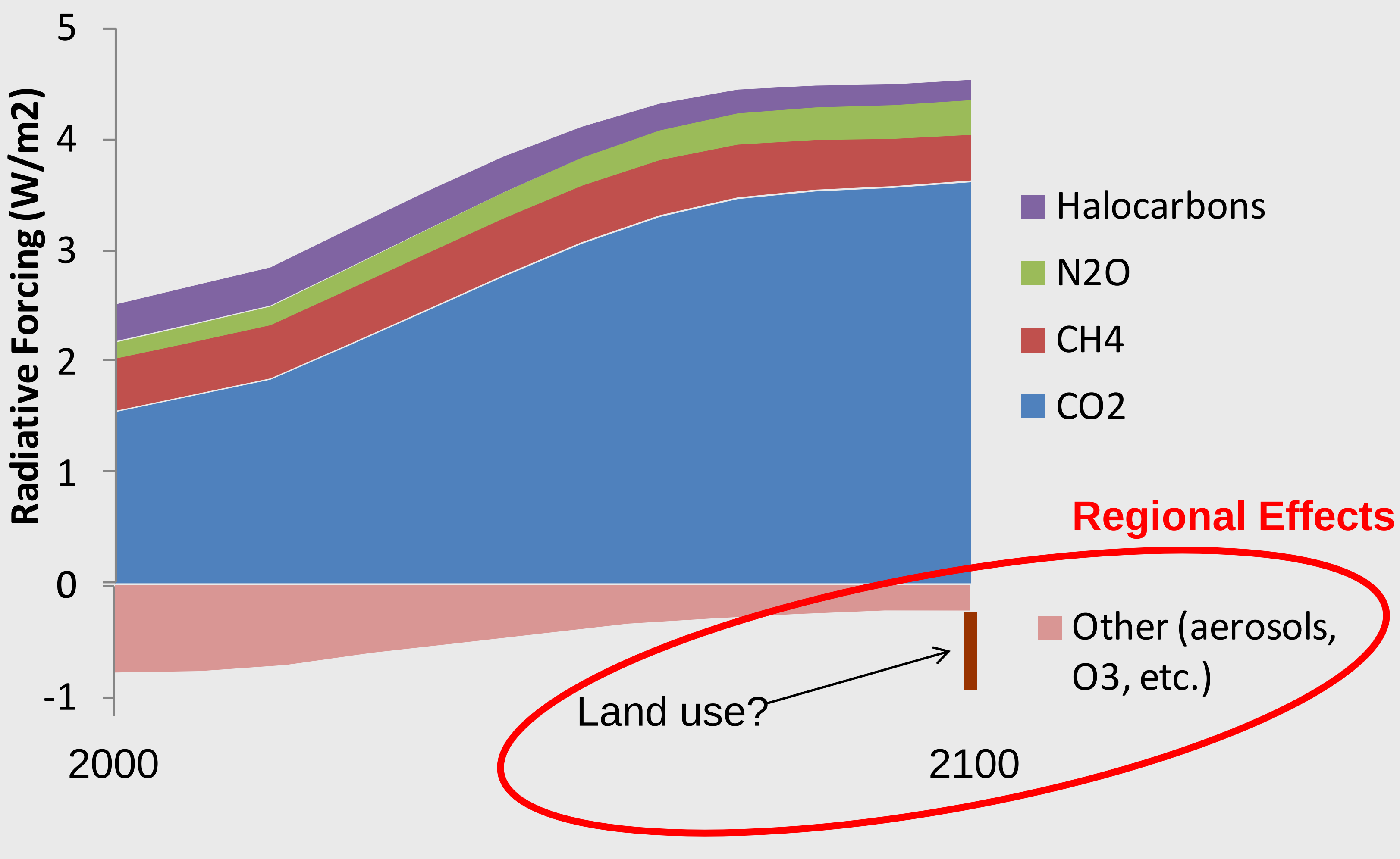
Emissions Uncertainty

Brian O’Neill, NCAR

Outline

- Introduction
  - Emissions and drivers
  - Approaches to uncertainty
- Models used to project emissions
- Probabilistic projections – MIT example
- Alternative scenarios – SSP/RCP example
- Other approaches – brief examples?

Radiative Forcing, RCP-4.5



Indirect Drivers* → Direct Drivers → Emissions

Indirect Drivers*

- Economic
  - Income, distribution
  - Trade
  - Globalization
- Demographic
  - Size, age structure
  - Urbanization
  - Spatial distribution
- Science and technology
  - Investments
  - Technological change across industries
- Socio-political
  - Education
  - Institutions, laws
- Cultural and Religious
  - Lifestyles

Interactions

Direct Drivers

- Energy use
  - Fuel mix (fossil, coal, quality, …)
  - Conversion technology
  - Control technology
  - End use efficiency
  - Transportation
  - Household traditional fuel use
- Land use
  - Ag production
  - Ag production technology
  - Ag inputs (fertilizer, irrigation)
  - Forest management
- Industry
  - Production processes
  - Control technology

Emissions

- CO2
- CH4
- N2O
- Halocarbons
- SO2
- O3 precursors
- BC, OC
- Ammonia

↓

Climate
Air quality

Feedbacks

* Based on Millennium Assessment Conceptual Framework

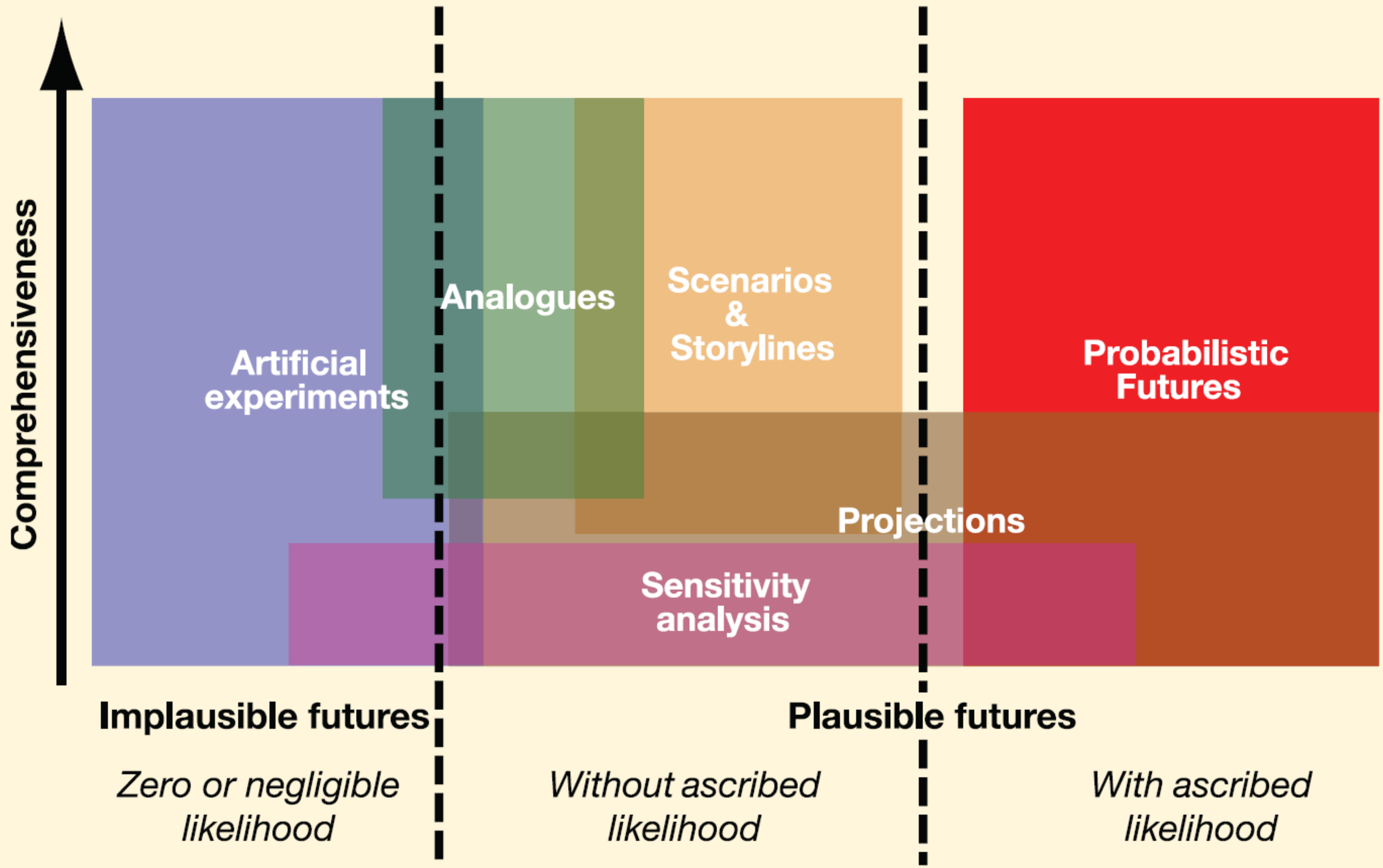
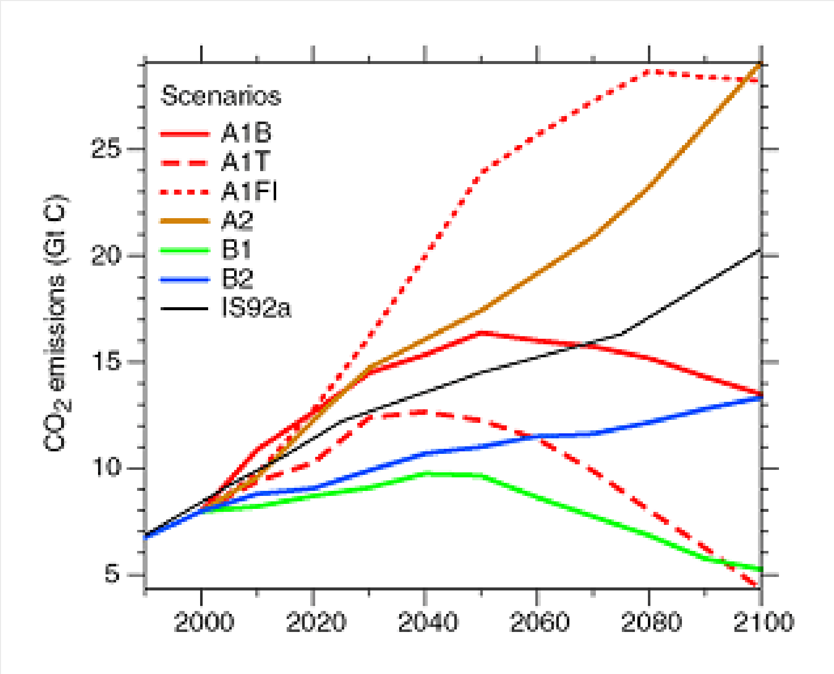
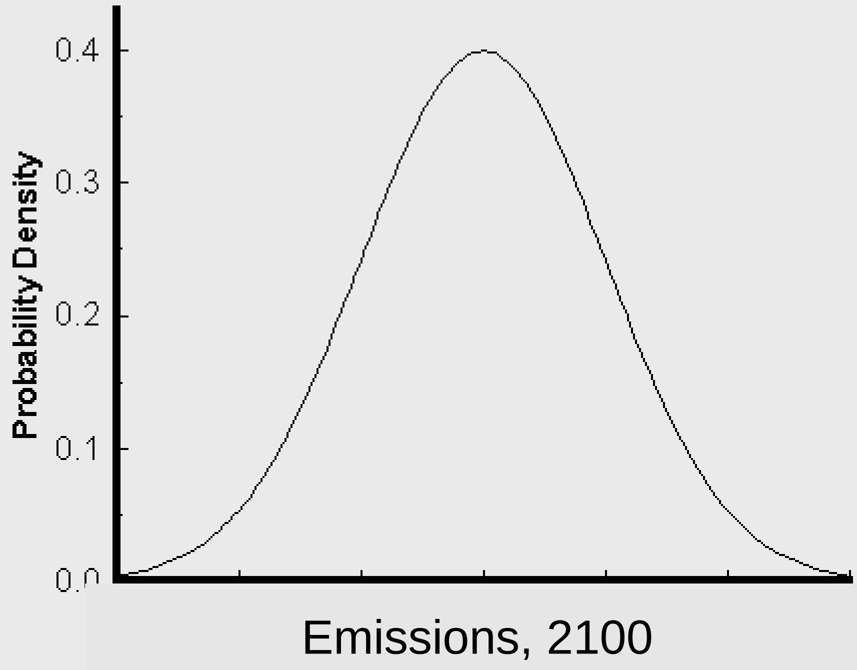


