# Economic Impacts of Climate Change


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MIT Joint Program on the Science and Policy of Global Change


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GLOBAL CHANGE

With slide contributions from Steve Rose (EPRI); and based on work with Angelo Gurgel, Sergey Paltsev, Brent Boehlert (Iec), Ken Strzepek, Niven Winchester (AUT), Mei Yuan, Steve Rose

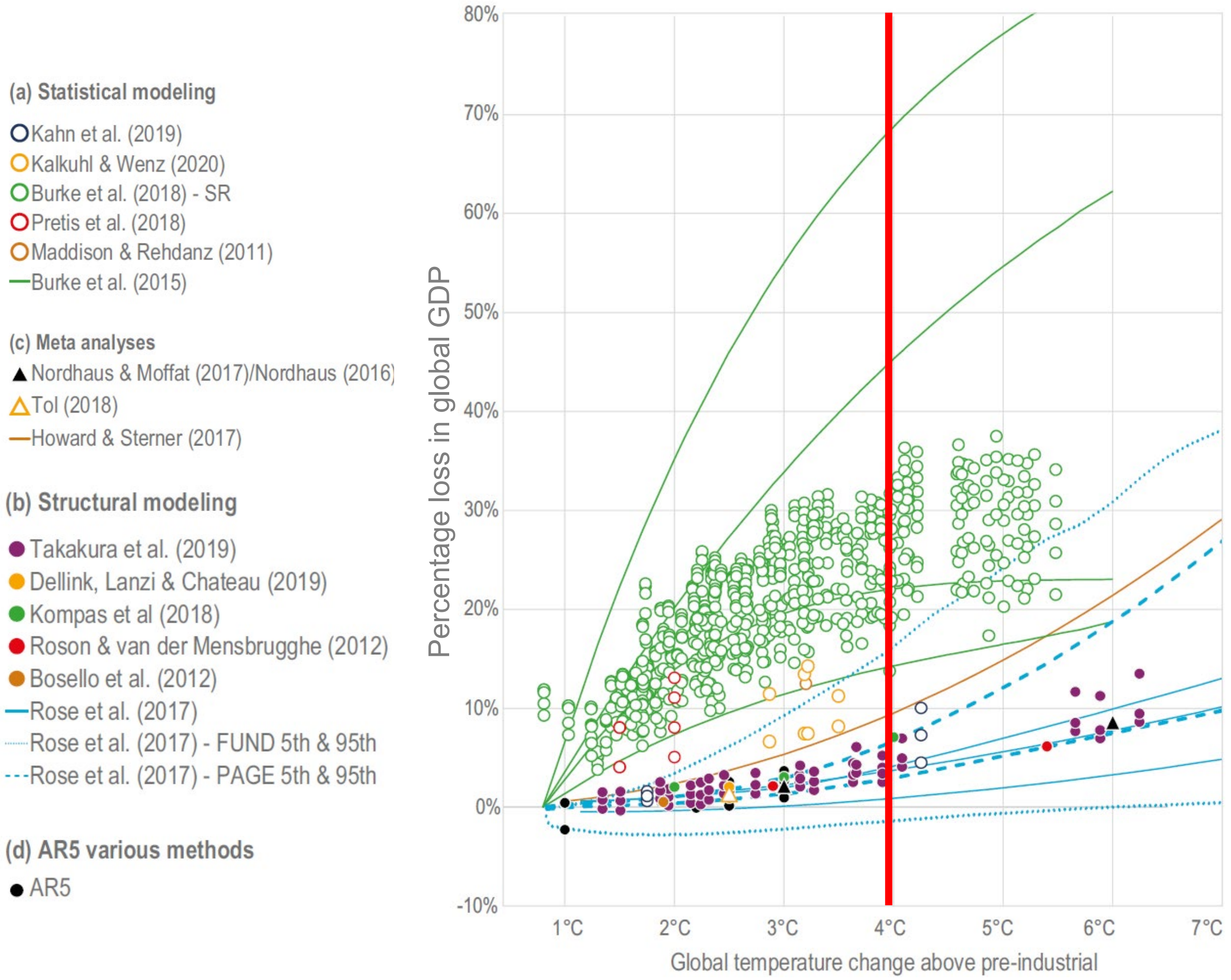
**MAIN MESSAGE 1:**

# We do not have robust, comprehensive estimates of global economic impacts of climate change

Despite impressive recent advances, many scientific challenges remain

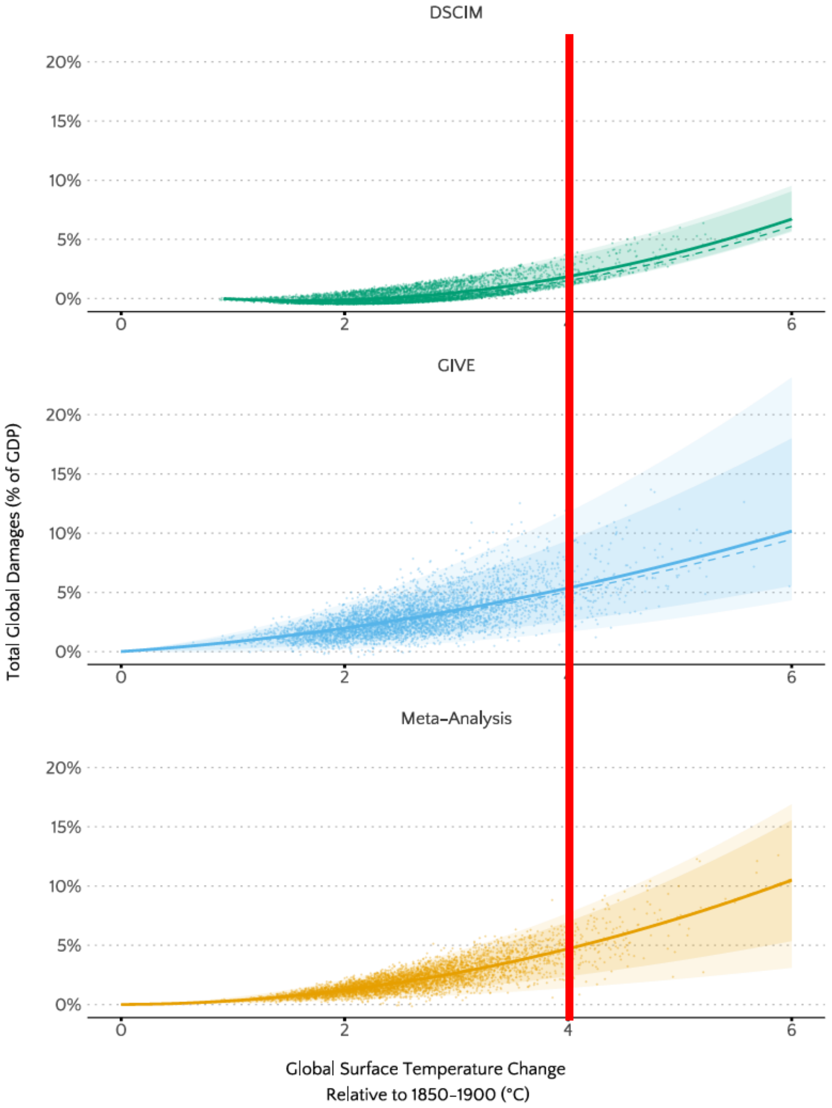
# Estimates of Global Economic Impacts of Climate Change