Figure 2.4. *Characterisations of the future.*

AR4 WG2 Ch 2

Alternative approaches





Alternative Scenarios

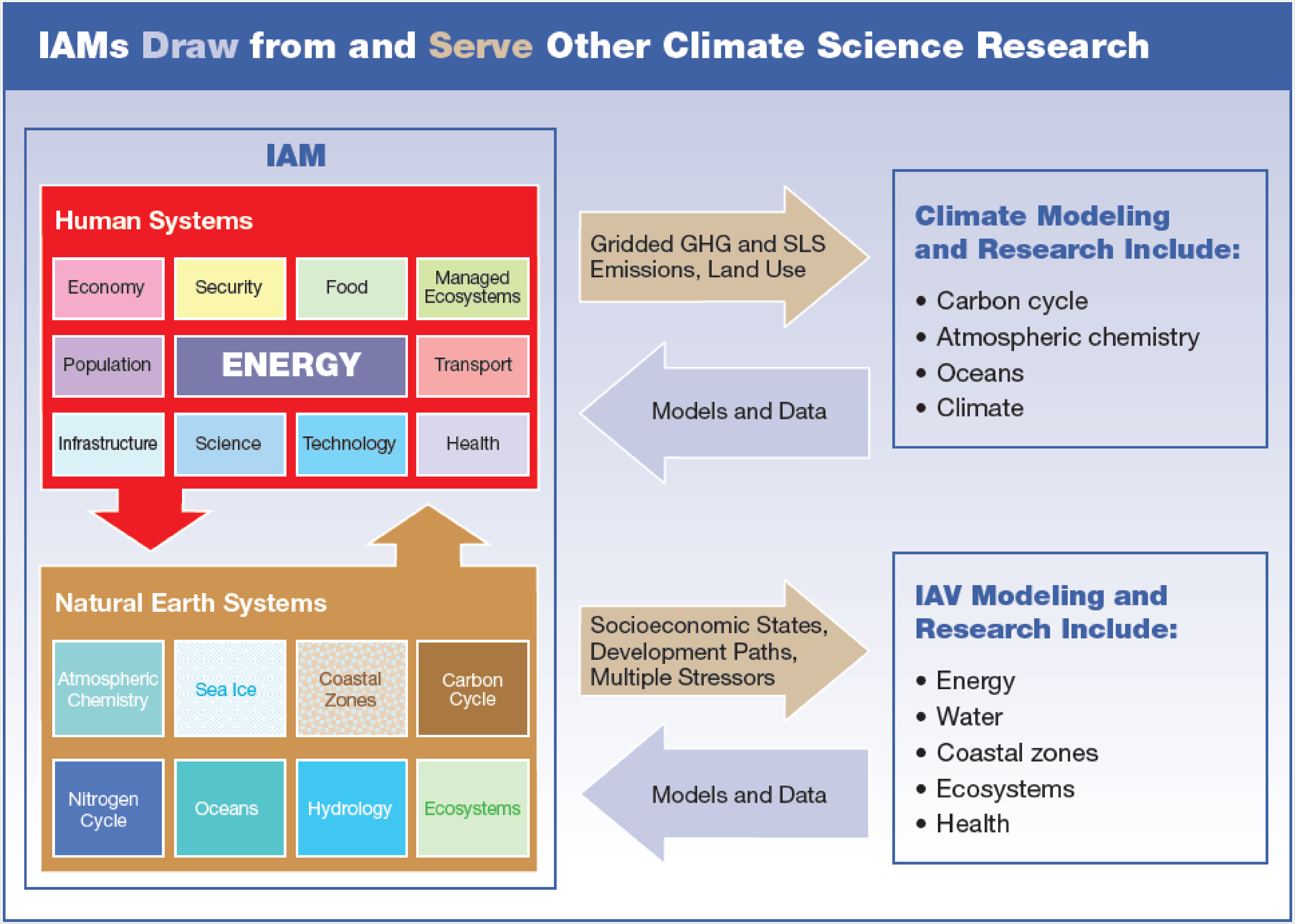
Probabilistic

Multi-model ensembles

Exploratory analysis

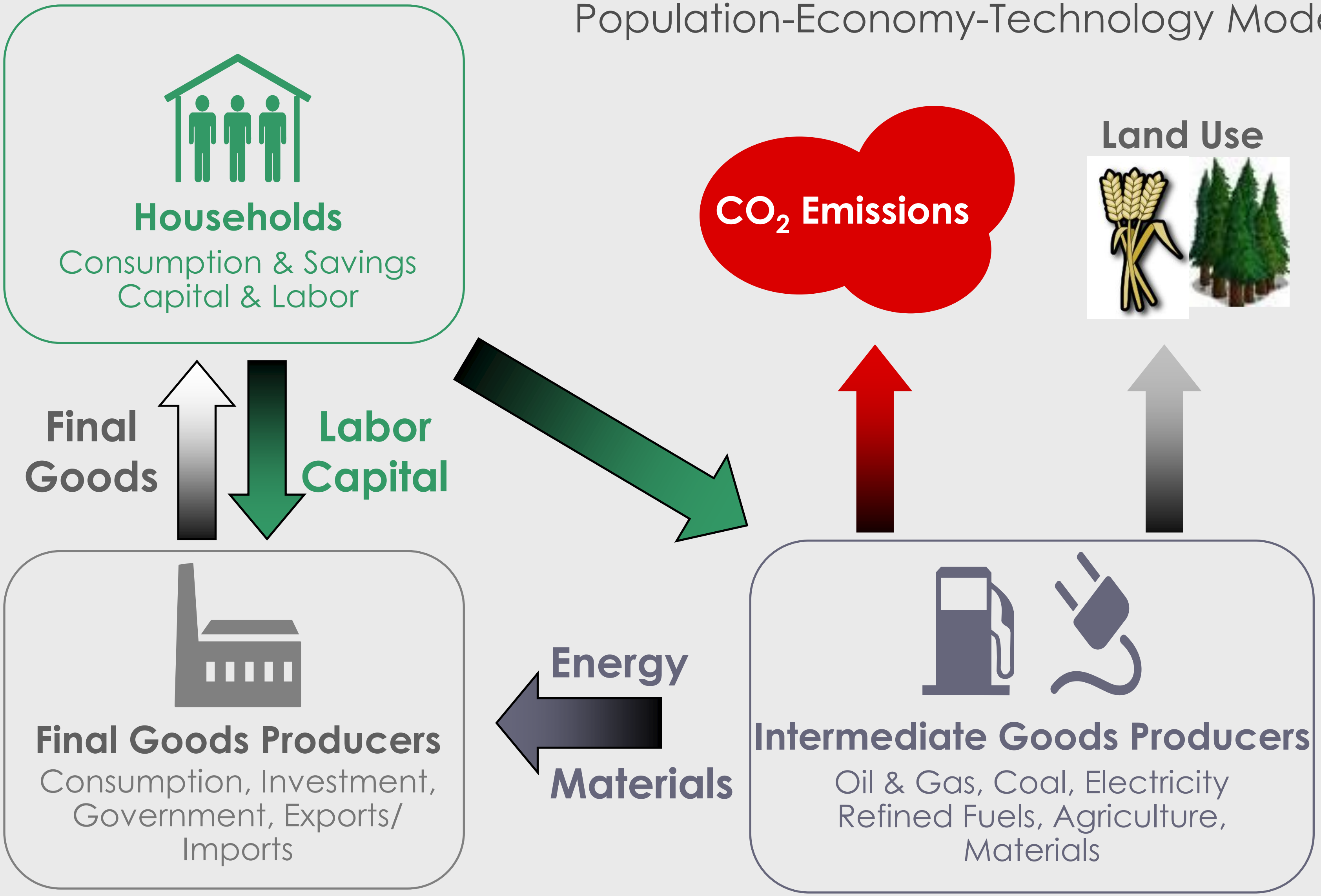
Robustness

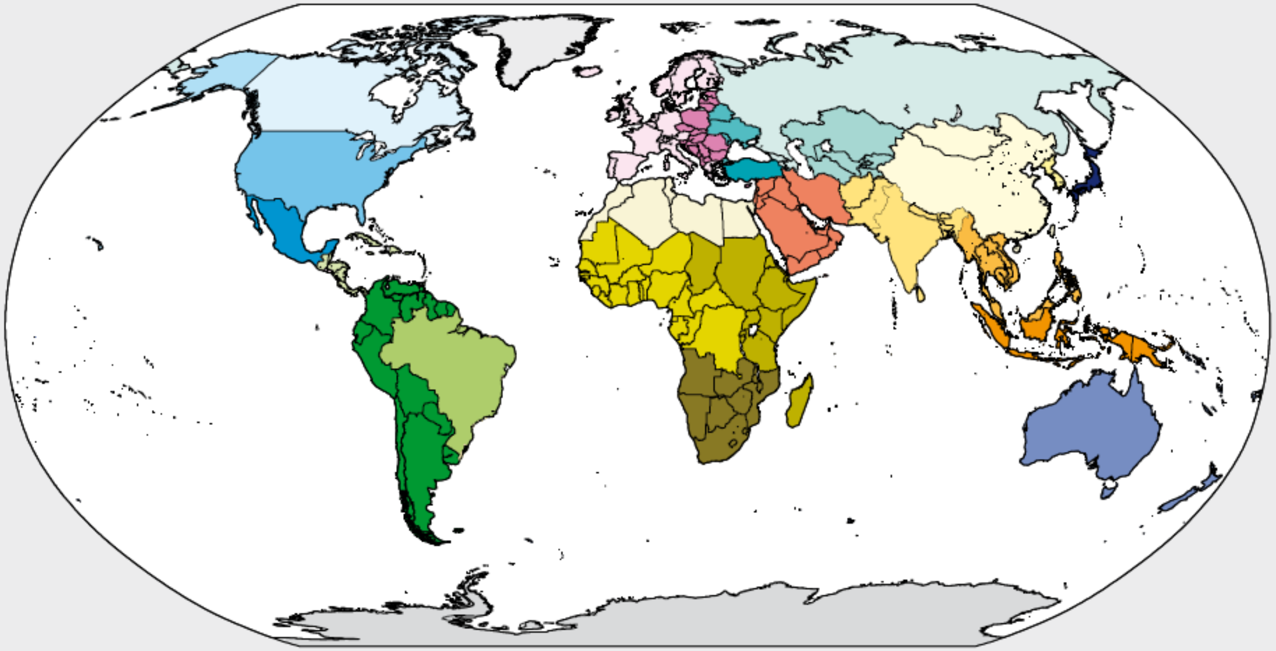
Conditional Probabilistic


IAMs Draw from and Serve Other Climate Science Research
IAM
Human Systems
Economy
Security
Food
Managed Ecosystems
Population
ENERGY
Transport
Infrastructure
Science
Technology
Health
Natural Earth Systems
Atmospheric Chemistry
Sea Ice
Coastal Zones
Carbon Cycle
Nitrogen Cycle
Oceans
Hydrology
Ecosystems
Gridded GHG and SLS Emissions, Land Use
Models and Data
Climate Modeling and Research Include:
• Carbon cycle
• Atmospheric chemistry
• Oceans
• Climate
Socioeconomic States, Development Paths, Multiple Stressors
Models and Data
IAV Modeling and Research Include:
• Energy
• Water
• Coastal zones
• Ecosystems
• Health

PET Model

Population-Economy-Technology Model

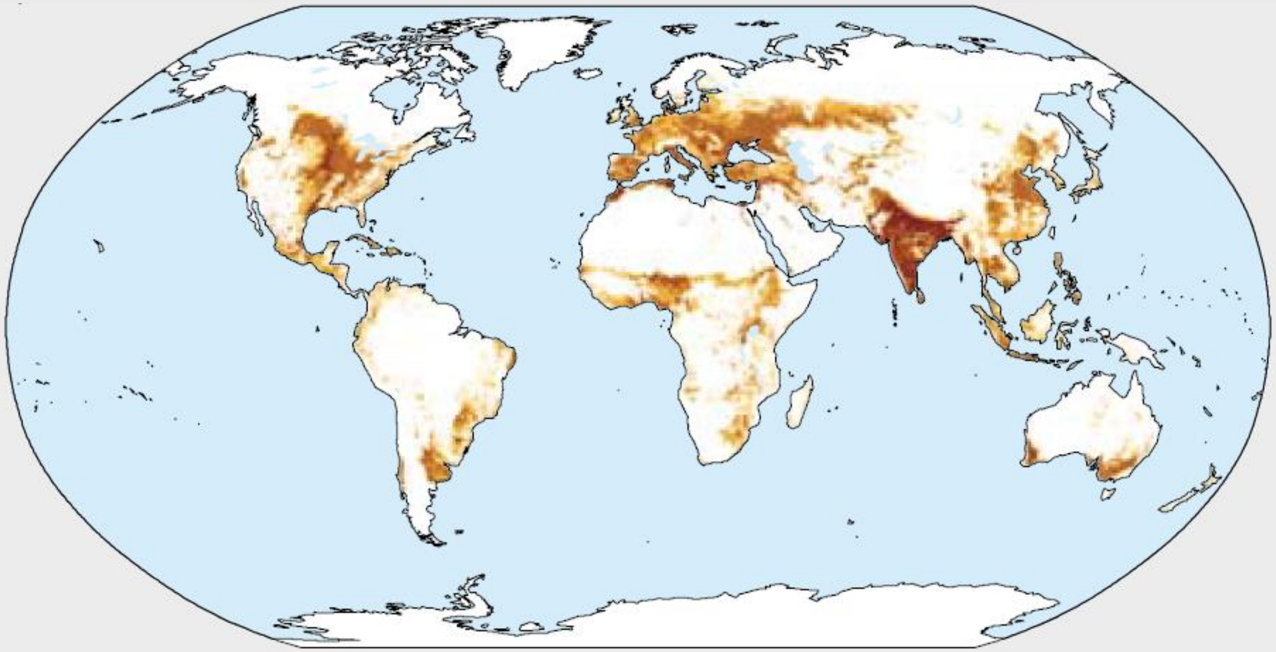




- Global scale
- Climate change mitigation, impacts, adaptation
- Insights into questions at level of nation+

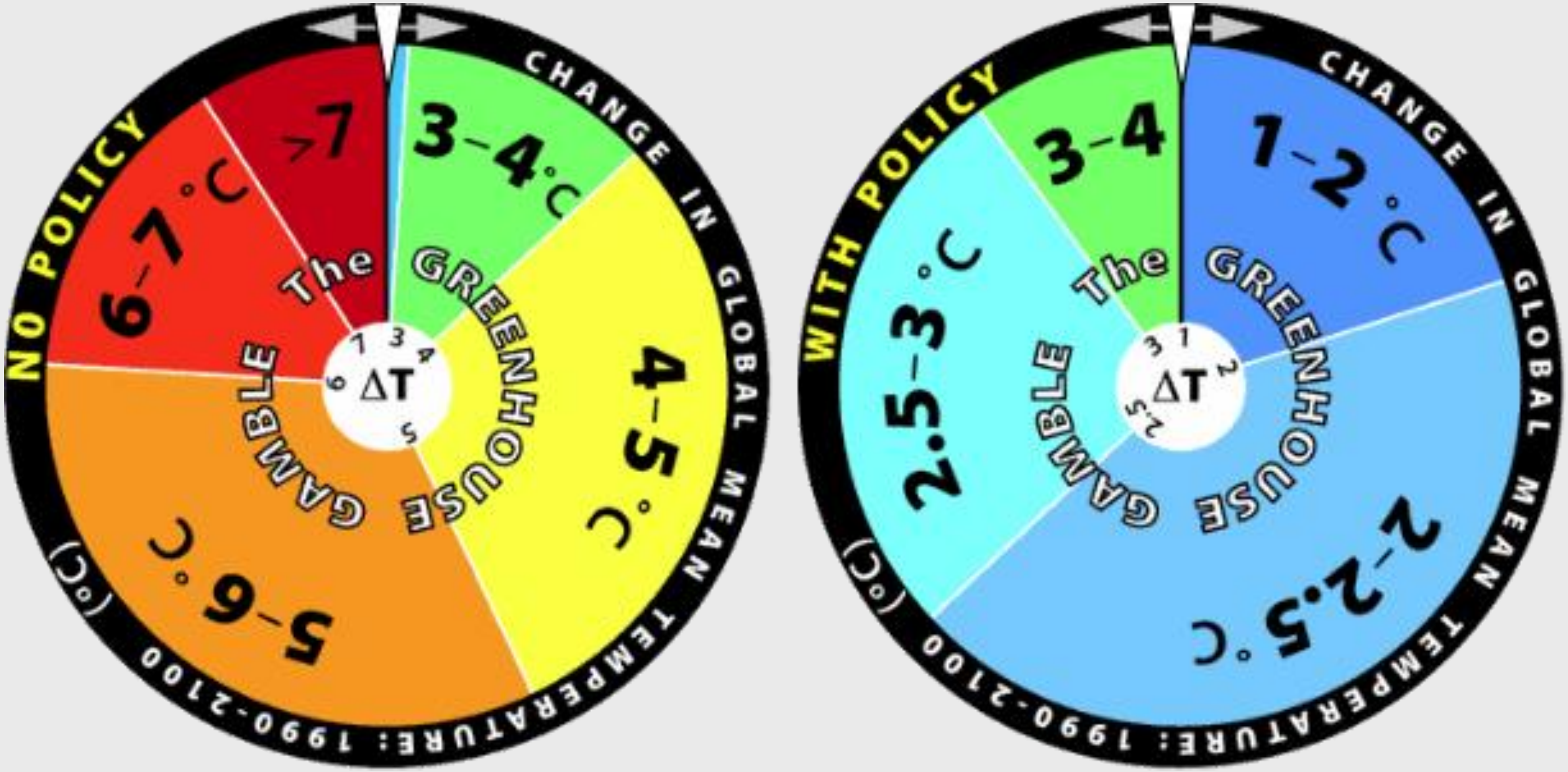
Some factors/processes represented at finer resolution:

soils
climate
population
urban extent
GDP
land use
emissions



Figures from IMAGE model, from Bouwman, Kram and Klein Goldewijk, 2006.

MIT "Greenhouse Gamble"



http://globalchange.mit.edu/focus-areas/uncertainty/gamble

Probabilistic Approach to Emissions

- Sensitivity analysis to understand relative importance of parameters to outcome of interest (emissions)
- Define PDFs for a subset of important parameters
- Define correlations among parameters
- Use Monte Carlo techniques to sample from parameter distributions and produce distribution of outcomes

- i.e., a "perturbed physics ensemble" approach

Key parameters

- Elasticities of substitution
- GDP growth (based on labor productivity growth)
- Autonomous Energy Efficiency Improvement (AEEI)
- Fossil fuel resource availability
- Population growth
- Urban pollutant trends
- Future energy technologies
- Non-CO2 greenhouse gas trends

Webster et al., 2008.

Deriving PDFs: Econometric estimates

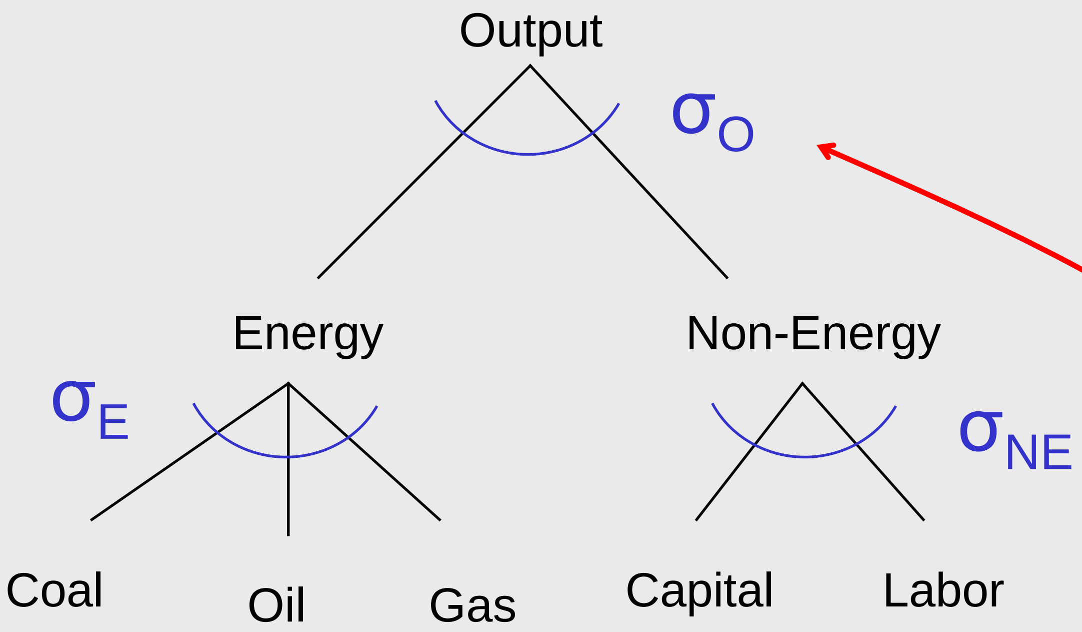


Table 4. Energy vs. Non-Energy Substitution Elasticity Uncertainty.

	Estimate	Std. Err.	Relative Err.
Kemfert (1998)	1.18	0.61	0.52
Kemfert and Welsch (2000)	0.43	0.13	0.29

Webster et al., 2008.

Table 8. Uncertainty in Available Supply of Fossil Fuels.

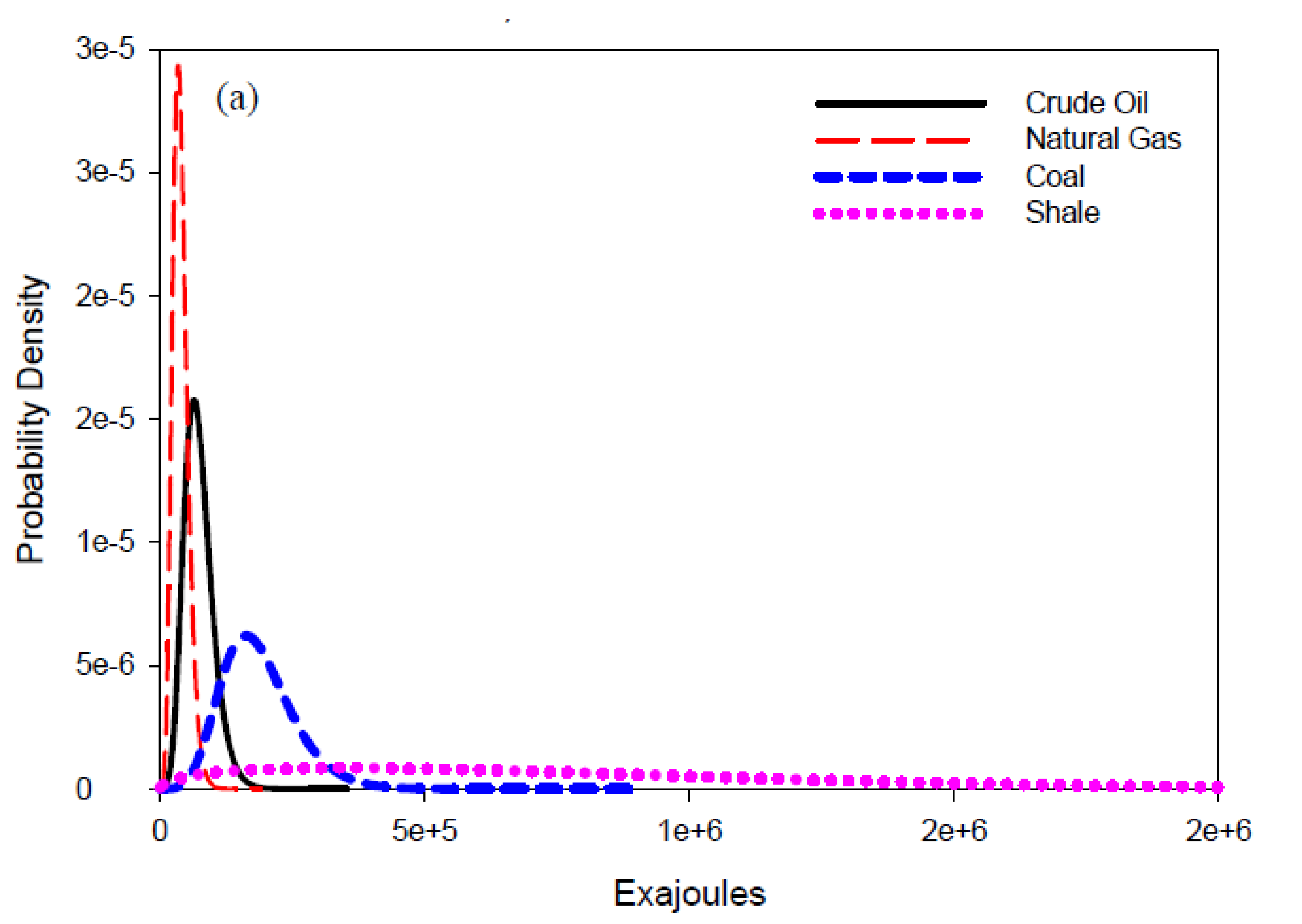
		Oil (Billion Barrels)				Natural Gas (Trillion Cubic Feet)			
		F95	***F50***	***F5***	***Mean***	***F95***	***F50***	***F5***	***Mean***
World Excluding U.S.	***Undiscovered Conv.***	334	607	1107	649	2299	4333	8174	4669
	Reserve Growth (conv.)	192	612	1031	612	1049	3305	5543	3305
	Remaining Reserves				859				4621
	Cum. Production				539				898
	Total	526	1219	2138	2659	3348	7638	13717	13493
	Relative to Median	***43%***		***175%***		***44%***		***180%***	
U.S.	***Undiscovered Conv.***	66		104	83	393		698	527
	Reserve Growth (conv.)				76				355
	Remaining Reserves				32				172
	Cum. Production				171				854
	Total	345		383	362	1774		2079	1908
	Relative to Mean	***95%***		***106%***		***93%***		***109%***	

Source: Ahlbrandt *et al.*, 2005

Note: Blanks are shown where results were not provided in the original source.

Webster et al., 2008.

Deriving PDFs: Inventory + Expert Judgment



Webster et al., 2008.

Derving PDFs: Time-series models

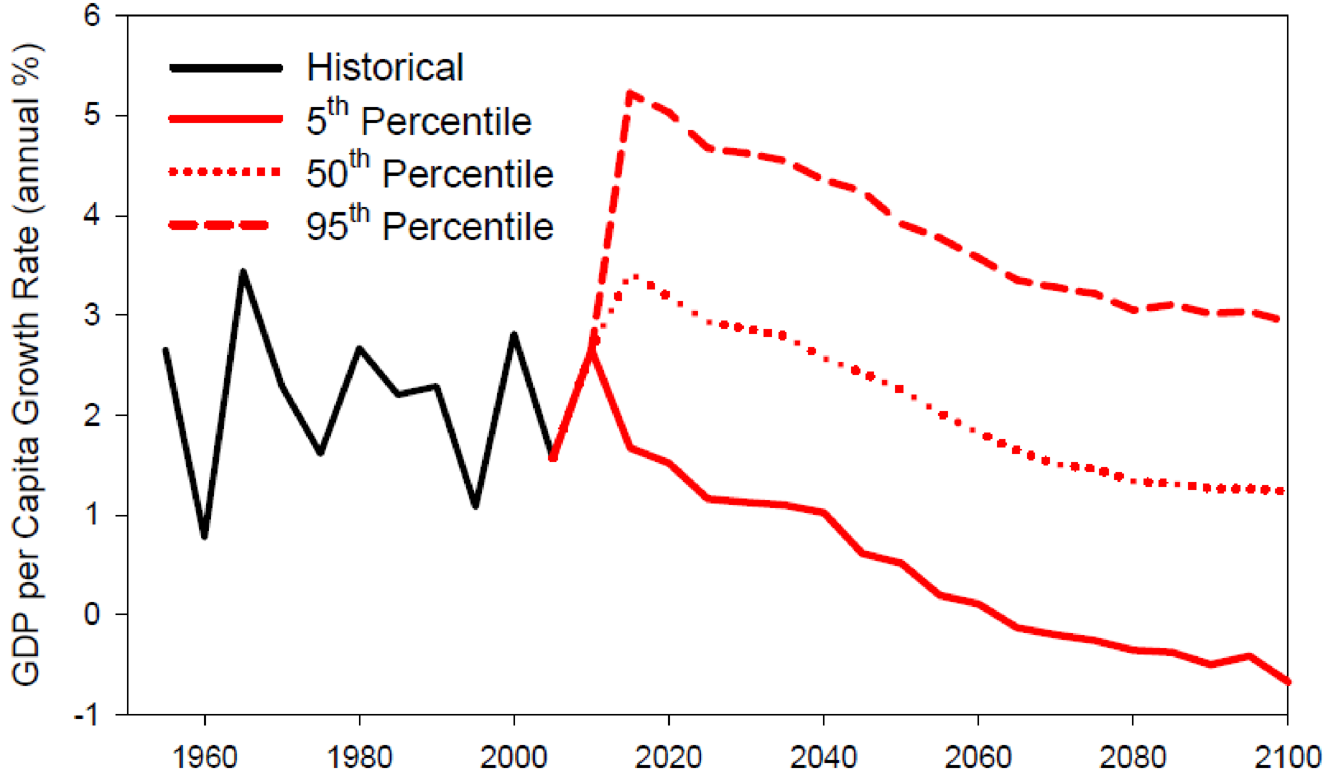
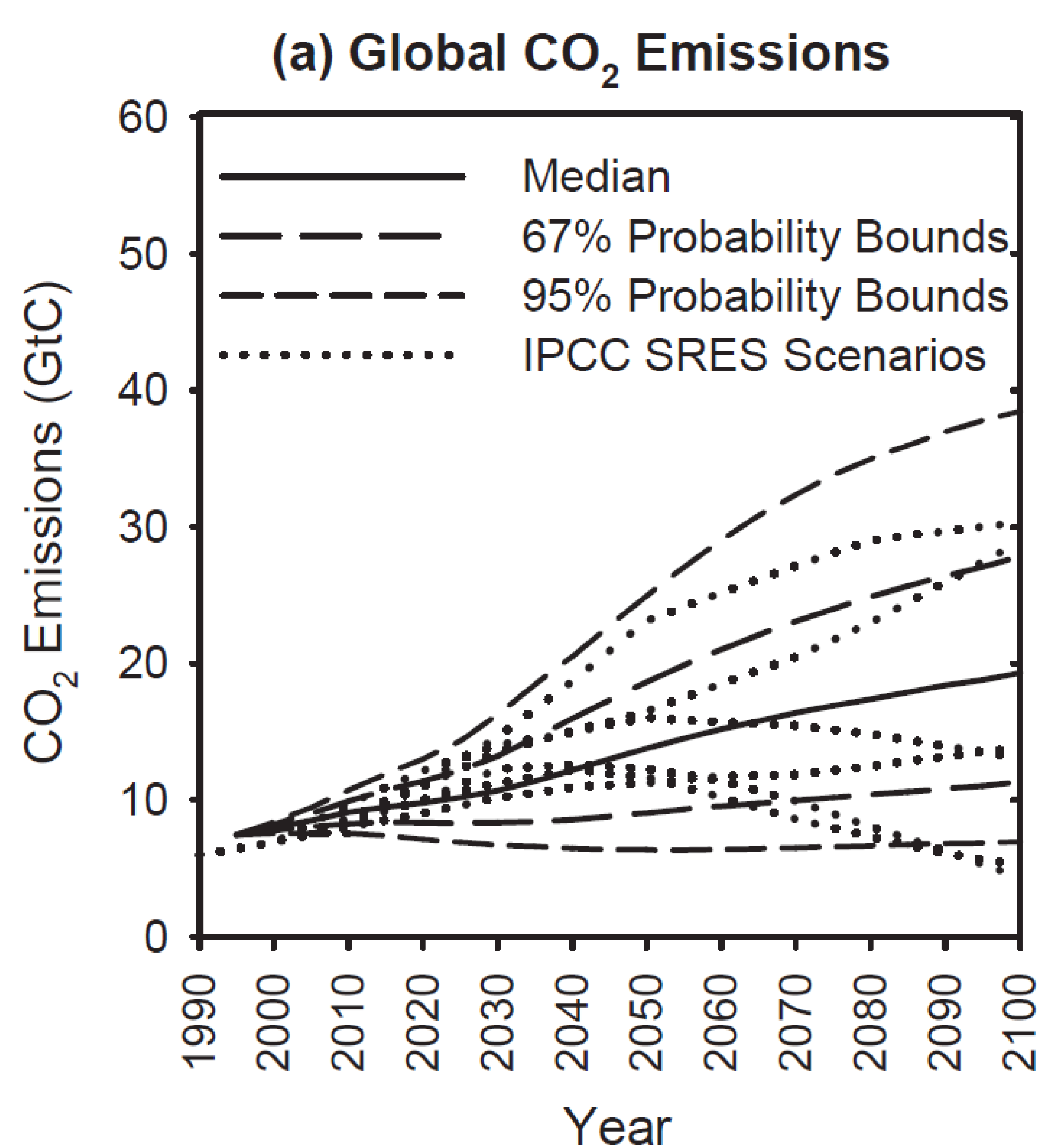


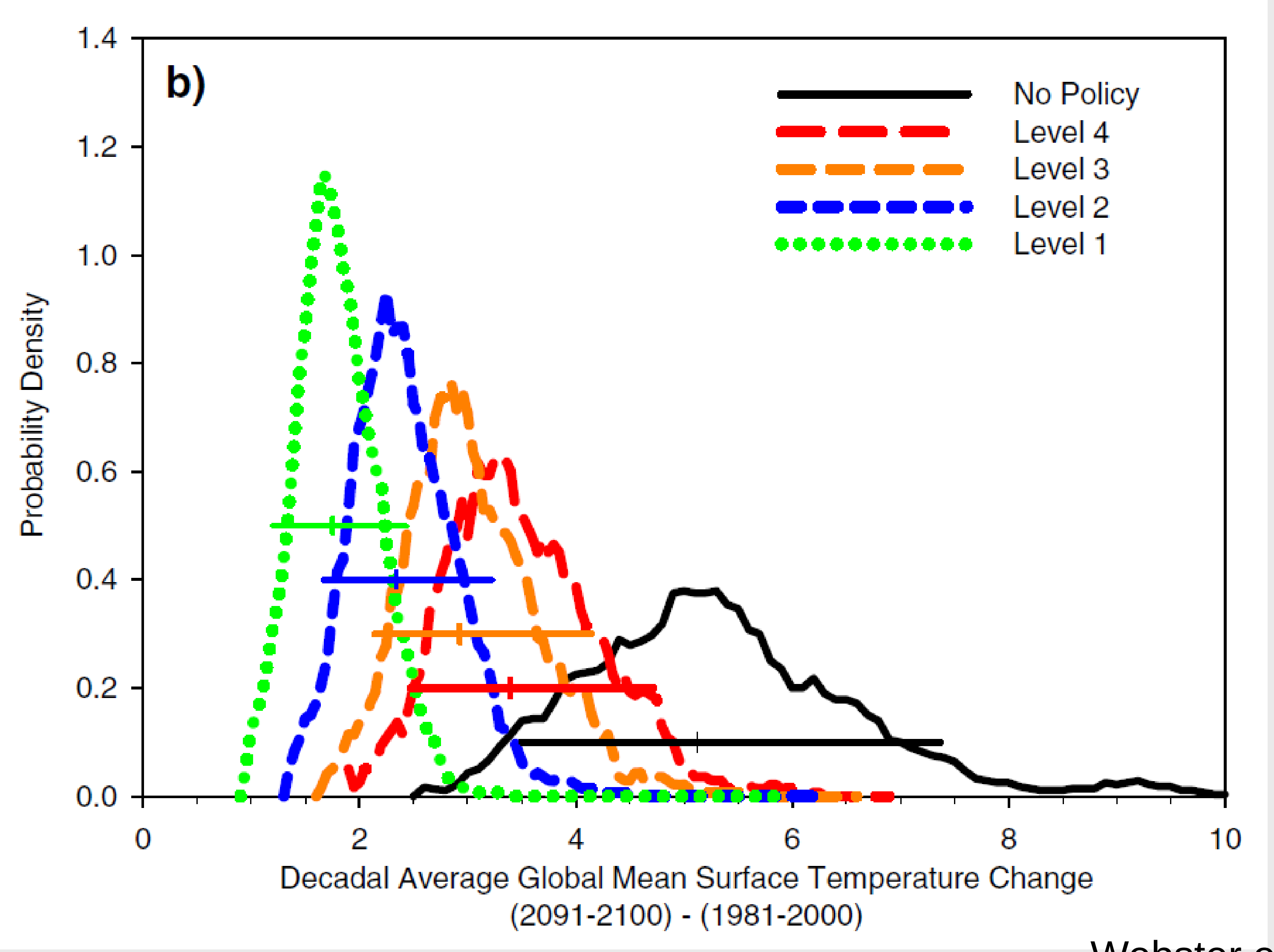
Figure 2. Historical and projected GDP per capita growth rates for the United States. Projections are shown for the 5th, 50th, and 95th percentiles in each period.