## IPCC AR6 WGII (2022)



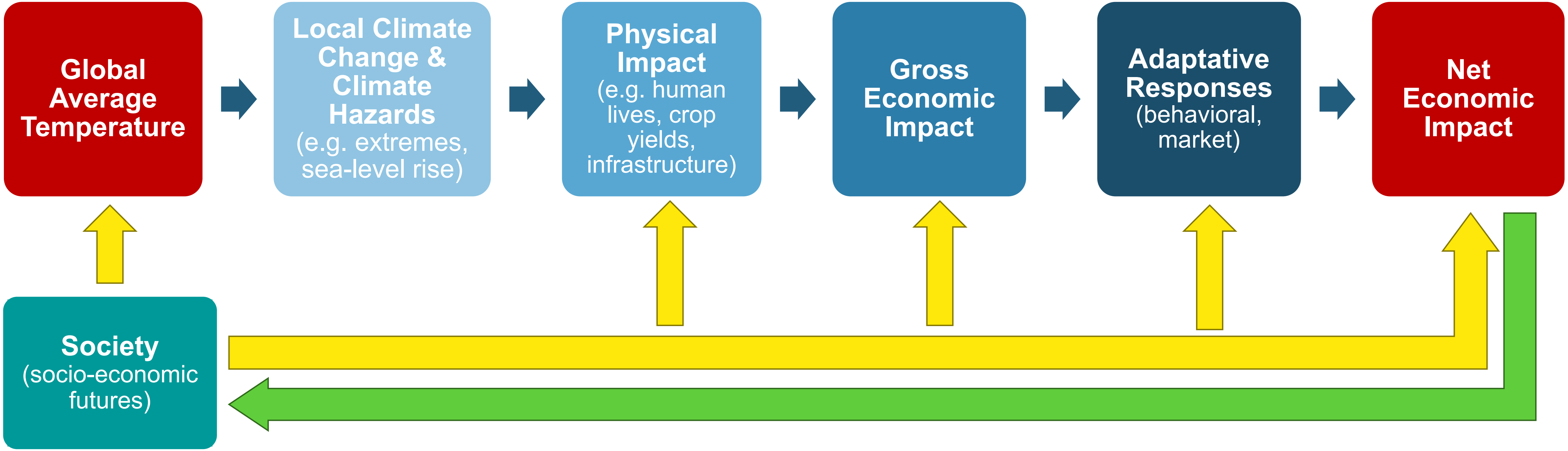

## USEPA (2023)

*Figure 2.3.2: Annual Consumption Loss as a Fraction of Global GDP in 2100 due to an Increase in Annual Global Mean Surface Temperature in the three Damage Modules*




Slide credit: Steve Rose (EPRI)

# Estimating of Global Economic Impacts of Climate Change




## Studies vary significantly in if/how each piece is represented

**Methods:**

-Statistical Analysis

-Process/Structural Modeling

-Meta Analysis

**Scopes:**

-Geographic: global, regional, local

-Impacts: aggregates, by impact category

-Economic: simple macro, multi-sector CGE



Slide adapted from Steve Rose (EPRI)

## Statistical

*Observational relationships*

**Strengths:**

- Based on observations
- Reflects net outcomes

**Concerns:**

- Constrained by available data
- Out-of-sample extrapolations (economic and climate)
- Estimating weather (not climate) relationships
- Model specification sensitivity;
- Impact and response mechanisms not explicit

[e.g., Auffhammer (2018), Dell et al. (2014), Burke et al. (2015), Hsiang et al. (2017), Pretis et al. (2018), Kahn et al. (2019)]

**Older Approaches:**

- **Pure Time Series Comparisons:** measure short-run response to weather, not long-run response to climate
- **Cross Sectional Comparisons:** good at long-run response to climate, but confounding effects hard to tease out
- **Panel "Weather" Models:** weather not climate

**Newer Approaches**

- **Long Differences:** great but need tons of data
- **Panel "Adaptation" Models:** response as function of not just climate but also income

Adapted from Max Auffhammer

## Statistical
***Observational relationships***

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## Process/Structural
***Process-based modeling of components***

**Strengths:**
- Projects future process or economic conditions and responses;
- Evaluates how impacts enter and transmit
- Models adaptation responses
- Explicit and interpretable

**Concerns:**
- Can be computationally intensive
- Can omit relevant impact channels, interactions and market dynamics
- Can lack empirical basis for calibration / observational grounding
- Difficult to do for global analysis

[e.g., Anthoff and Tol (2014); Sieg et al. (2019); Narita et al. (2020); Darwin and Tol (2001), Reilly et al. (2007), Roson and Van der Mensbrugghe (2012), Anthoff and Tol (2014), Dellink et al. (2019), Takakura et al. (2019)]

## Meta
***Estimating functions treating literature as data points***

**Strengths:**
- Accounts for estimates across literature

**Concerns:**
- Limited assessment of data
- Limited consideration of methodological differences and details

[e.g., Howard and Sterner (2017), Nordhaus and Moffat (2017), Tol (2018, 2024)]

See IPCC AR6 WGII for references

Slide adapted from Steve Rose (EPRI)