Webster et al., 2008.

PDFs of Emissions Outcomes



PDFs of Global Avg Temperature Outcomes



Webster et al., 2012

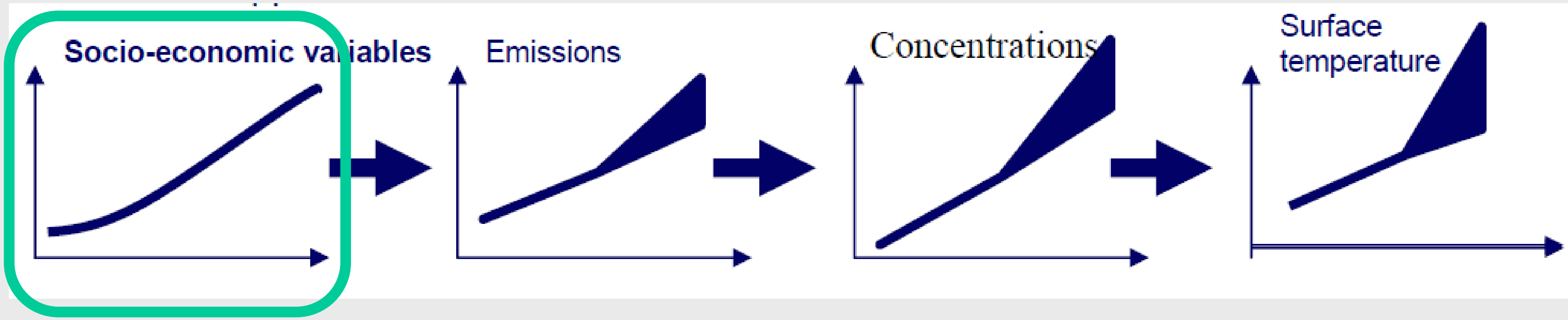
Alternative Scenarios

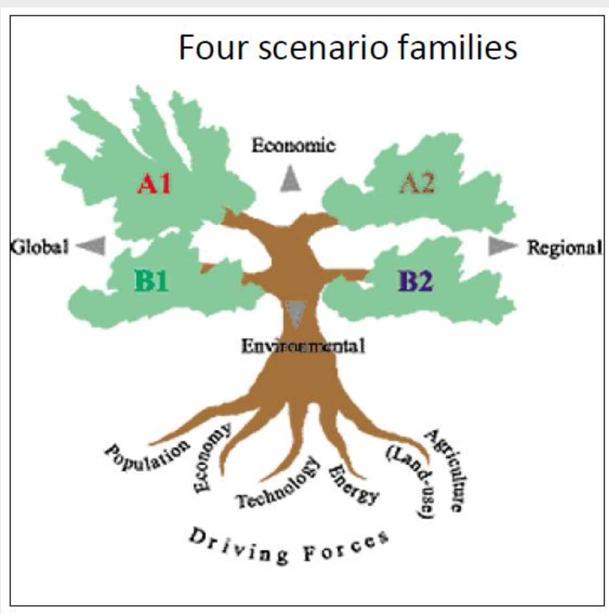
"…a description of potential future conditions produced to inform decision-making under uncertainty" -- Parson et al., 2007

Scenario purposes

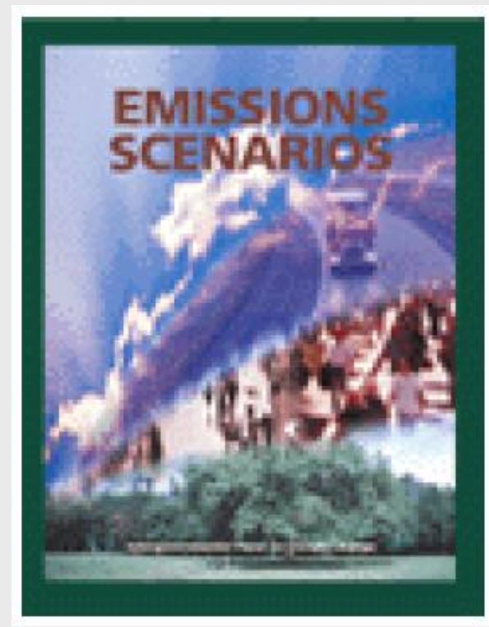
- Cope with poorly characterized uncertainty
- Inform specific decisions
- Scope (bound) a problem
- Shake up conventional wisdom (guard against over-confidence)
- Frame decisions
- Engage stakeholders
- Provide structure for analysis, facilitate assessment across disciplines and researchers

Traditional/Linear/Forward Scenario Process

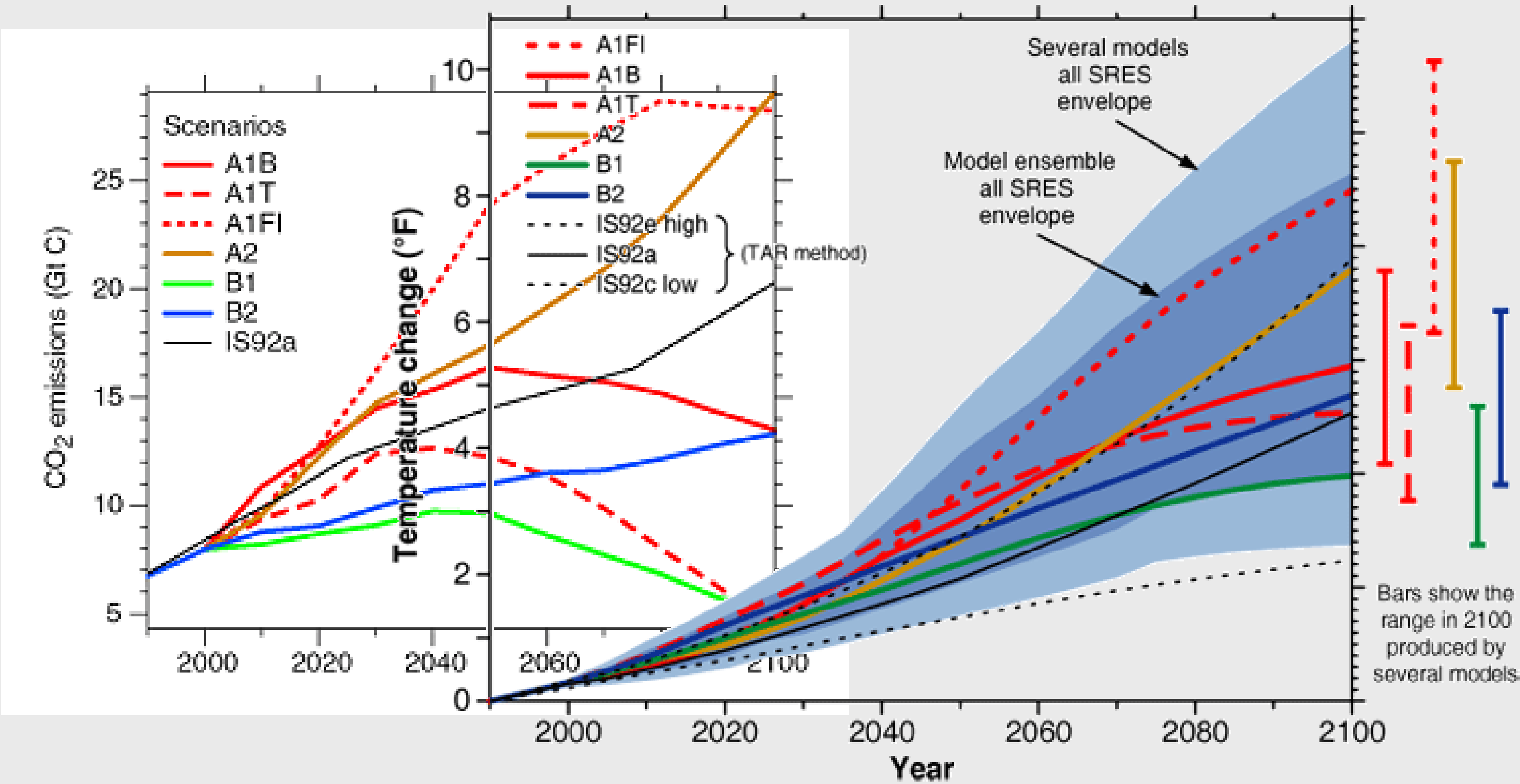




SRES Scenarios



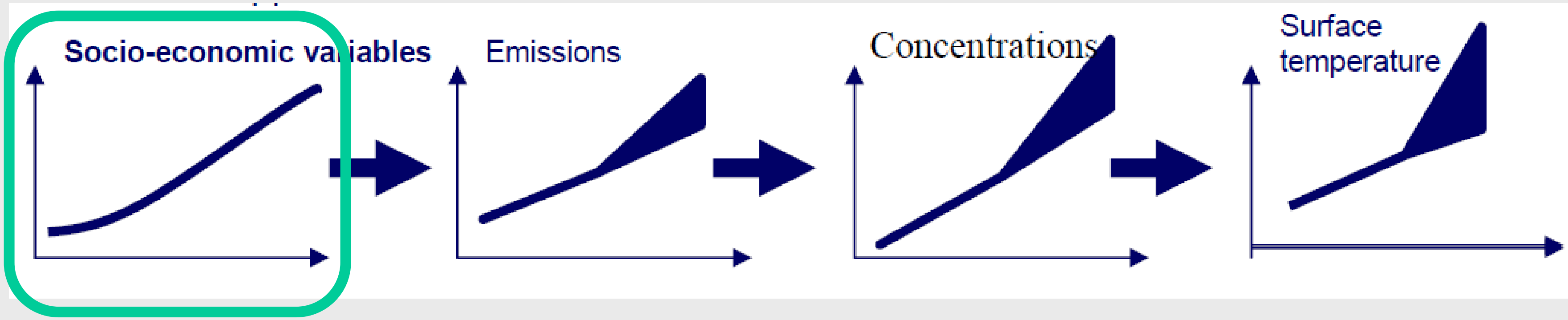
Meehl, Hibbard, et al. 2007, WCRP Report.



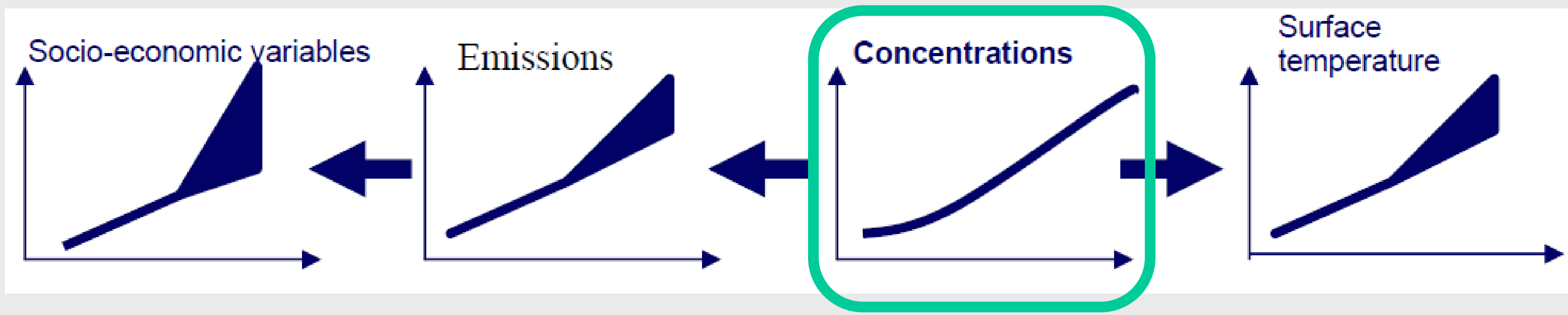
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a
CO_2 emissions (Gt C)
5
10
15
20
25
2000
2020
2040
2060
2100
A1FI
A1B
A1T
A2
B1
B2
IS92e high
IS92a
IS92c low
(TAR method)
Temperature change (°F)
0
2
4
6
8
10
Several models all SRES envelope
Model ensemble all SRES envelope
Bars show the range in 2100 produced by several models
2000
2020
2040
2060
2080
2100
Year

IPCC TAR.