# Issue: Incomparability of Methods

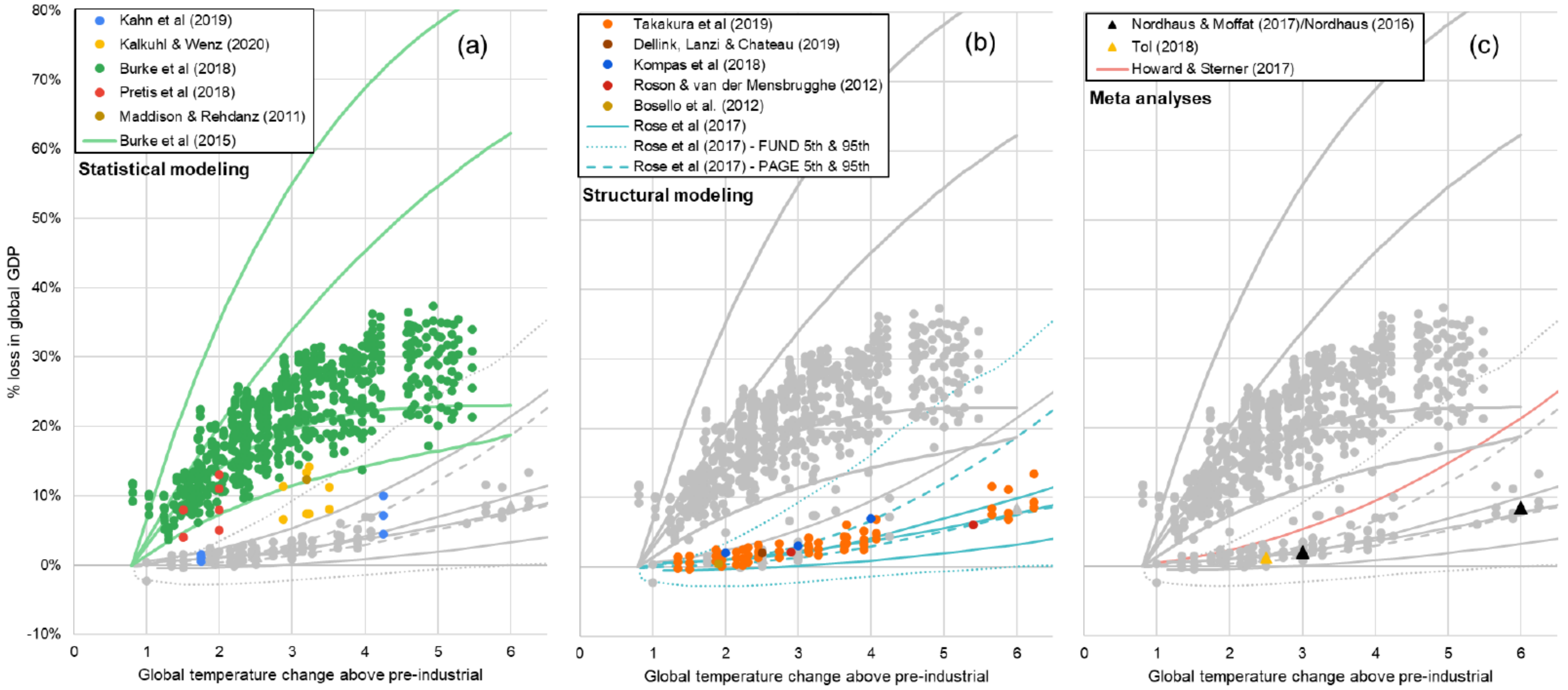
## IPCC assessed global estimates and found methodological differences cannot be ignored

"The wide range, and the lack of comparability between methodologies, does not allow for identification of a robust range of estimates with confidence (high confidence)"

"Evaluating and reconciling differences in methodologies is a research priority for facilitating use of the lines of evidence (high confidence)"

NASEM (2017) also raised this comparability issue

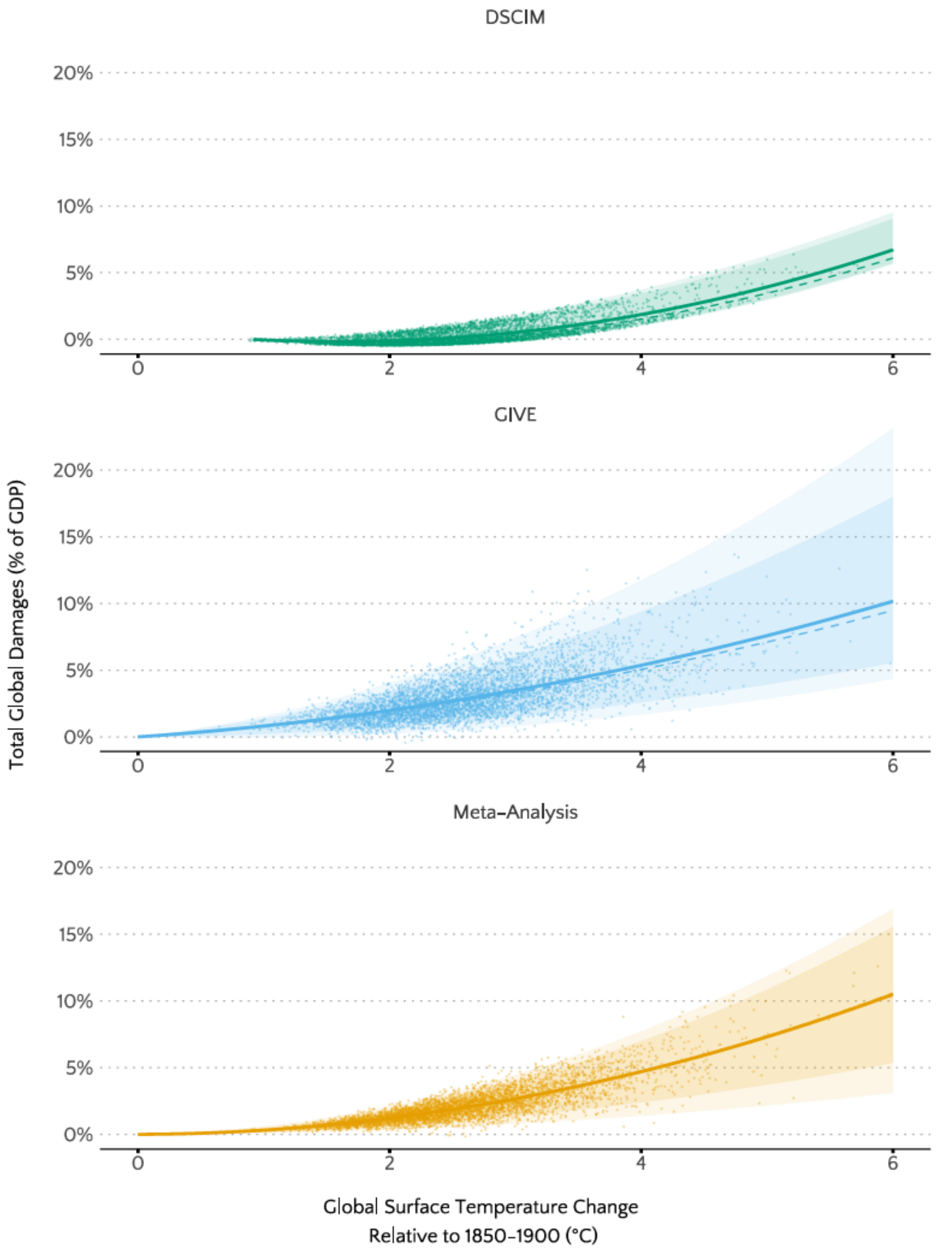
Global aggregate economic impact estimates by global warming level
(% global GDP loss, all estimates from a paper have the same color)




*Source: Rose, S, D Diaz, T Carleton, L Drouet, C Guivarch, A Méjean, F Piontek. Cross-Working Group Box ECONOMIC | Estimating Global Economic Impacts from Climate Change. In Climate Change 2022: Climate Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the IPCC, Chapter 16 (O'Neill et al, Key Risks Across Sectors and Regions), [https://www.ipcc.ch/report/ar6/wg2/](https://www.ipcc.ch/report/ar6/wg2/).*

Slide credit: Steve Rose (EPRI)

# Same issue in USEPA (2023) Social Cost of GHGs




DSCIM (Climate Impacts Lab): sum of 5 impact categories, primarily based on separate statistical modeling

GIVE (Resources for the Future): sum of 4 impacts categories, each based on separate structural modeling

Meta-Analysis (Howard and Sterner, 2017): meta-analysis of global aggregate functions in previous literature



Slide adapted from Steve Rose (EPRI)

# Issue: Limited Coverage of Climate Impacts

- **Temperature-Related Mortality**
- **Labor Productivity**
- **Agricultural Crop Productivity**
- **Energy Consumption**
- **Coastal Infrastructure (Sea Level Rise)**

**Suggested read: Rising, J., Tedesco, M., Piontek, F. *et al.* (2022). The missing risks of climate change. *Nature* 610, 643–651. https://doi.org/10.1038/s41586-022-05243-6**

- Rainfed crop productivity
- Irrigated crop productivity
- Livestock productivity
- Water availability
- Water quality
- Hydropower production
- Marine fisheries
- Erosion
- Forest cover changes
- Reservoir sedimentation
- Spread of disease
- Tourism
- Education
- Air quality
- Inland/urban flooding
- Road infrastructure
- Bridge infrastructure
- Rail infrastructure
- Grid infrastructure
- Tropical storms/hurricanes
- Subsidence
- Wildfire
- **Ecosystem services & recreation**
- **Species loss / biodiversity**
- **Crime & conflict**
- **Mass migration**
- **Extreme events**
- **Tipping Points**

# Issue: Incomplete Assessment of Individual Impacts

## Example: Labor Impacts

- Labor supply losses due to mortalities
- Medical expenditure increases due to work-related mortalities and morbidity
- Lost working hours due to morbidity
- Labor productivity decreases due to heat/cold stress
- Lost labor time due to disruptions (e.g. from extreme events like flooding, wildfires, hurricanes)

→ Due to insufficient data or methodological limitations, most studies include only a subset of these impact channels, often focusing on lost work hours or lost productivity due to heat