Traditional/Linear/Forward Scenario Process

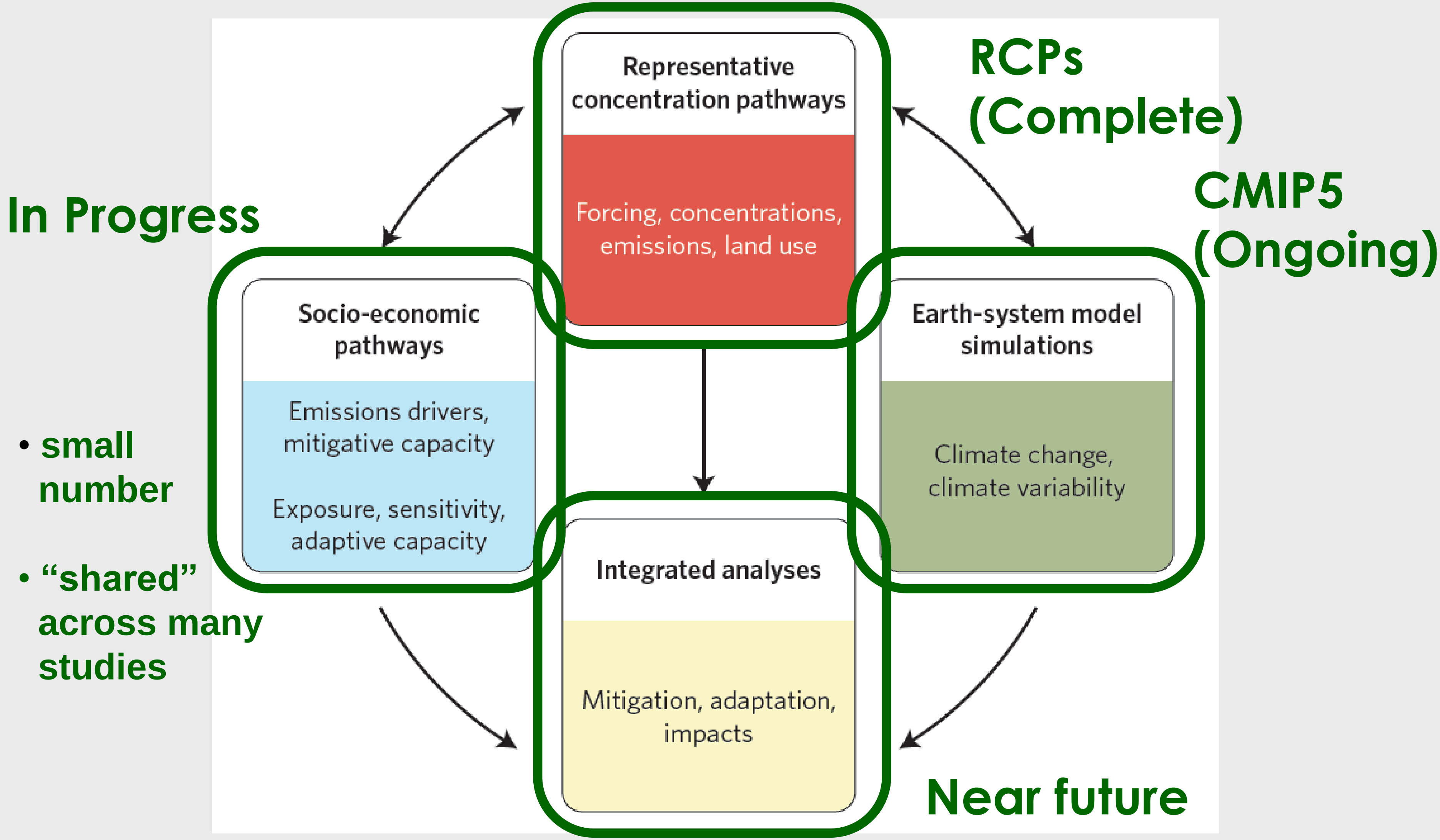


New/Parallel/Reverse Scenario Process



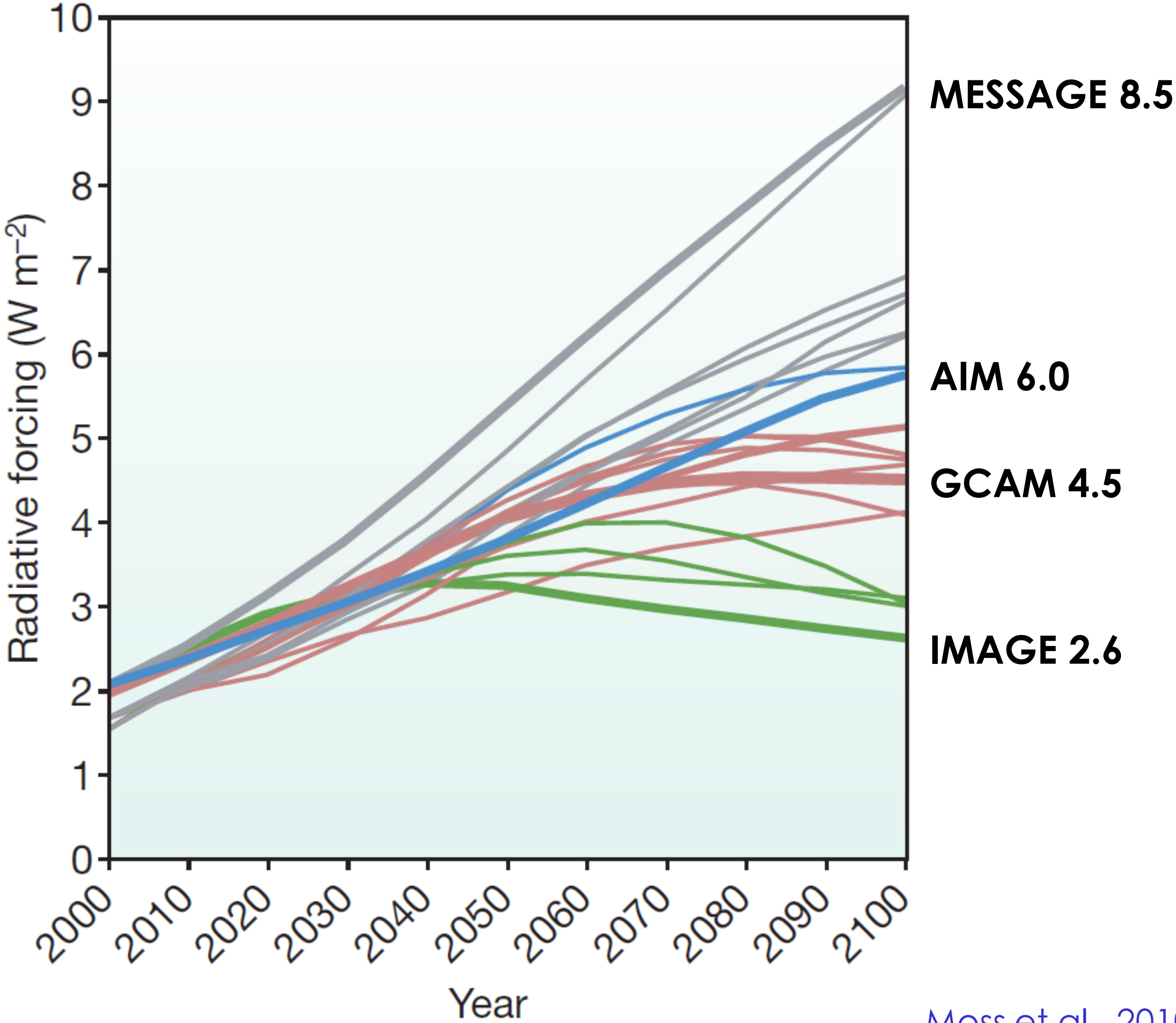
Meehl, Hibbard, et al. 2007, WCRP Report.

The Parallel Process



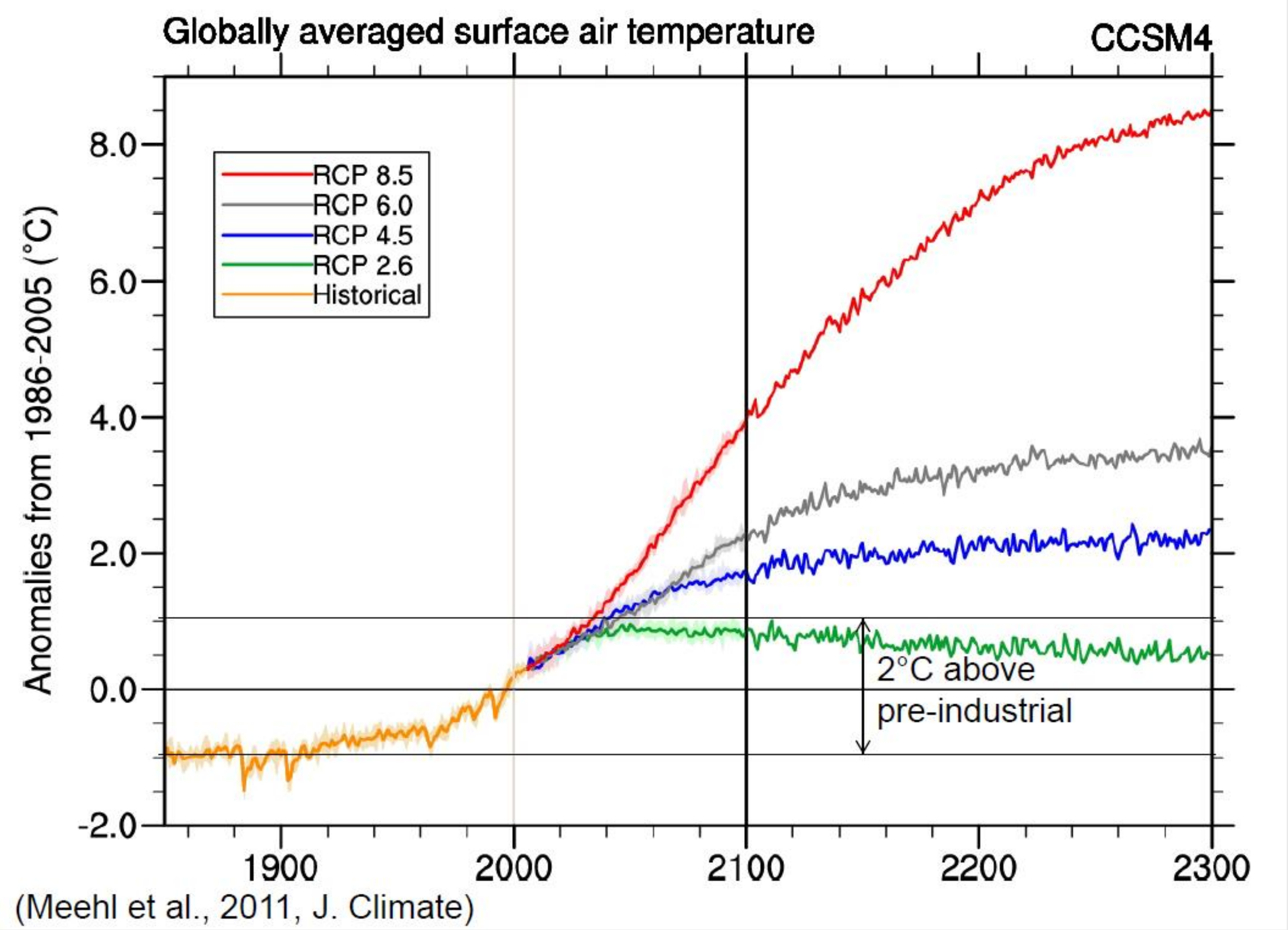
O'Neill & Schweizer, 2011.

Representative Concentration Pathways (RCPs)



Moss et al., 2010.

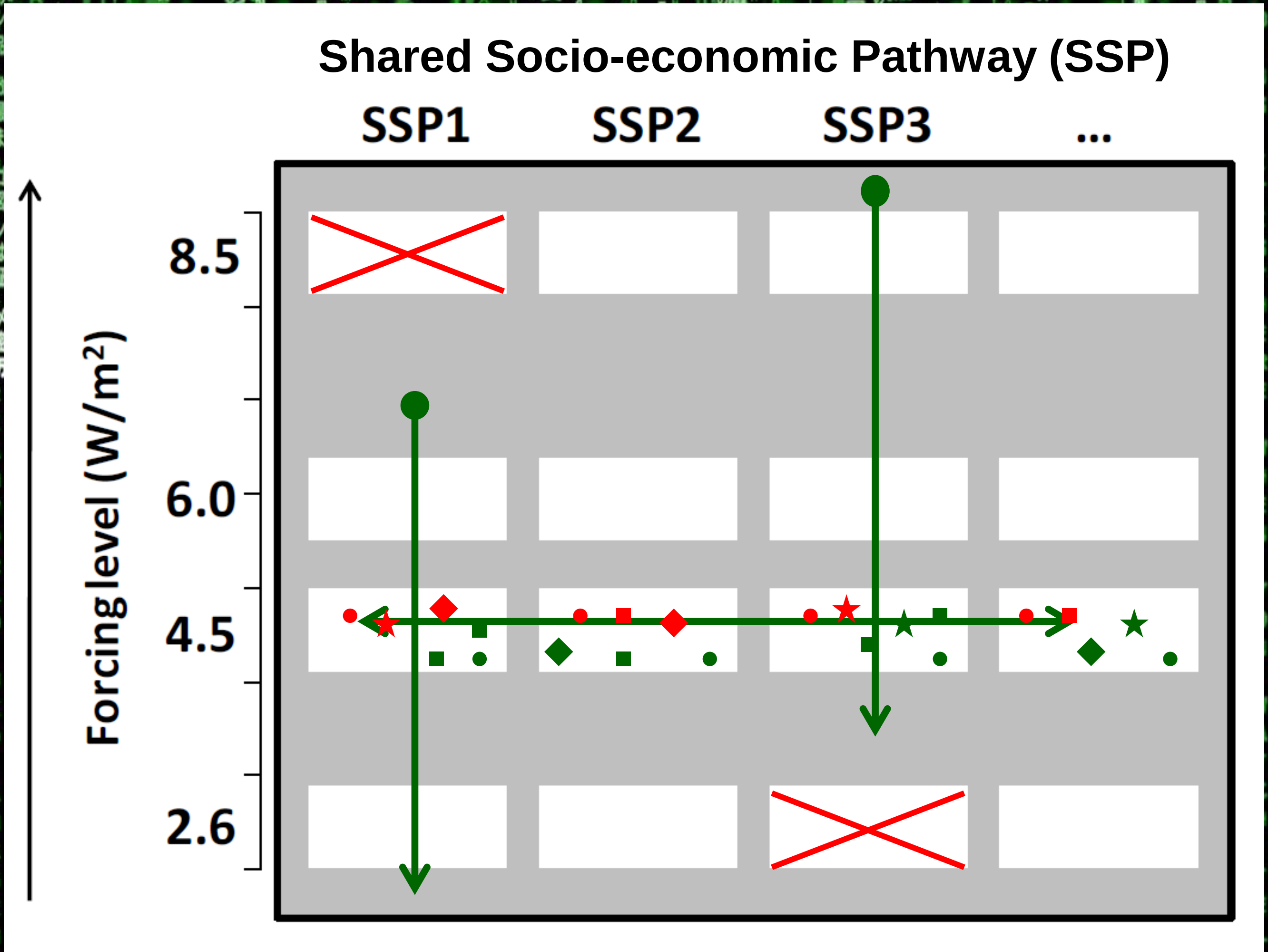
CCSM4 simulations of RCPs



Courtesy Jerry Meehl.

The Matrix

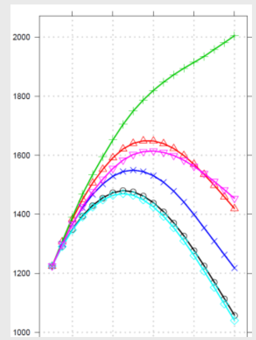
The Scenario Matrix Architecture



Framework paper posted on NCAR website: http://www.isp.ucar.edu/socio-economic-pathways

What's in an SSP

Narrative



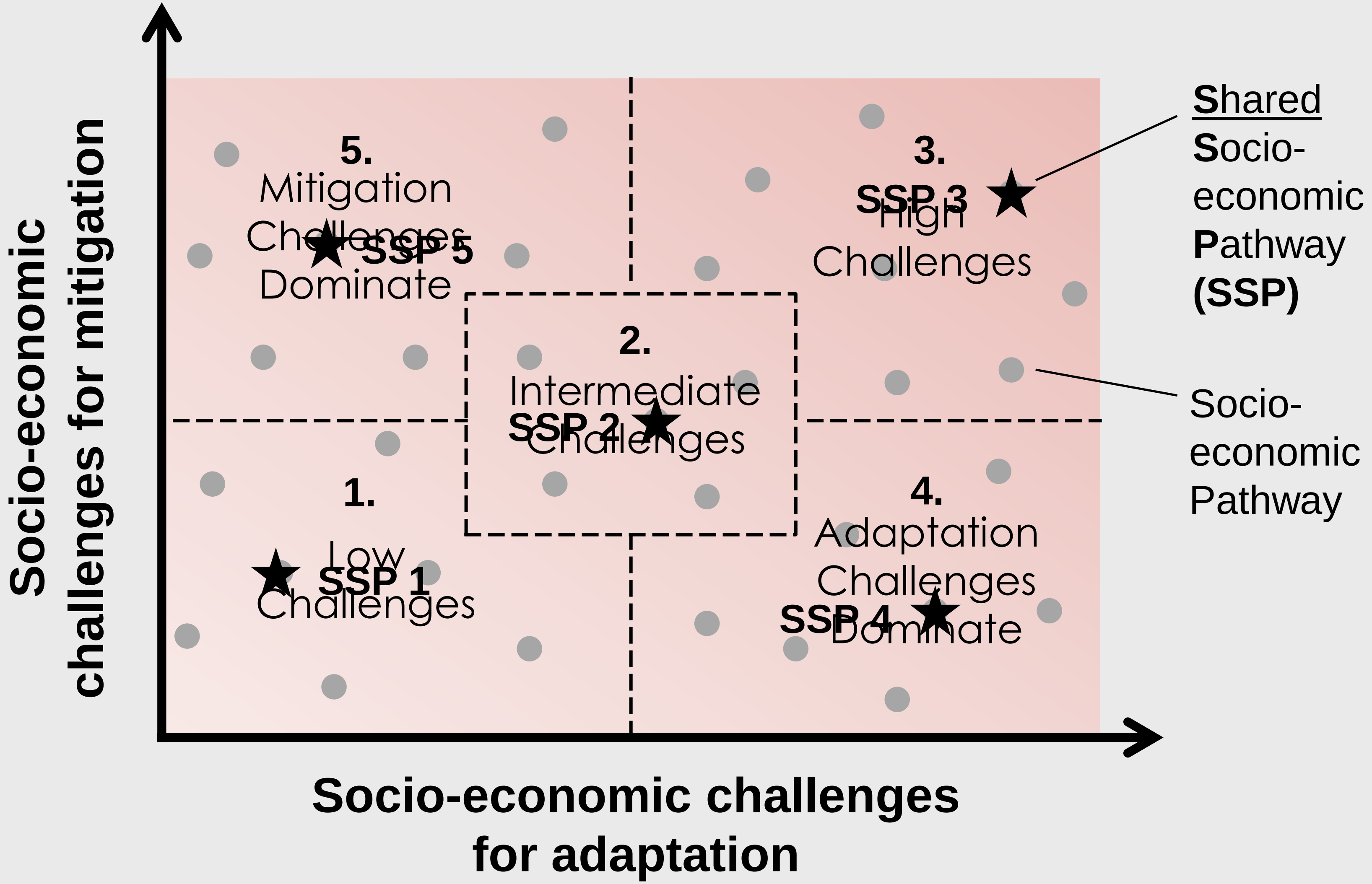
Quantitative elements

Population
Urbanization
Rates of technological change
Income
Human Development Index
Income distribution
Etc.