IPGGutenbergUKLtd

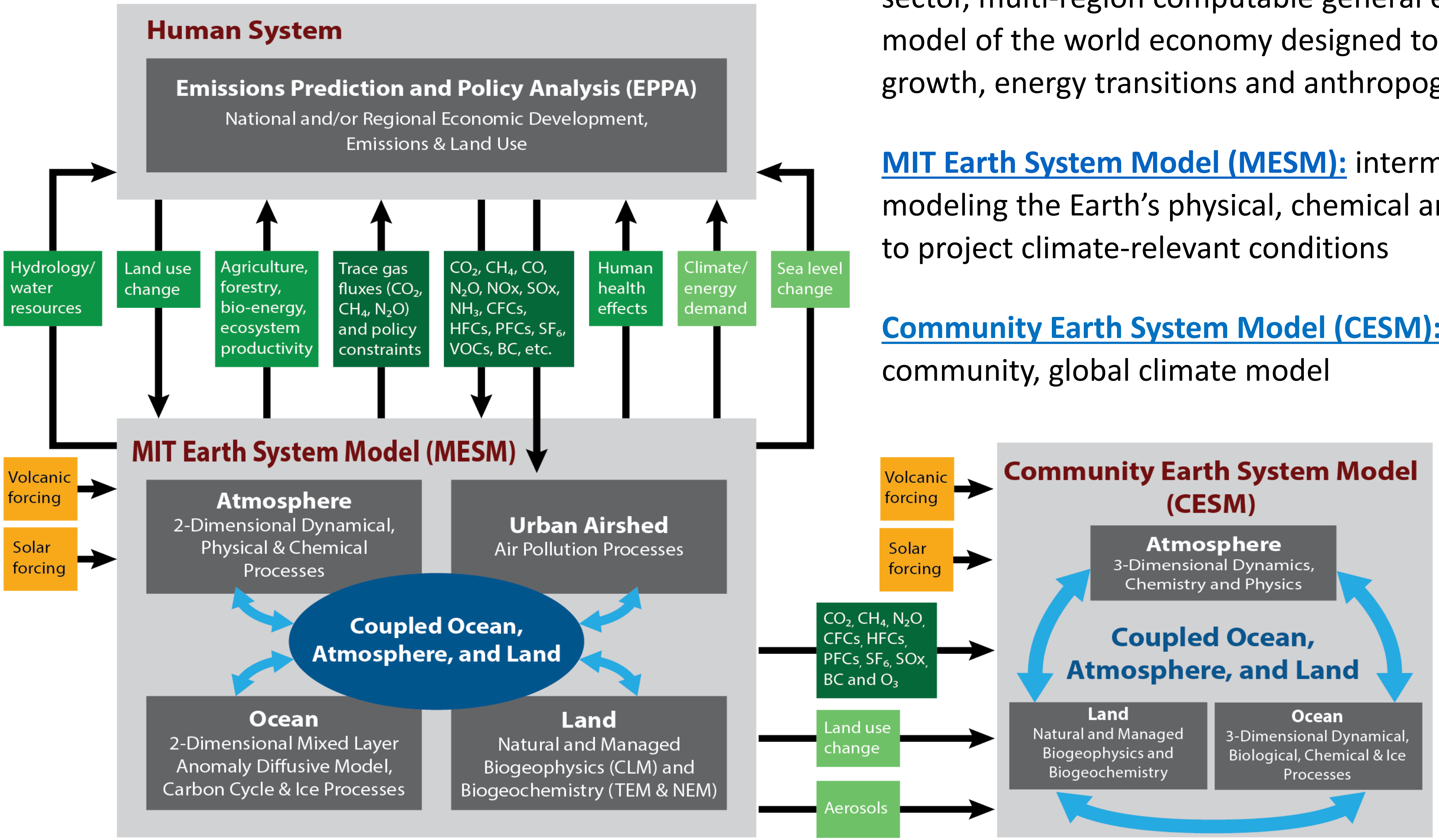
# Scientific Challenges

- Comparability of different methodologies and results
- Assessment & incorporation of alternative estimates within a category
- Accounting for more climate impacts
    - Sufficiency of data, scientific understanding (e.g. physical system dynamics)
- Accounting for uncertainty
- Accounting for potential adaptation
- Aggregating across categories and regions
    - Interactions, feedbacks, spatial heterogeneity
    - Consistency across modules (projections of climate and society)
- Considering equity, justice and risk
    - Distribution of impacts across space, time, social groups

Slide adapted from Steve Rose (EPRI)

# MIT Joint Program Efforts on Economic Impacts of Climate Change

## MIT Integrated Global System Modeling (IGSM) Framework



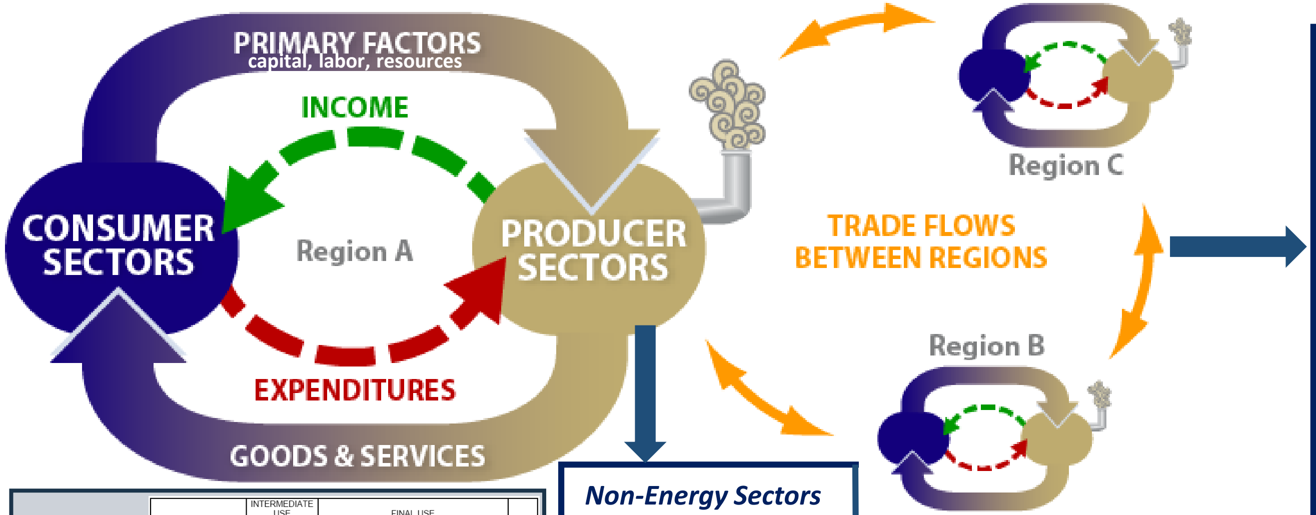

**Economic Projection and Policy Analysis (EPPA) model:** multi-sector, multi-region computable general equilibrium (CGE) model of the world economy designed to project economic growth, energy transitions and anthropogenic emissions

**MIT Earth System Model (MESM):** intermediate complexity, modeling the Earth's physical, chemical and biological systems to project climate-relevant conditions

**Community Earth System Model (CESM):** fully-coupled, community, global climate model

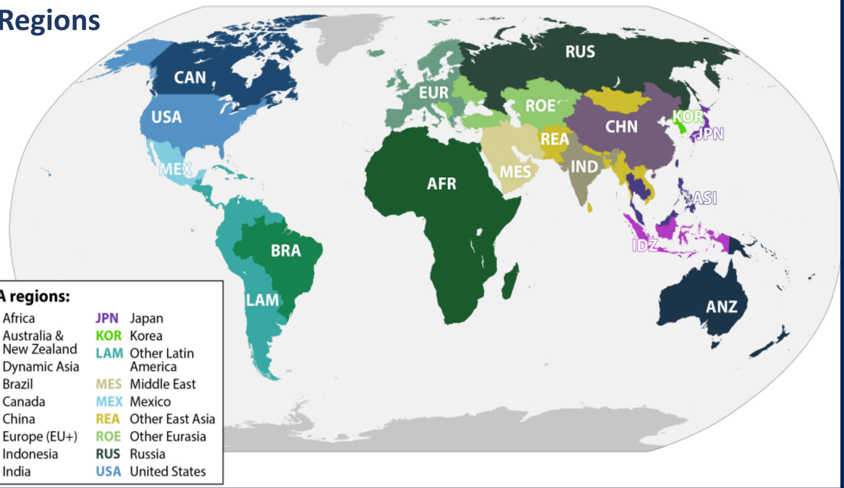
# MIT Economic Projection and Policy Analysis (EPPA) Model

**Multi-sector, multi-region computable general equilibrium (CGE) model of the world economy for energy, economy and emissions projections**




**Regions and sectors can be added for special studies**

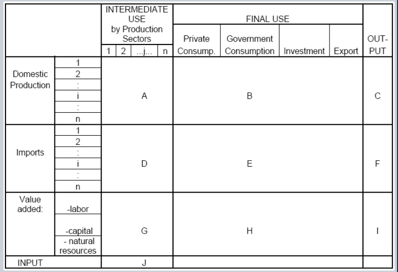
## 18 Regions




**Technical Features**

- Written in GAMS using MSPGE
- Recursive-Dynamic
- Uses GTAP Database
- Calibrated to current economic and energy levels based on IMF and IEA
- Documented in peer-reviewed literature
- Publicly Available Version
- 2100+ (in 5-year steps)