Does not include:

- climate policy (mitigation or adaptation)
- not influenced by climate change
- typical model output such as emissions, land use, climate change

SSP Logic


Socio-economic challenges for mitigation
Socio-economic challenges for adaptation
5.
Mitigation Challenges Dominate
SSP 5
3.
High Challenges
SSP 3
2.
Intermediate Challenges
SSP 2
1.
Low Challenges
SSP 1
4.
Adaptation Challenges Dominate
SSP 4
Shared Socio-economic Pathway (SSP)
Socio-economic Pathway

Adaptation challenges

↓

Exposure
Sensitivity
Adaptive Capacity

↓

Average Wealth
Extreme Poverty
Governance
Water Availability
Innovation Capacity
Coastal Population
Educational Attainment
Urbanization
…
Quality of Healthcare
Availability of Insurance

Mitigation challenges

↓

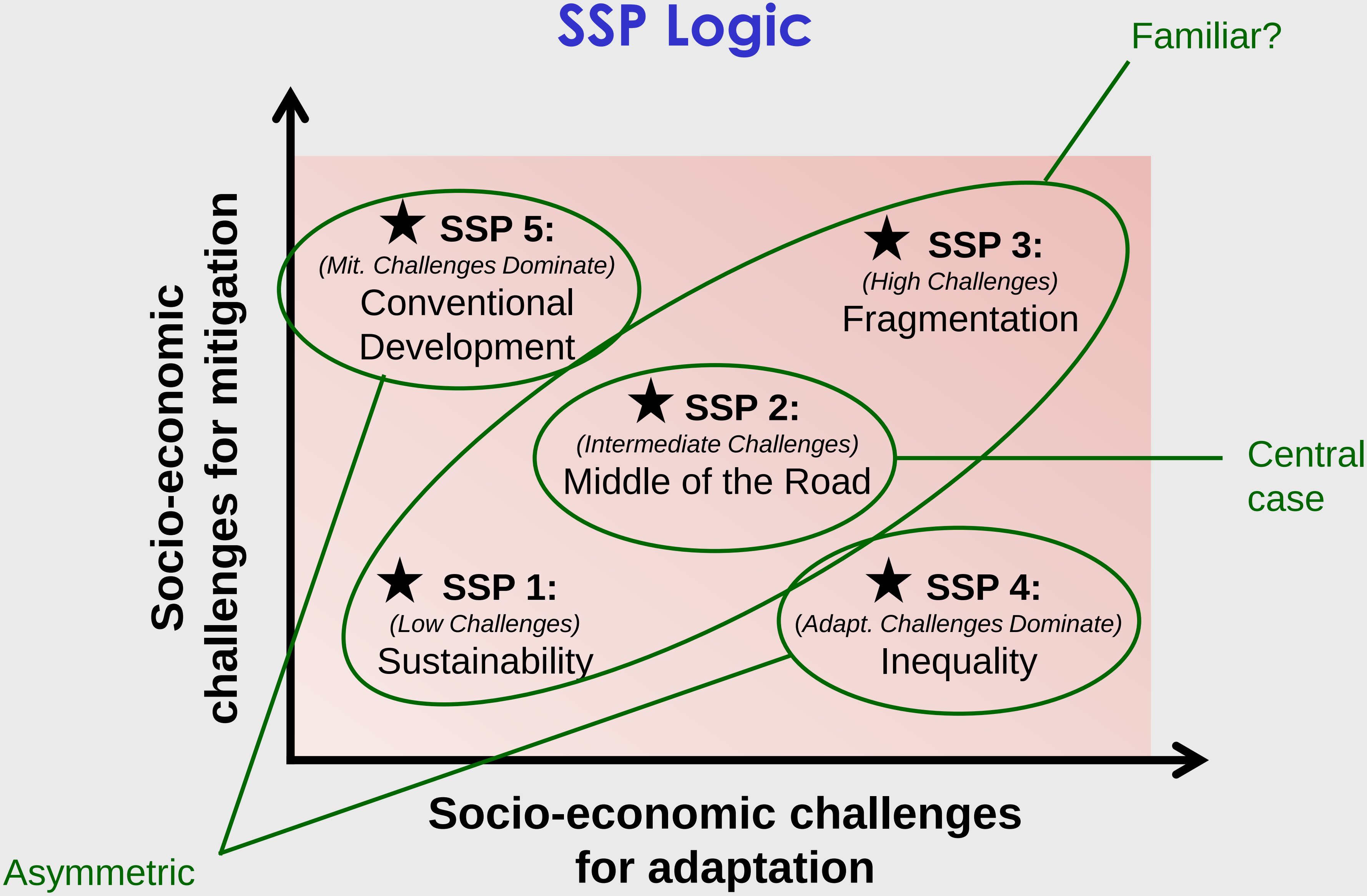
Baseline(no-policy) emissions
Mitigation capacity

↓

Population
Carbon Intensity
Agricultural Productivity
Energy Intensity
Energy-related Tech. Change
CCS availability
…
Effectiveness of Policy Institutions
Energy Tech. Transfer
Diet

Schweizer & O'Neill, in prep.

SSP Logic


Familiar?
SSP 5:
(Mit. Challenges Dominate)
Conventional Development
SSP 3:
(High Challenges)
Fragmentation
SSP 2:
(Intermediate Challenges)
Middle of the Road
Central case
SSP 1:
(Low Challenges)
Sustainability
SSP 4:
(Adapt. Challenges Dominate)
Inequality
Socio-economic challenges for mitigation
Socio-economic challenges for adaptation
Asymmetric

SSP 4: Inequality

Narrative: This pathway envisions a highly unequal world, both within and across countries. A relatively small, rich global elite is responsible for much of the emissions and is able to mitigate at low cost. This elite also emerges in developing countries, and is highly globally connected and mobile. The larger, poorer part of the population contributes little to emissions,but is vulnerable to the impacts of climate change. This vulnerable group exists in both developing and industrialized countries, and is concentrated in rural areas and large mega-cities. Those mega-cities with a large fraction of relatively poor and less educated people lack the capacity to protect themselves from extreme weather events. Access to high quality education, health services and family planning is also limited, leading to high population growth in low-income countries. In industrialized countries, economic uncertainty for most of the population leads to relatively low fertility and low population growth. Urbanization is high, induced by the large income differences, but takes place in an unorganized way that leads to large slums in developing countries.

In economic terms, this is a mixed world: as inequality increases within all regions, it is not clear beforehand how the diverging growth rates would aggregate to averages. Economic growth is probably medium/high in industrialized countries, low-income countries have low economic growth (though at the same time a rapidly rising elite) and middle-income income countries have medium growth, also driven by the increasingly rich elite groups.

This is a world with low social cohesion. Poor people have the hope, and sometimes the opportunity, to become a member of the elite, but are mostly trapped in their conditions. Governance is dominated by regulatory capture: the government works for the elite, by the elite. Challenges to adaptation are high due to the relatively low incomes and education of large proportions of the population in all regions, as well as to poorly functioning institutions for all but the elite, and lack of investment in reducing vulnerability.

With respect to energy and emissions, a main characteristic is that global elite emits very much, but is capable of changing its patterns, whereas the poor do not emit that much and, hence, there is hardly any transformation needed for them. Actions are taken to control local pollution only in the interests of the elite, likely to live largely in urban areas. As an example, power production could be moved out of city areas to reduce urban air pollution, while there would be little regard for the environmental consequences of land use in rural areas. Overall air pollution levels would thus remain relatively high compared to other SSPs. ...

SSP 4: Inequality, continued

• • • In this world, global energy corporations use investments in R&D as a hedging strategy against perceived or potential resource scarcity and the option that climate policy will be imposed. Their main aim is to remain global players in energy supply, also under changing circumstances. This leads to the development of low-cost renewables, CCS-ready power plants and energy-efficient technology. Some of these technologies, like energy efficiency or renewables, may be applied without climate policy, as a response to resource scarcity. Hence, the mitigation challenges are low due to some combination of 1) low reference emissions and/or 2) a high latent capacity to mitigate.

A typical example of hedging against resource scarcity could be a strong push for bio-energy by global energy corporations. In the absence of sustainability regulations, large energy corporations would acquire the necessary land-resources in developing countries to grow energy-crops, while reducing options for adaptation for local communities and for nature conservation.

Another example of a typical climate measure under this pathway could be geo-engineering, where the elite decide on this measure without concern for the potential negative effects for others. This would only be plausible, however, if the elite were able to insulate themselves against the detrimental effects of these measures.

Land ownership is unevenly distributed and land use management is also left to the global elite. Productive areas of the world would be dominated by industrialized agriculture and monocultural production. Crop yields would be typically high in large-scale industrial farming, but low for small-scale farming. Food trade is global, but access to markets is limited, increasing vulnerability for non-connected population groups.

SSP 4: Inequality

Narrative:

- **highly unequal** both within and across countries
- a small rich **global elite**
- a **large poor population** that is **vulnerable** to impacts of climate change, including in industrialized countries
- **Governance** and **globalization** are effective for the elite, but ineffective for most of the population
- **Low-carbon energy** developed as a hedge against **resource scarcity**

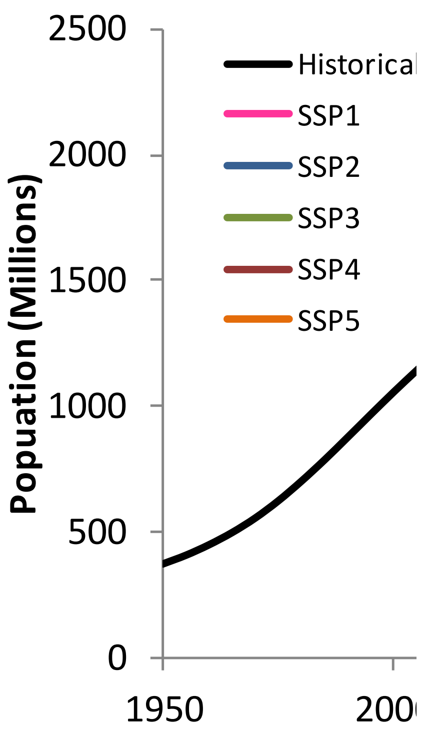
SSP 5: Conventional Development

Narrative:

- stresses **conventional economic development**
- **fossil fuels dominate the energy economy**, become locked in
- **robust economic growth**, attainment of **development goals**
- **highly engineered** infrastructure and highly managed ecosystems.

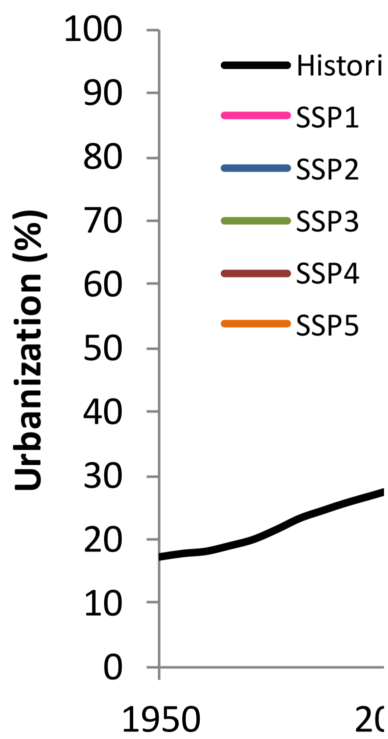
SSP Element Quantifications (e.g., India)

Population, Education



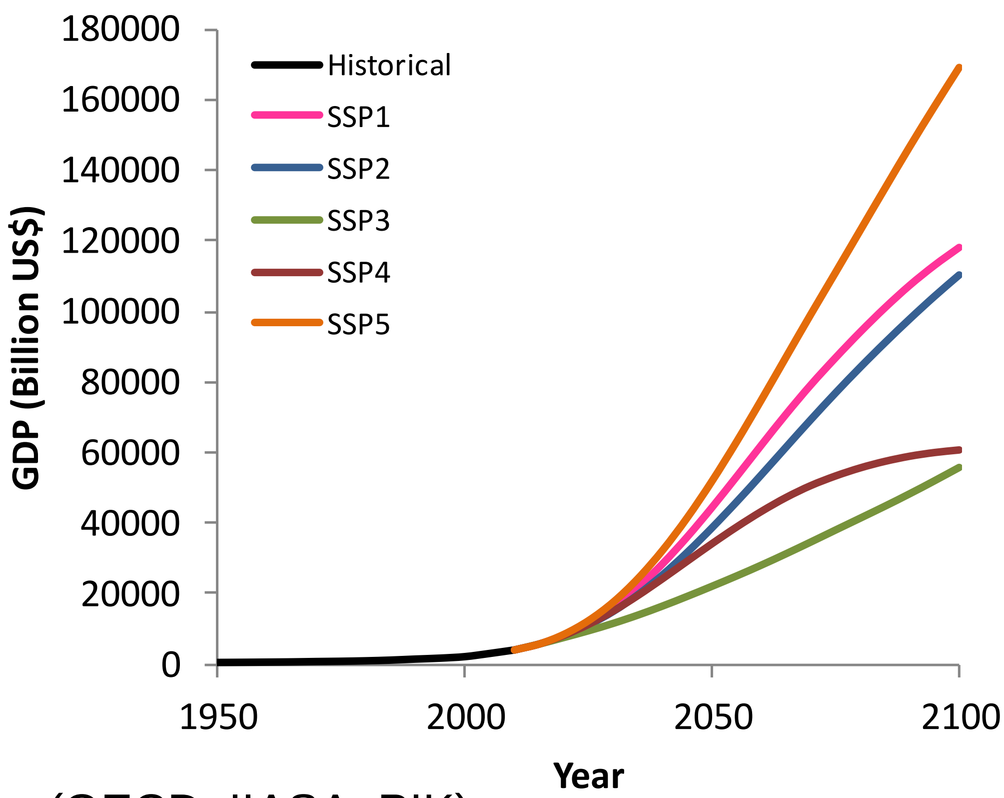
(IIASA)

Urbanization



(NCAR)

GDP

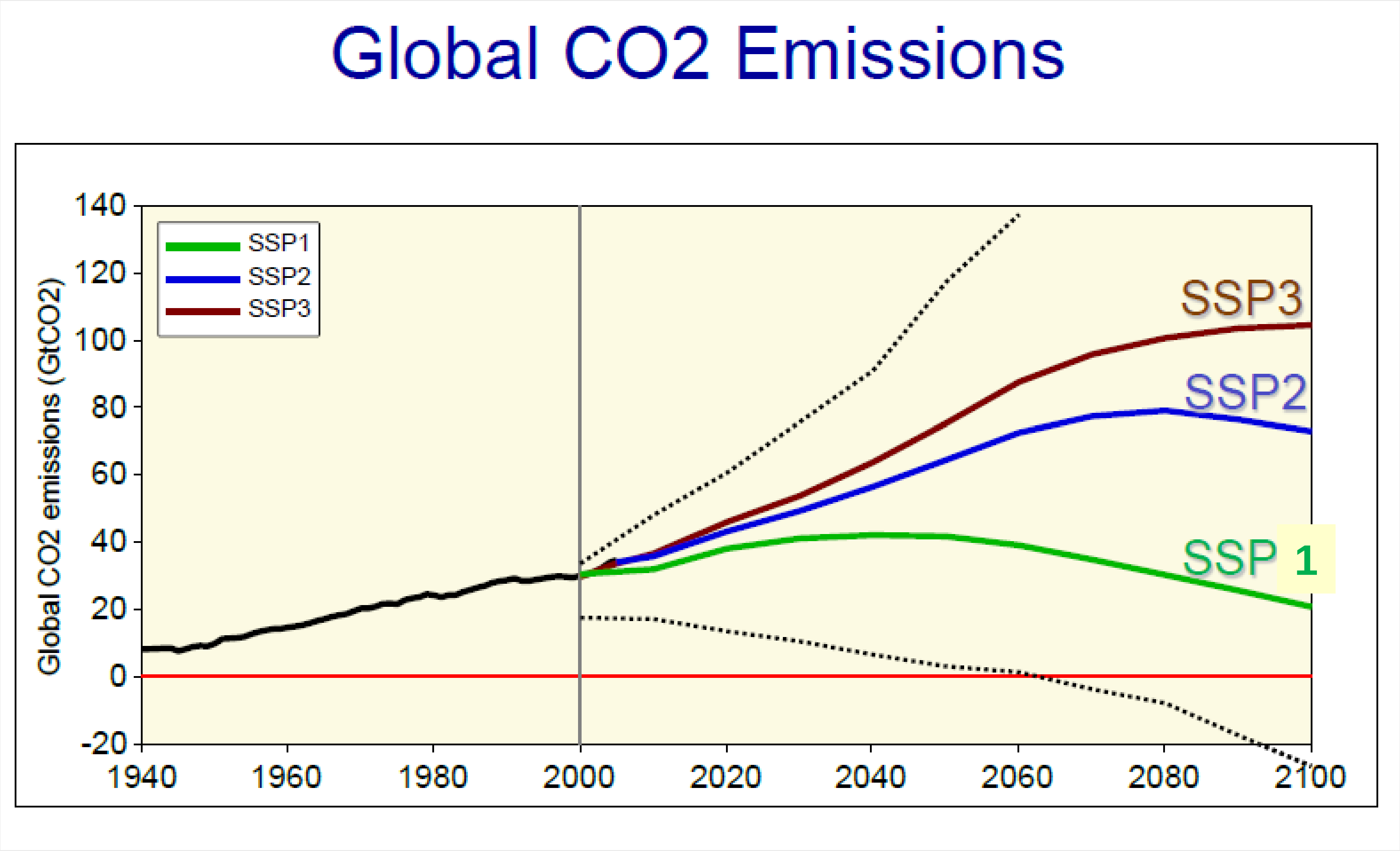


(OECD, IIASA, PIK)

Preliminary data available for review at

https://secure.iiasa.ac.at/web-apps/ene/SspDb

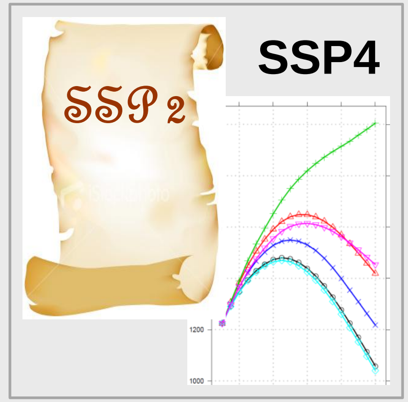
SSP-based IAM Scenarios



MESSAGE model results, Riahi presentation, Boulder, Nov. 2-4 2011.

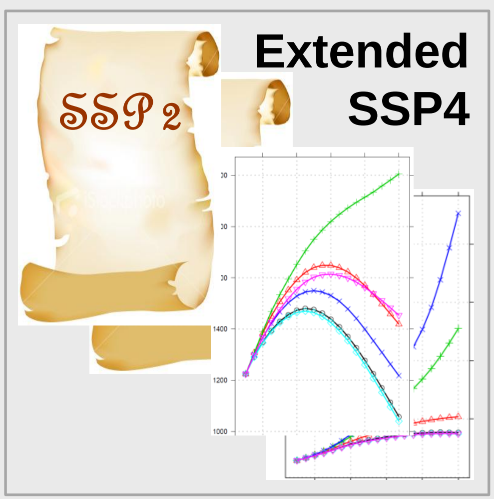
Basic vs Extended SSPs

Basic

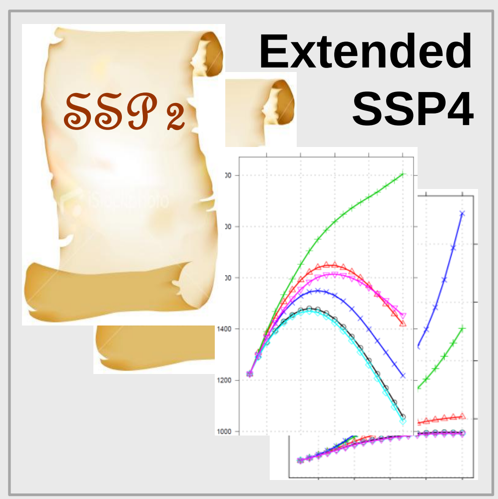


Information sufficient to locate SSP in Domain 4 of the challenges space

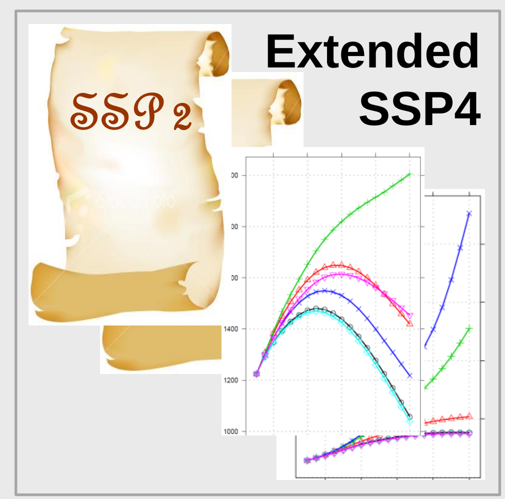
Regional Extension



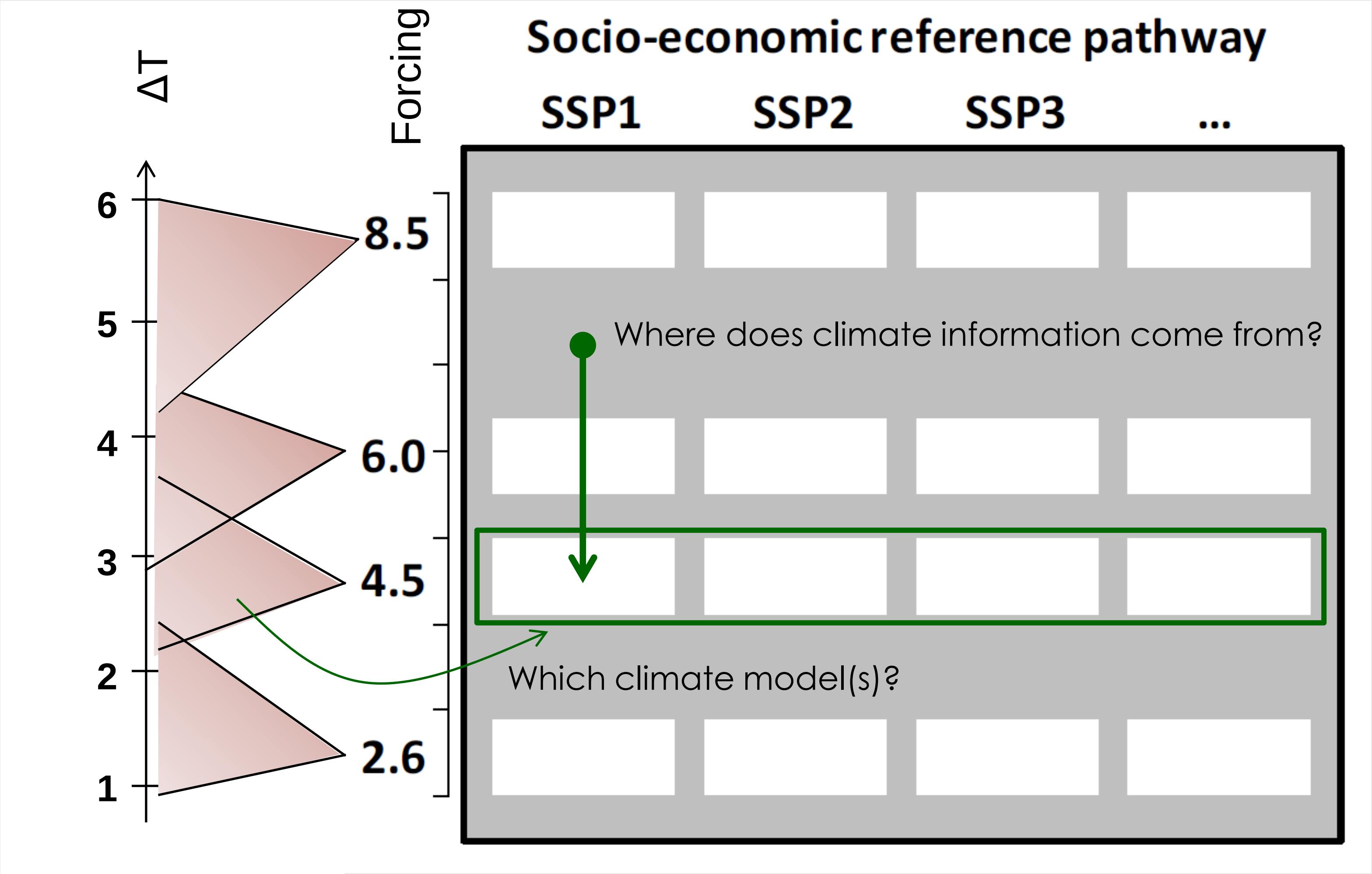
Sectoral Extension



Global Extension



Climate Change in the Scenario Matrix



Other approaches

Conditional Probabilistic Approaches

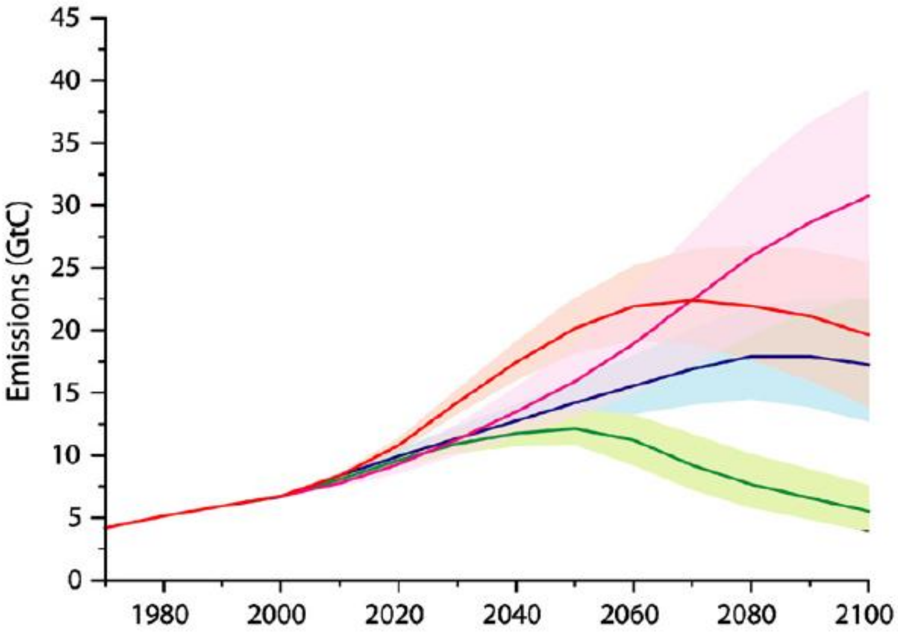


Fig. 5. CO_2 emissions as a function of time.

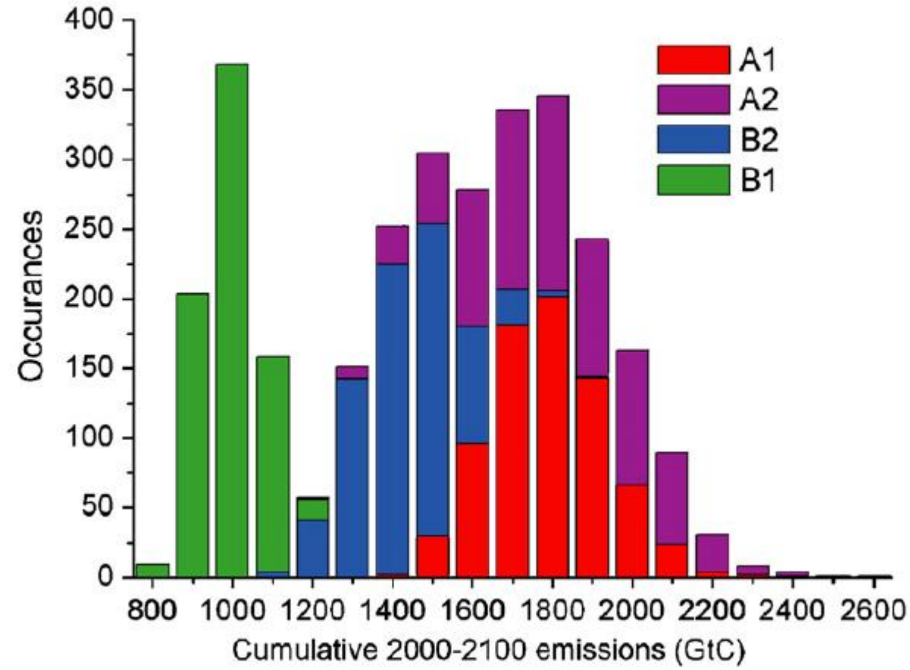
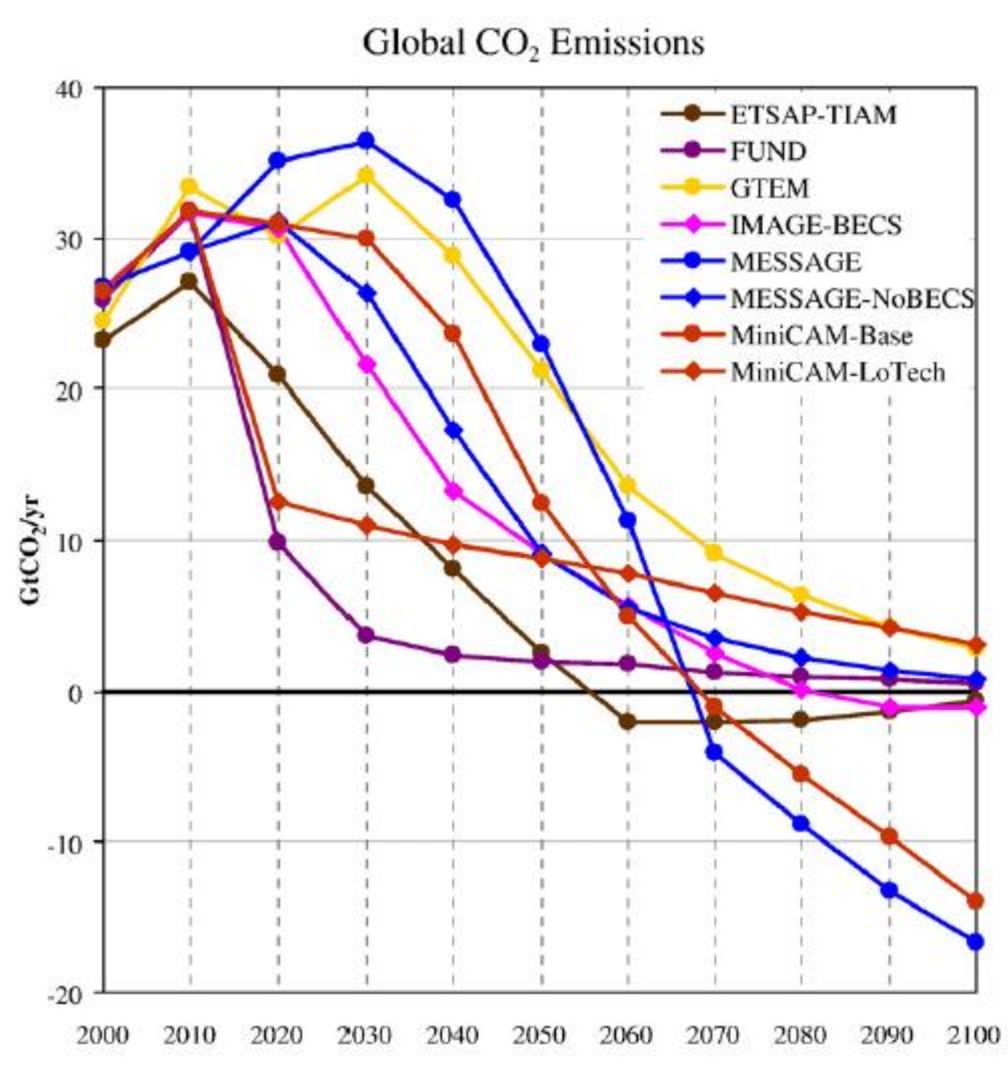


Fig. 6. Frequency distribution of cumulative emissions 2000–2100.