Full Input-Output Data for Every Region




***Non-Energy Sectors***

- **Crops**
- **Livestock**
- **Forestry**
- **Food**
- **Energy-Intensive Industry** — Iron & Steel; Cement; Chemicals; Non-Ferrous Metals; *+ low-carbon options*
- **Manufacturing**
- **Service**
- **Commercial Transport**
- **Household Transport** — ICE (gasoline & diesel); Plug-in Electric; Battery Electric; Hydrogen

***Energy Sectors***

- **Crude Oil**
- **Refined Oil**
- **Liquid Fuel from Biomass** — Current Generation; Advanced Biofuel
- **Oil Shale**
- **Coal**
- **Natural Gas (conv., shale, tight)**
- **Electricity** — Conv. Fossil (coal, gas, oil); Adv. Fossil (NGCC, Adv Coal); Coal with CCS; Coal + Bio Co-firing w/ CCS; Gas with CCS; Gas with Advanced CCS; Nuclear; Advanced Nuclear; Hydro; Solar; Wind; Renewables with Backup; Biomass; Biomass with CCS
- **Synthetic Gas (from Coal)**

**New Technologies Continually Added**

**Key Inputs**

- Policy Assumptions
- Population Growth
- Capital/Labor Productivity Growth
- Energy Efficiency Improvements
- Technology Costs
- Rate of Technology Penetration
- Elasticities of Substitution (related to labor, capital, energy, fuels, etc.)
- Fossil Fuel Resource Availability
- Urban Pollutant Initial Inventories & Trends
- Land Productivity

**Key Outputs**

- GDP
- Consumption
- Emissions (GHGs, Air Pollutants)
- Primary/Final Energy Use
- Electricity Generation
- Technology Mix
- Commodity and Factor Prices
- Sectoral Output
- Land Use

**At global and regional levels**

**Key Features**

- Global Coverage & International Trade
- Economy-Wide Coverage & Inter-Industry Linkages
- Feedbacks Across Regions & Sectors
- Theory-Based (microeconomics with full input-output data)
- Endogenous Prices, Investments & Capital Accumulation
- GDP and Welfare Effects
- Policies (emissions limits/prices, sector/technology regulations…)
- Distortions (taxes, subsidies, etc.)
- Accounting for Physical Quantities (energy, electricity, land)
- **Links to MIT Earth System Model (MESM)**

**Key Equations**

***Firms maximize profit:*** choose technology, level of output and inputs subject to production functions and costs

***Household maximize welfare:*** choose savings and consumption subject to budget constraint

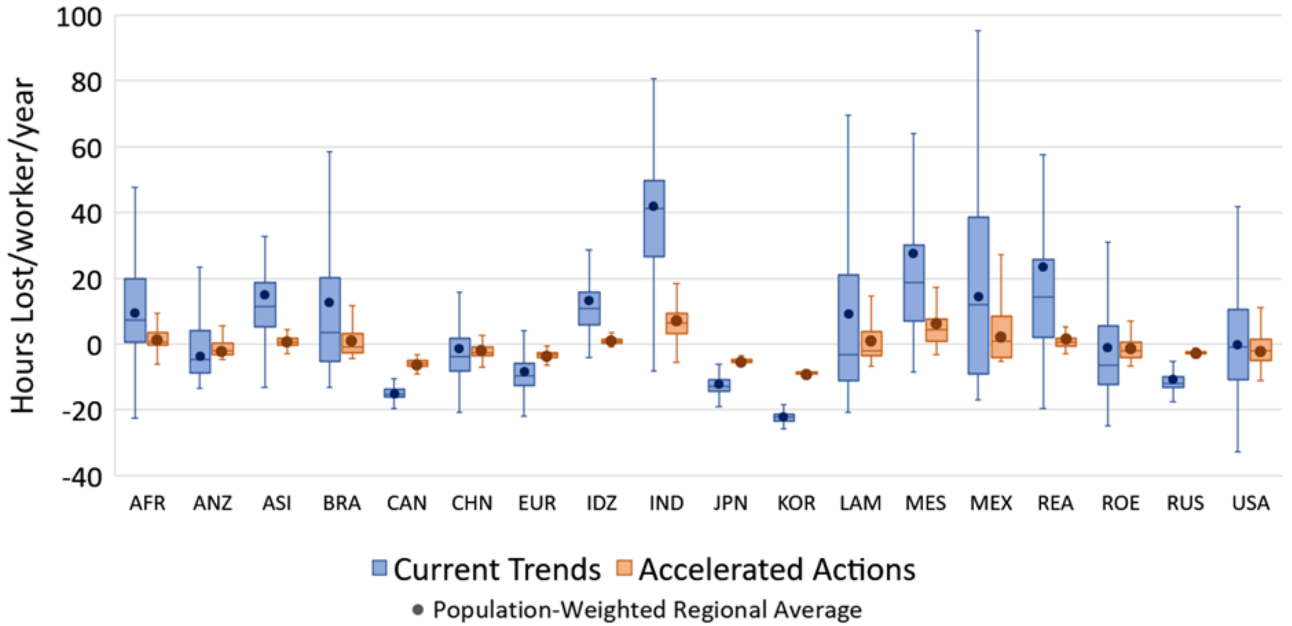
***Equilibrium Conditions:*** Market-Clearing, Zero-Profit, Income Balance