Van Vuuren et al., 2008.

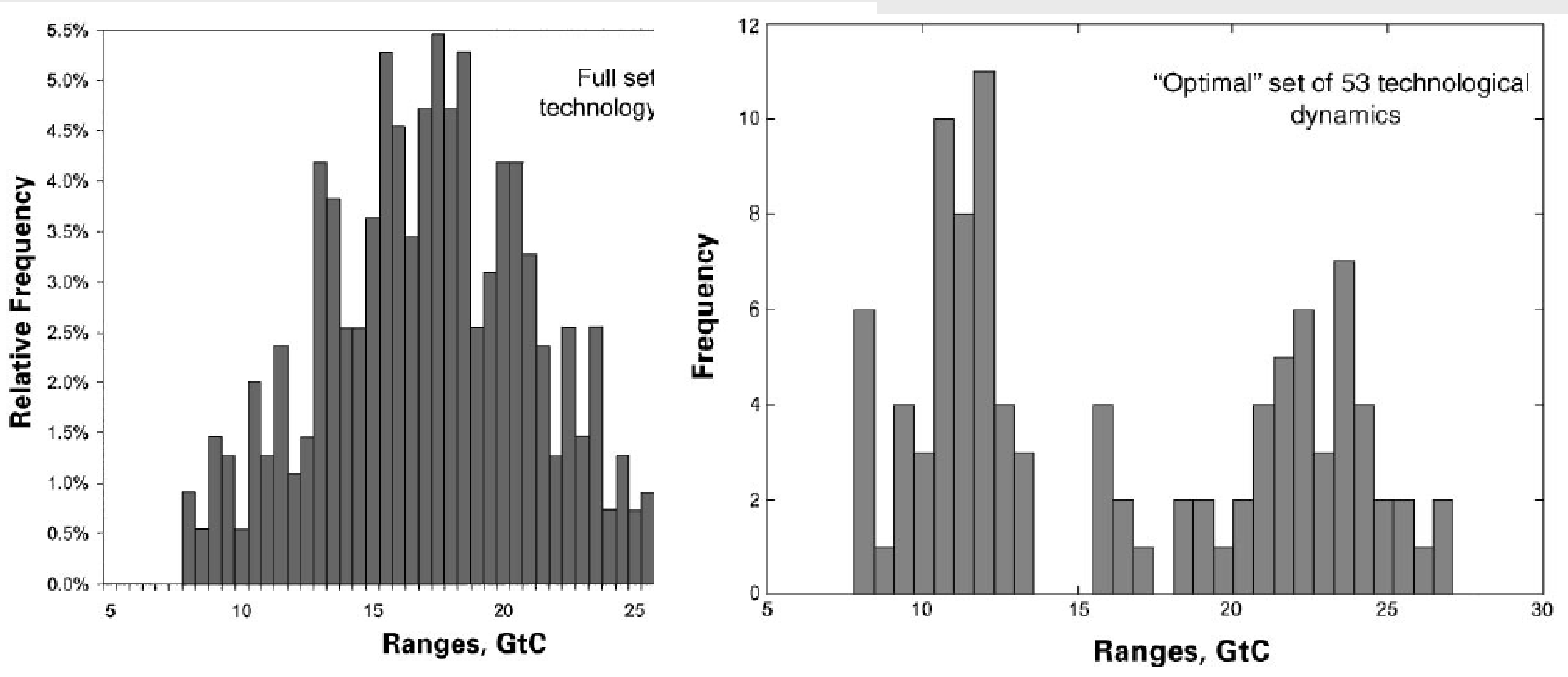
- storyline (dev. pathway) uncertainty vs. parameter uncertainty
- parameter uncertainty better constrained?
- could allow for separate judgments about uncertainty across storylines

Multi-model ensembles



Clarke et al., 2009
EMF-22

Exploratory Scenario Analysis



- not concerned with likelihood beyond plausibility
- path dependency ("lock in") leads to double peak in lowest cost scenarios

Gritsevky & Nakicenovic, 2000.

Robust Stratgies

See Rob's talk!

Summary

- A number of alternative approaches to characterizing uncertainty in emissions (and mitigation)
- Approach should be tailored to:
  - The question
  - Purpose of the exercise (process vs product)
  - Degree to which uncertainty can reliably be characterized in key components of the problem

Boulder Meeting Report containing SSP descriptions

http://www.isp.ucar.edu/socio-economic-pathways

SSP quantitative element database

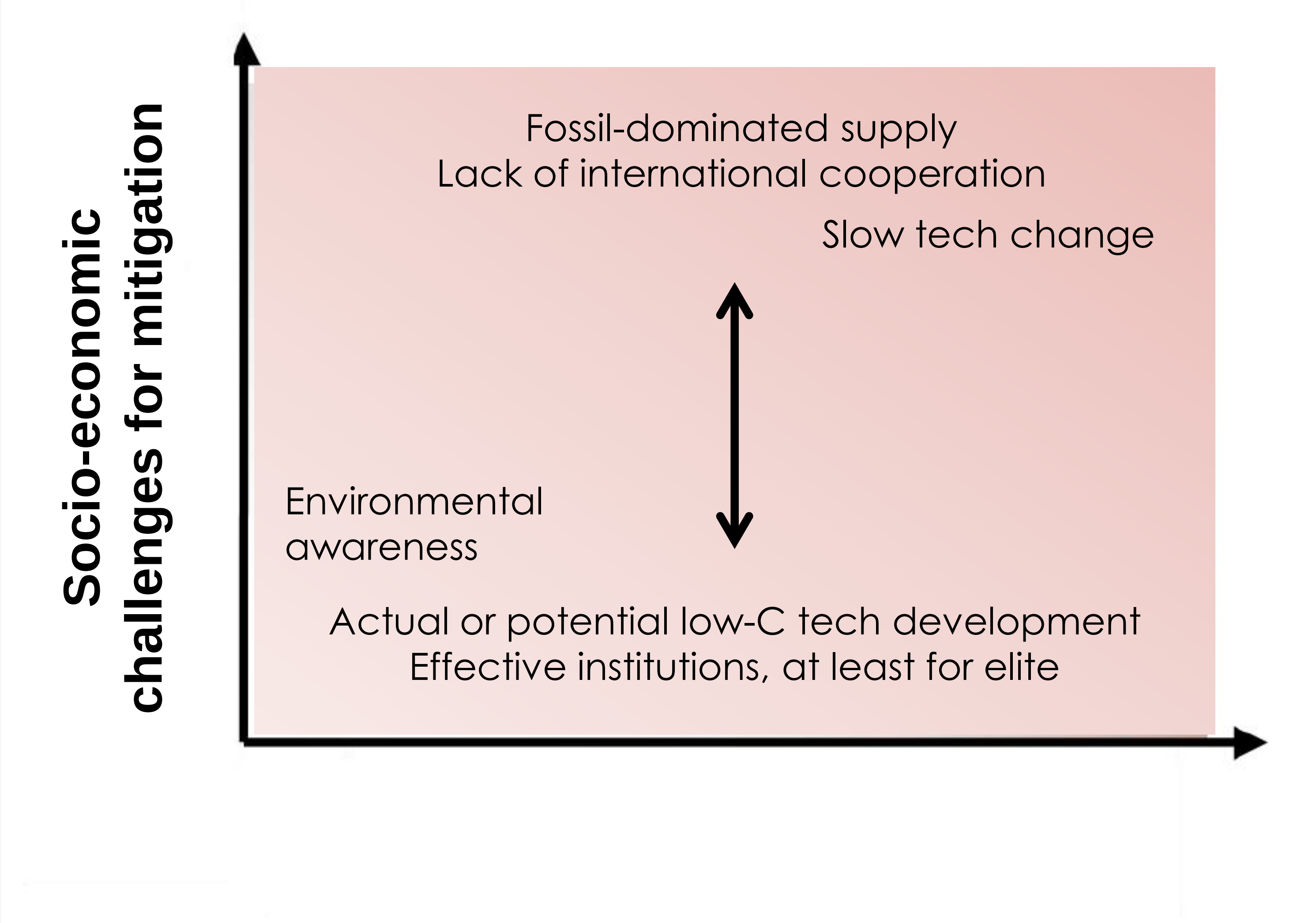
https://secure.iiasa.ac.at/web-apps/ene/SspDb

SSP 4: Unequal World

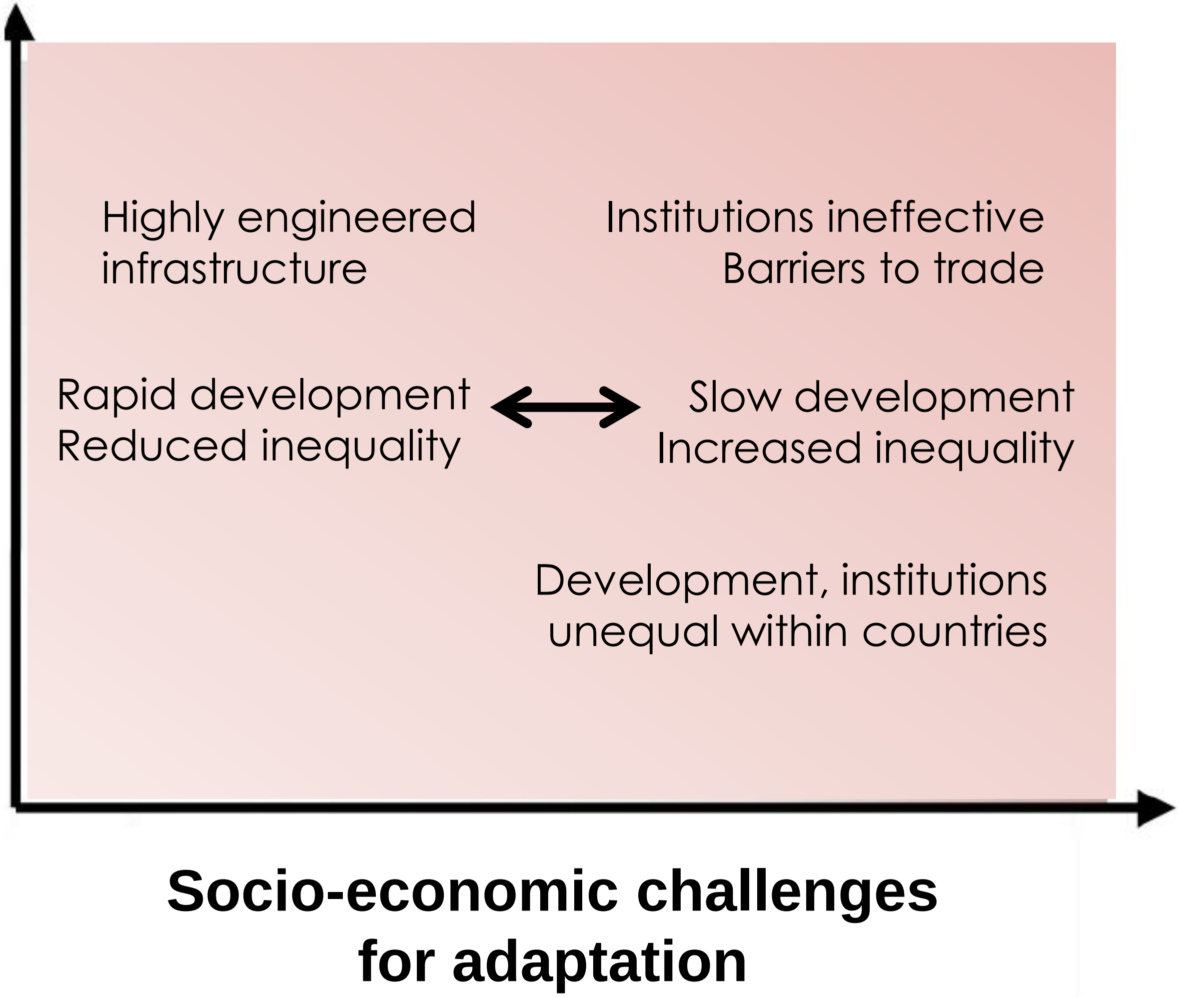
	Country Income Group		
SSP Element	**Low**	**Med**	**High**
Demographics			
Population	High	Low	Low
Urbanization	Central	Fast	Fast
Education	V. Low	Low	Med.
…			
Economy			
GDP/cap	Med.	Med.	Med.
Inequality	High	High	High
…			

	Country Income Group		
SSP Element	**Low**	**Med**	**High**
Policies & Institutions			
Envtl. policy	*Focus on local envt of elites*		
Instl. effectiveness	*Effective for elites*		
…			
Technology			
Low-C tech change	*Fast (hedge against fossil scarcity)*		
…			
Environment & Natl Rsces			
…			

Mitigation challenges



Adaptation challenges



Deriving PDFs: Expert Judgment

Table 13. Fractiles of Vintaged Capital Fraction from Expert Elicitation.

Fractile	Experts				
	Jacoby	***Reilly***	***Paltsev***	***Eckaus***	***Loeschel***
5%	30%	30%	20%	44%	20%
50%	50%	60%	45%	59%	35%
95%	80%	100%	80%	70%	70%

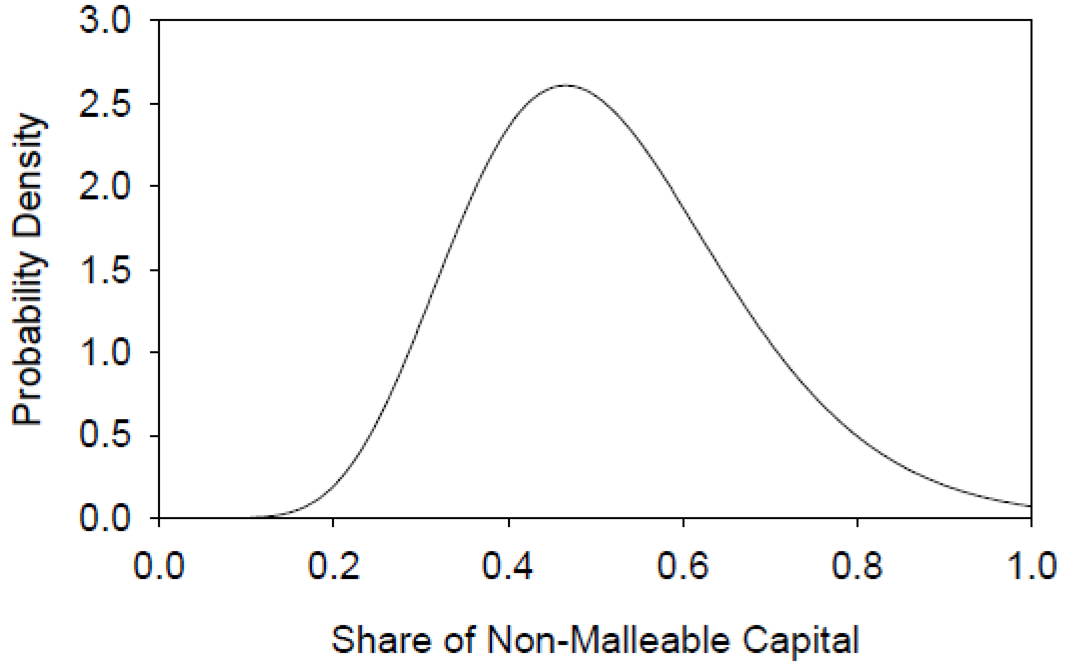


Figure 8. Probability density function for share of vintaged capital.