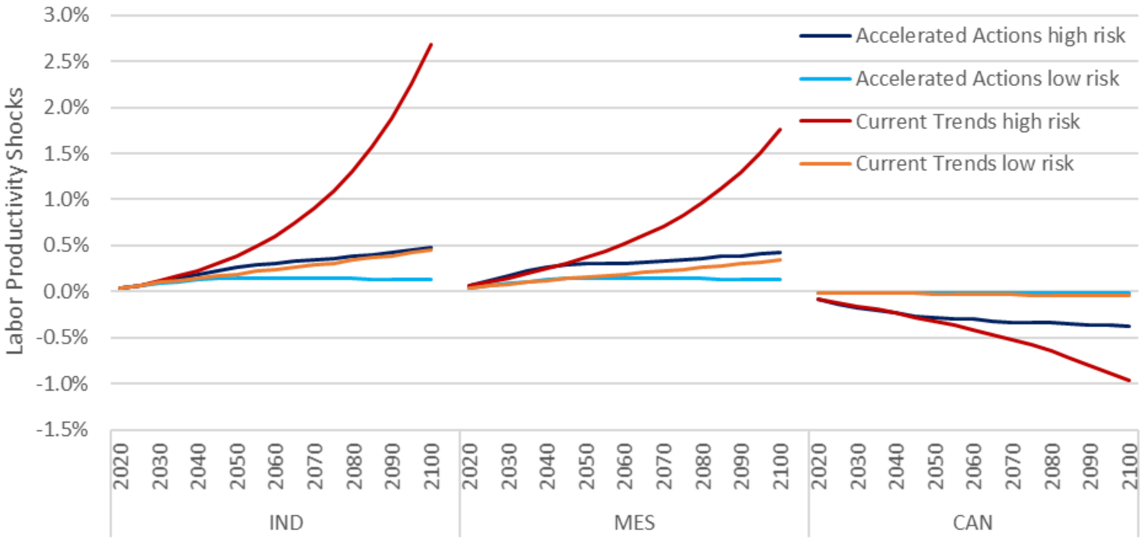
https://globalchange.mit.edu/research/research-tools/human-system-model

# Exploring Climate Impacts on the Economy in EPPA: Labor

- Climate Impact Lab: response functions for temperature impacts on labor (hours worked) for ~24,000 administrative units in the world, for two classes of labor (high-risk workers and low-risk workers) (Rode *et al.*, 2022)
- Drove functions with temperature and GDP/capita projections from our 2023 Outlook scenarios
- Aggregated labor impacts to EPPA's 18 regions by taking a population-weighted average of administrative units
- Imposed regional impacts in EPPA as labor productivity shocks for each scenario to find the economic implications



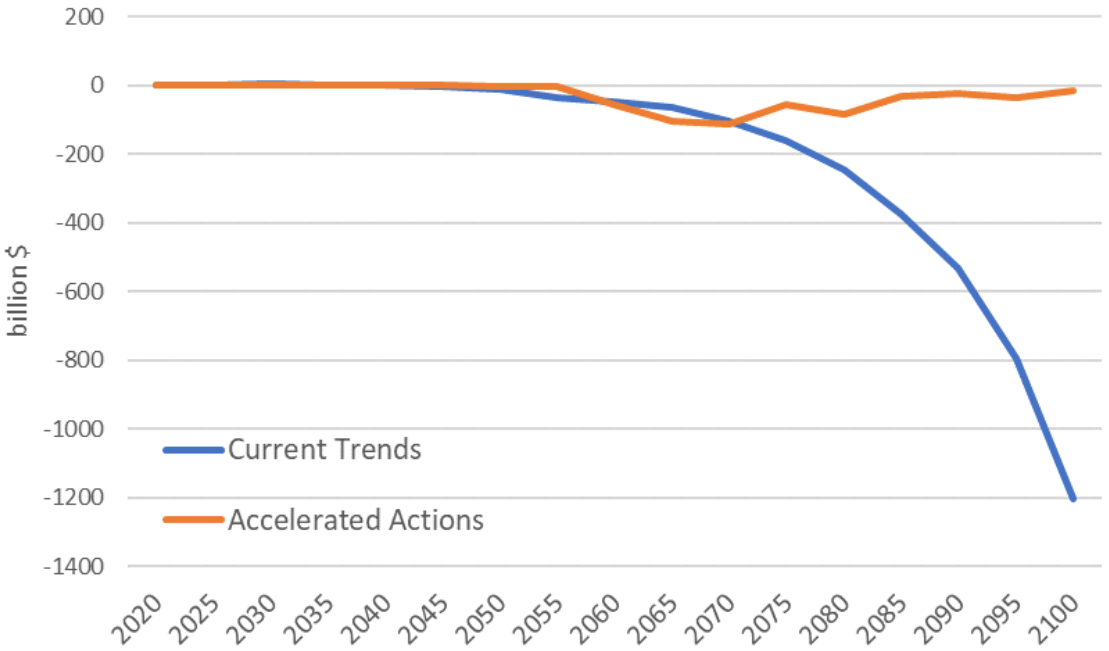

Direct impact of climate on labor of high-risk workers by region in 2100, in terms of hours of labor lost per worker per year (positive values = hours lost; negative values = hours gained). Box and whisker plots reflect the variation across the administrative units within an EPPA region. Points reflect the population-weighted average hours lost across administrative units in each EPPA region.




Regional differences in labor productivity impacts High-risk workers face non-linear labor impacts in response to temperature: temperature tipping points at which high-risk workers face exponential decreases in hours worked.

# Exploring Climate Impacts on the Economy in EPPA: Labor

**Global changes in GDP due to climate impacts on labor**




Global economic impact small through mid-century, then grows rapidly through 2100 in Current Trends (linear temperature increase but exponential labor losses and economic impact).

Impacts can be largely avoided through strong mitigation
-$1 billion vs. $1.2 trillion in 2100

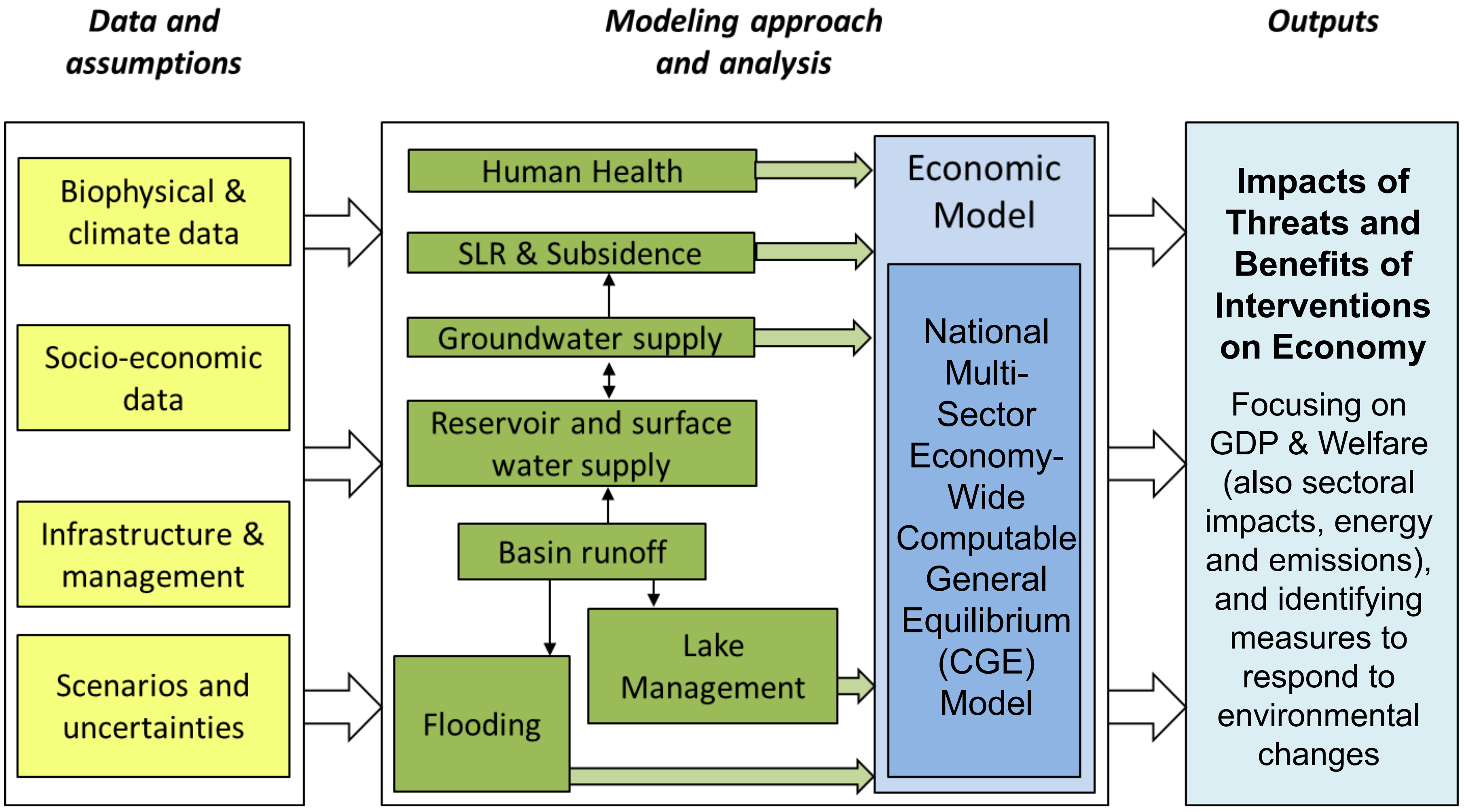
**GDP impacts vary significantly by region**

| | Current Trends | Accelerated Actions |
|---|---|---|
| IND | -704 | -98 |
| MES | -304 | -61 |
| AFR | -152 | -7 |
| REA | -101 | -14 |
| BRA | -99 | -19 |
| ASI | -99 | -25 |
| LAM | -88 | -12 |
| MEX | -75 | -23 |
| USA | -50 | 65 |
| IDZ | -44 | 4 |
| ROE | -2 | 8 |
| ANZ | 1 | 4 |
| RUS | 16 | -1 |
| CAN | 38 | 20 |
| JPN | 43 | 17 |
| CHN | 56 | 4 |
| KOR | 69 | 21 |
| EUR | 294 | 103 |

Tropical regions generally face more negative impacts, while more temperate and colder regions can see positive impacts

EPA FrEDI estimates $51 billion in USA at end of century

# Country-Level Economic-Biophysical Modeling: “Impact Channels”




*representative set of biophysical models

**Impact Channels = specific pathways by which biophysical changes and adaptive measures link to changes in the economy-wide model**

MIT-IMPACTS — Integrated Modeling Project Assessing Climate Threats and Solutions

MILLENNIUM CHALLENGE CORPORATION
UNITED STATES OF AMERICA

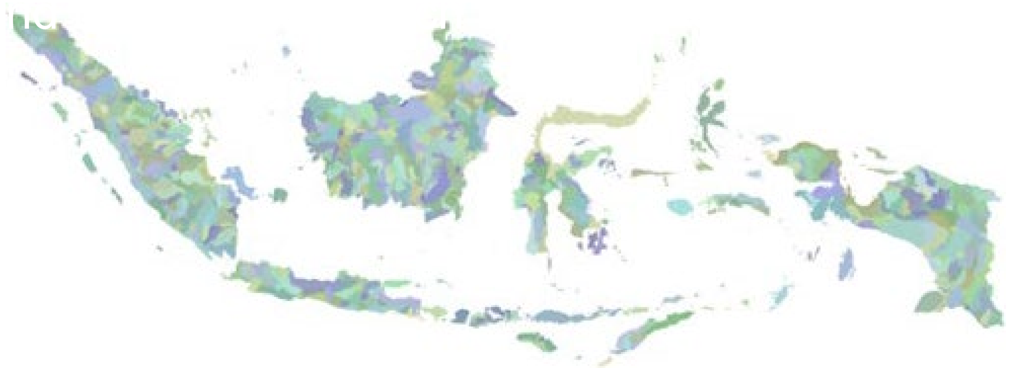
IEc INDUSTRIAL ECONOMICS, INCORPORATED

AUT

# Indonesia Example: Channel for Flooding

**1) Specify Scenarios**

| | | | **Without Adaptation** | **With Adaptation** |
|---|---|---|---|---|
| | | | Continued Land Degradation | No Further Land Degradation |
| **Low Threat Impacts** | Mean Flooding | Baseline Precipitation | | |
| | | Future Precipitation | | |
| **High Threat Impacts** | 50-Year Flooding | Baseline Precipitation | | |
| | | Future Precipitation | | |



**2) Specify impact channels and CGE hooks:**

(1) **Capital:** *decreases in sector-specific capital and aggregate capital*

(2) **Labor:** *decreased labor productivity*

**3) Estimate magnitudes of CGE model shocks for each impact channel:**

- Flood runoff models for 752 drainage basins in Indonesia to estimate flood peak magnitudes considering land use change and climate change
- Processed into infrastructure damages using damage functions for transportation sector developed by Wright et al. (2012), and on labor productivity by Hu et al. (2019)
- Impacts aggregated to 514 districts using spatial averaging, and then from districts to national level based on capital density (capital effects) and population (labor productivity)

**4) Implement the shocks in CGE model**

**5) Analyze impacts on GDP**

# Example: Economic Costs of Flooding

## INPUT INTO CGE (from Biophysical Modeling)

### Values of CAPITAL Shocks from Flooding for a Scenario of 50-Year Flooding

| Economic Sector | Abbreviation | Baseline Precip, Current Land Degradation | Baseline Precip, 2030 Land Degradation | Baseline Precip, 2045 Land Degradation | 2030 Precip, Current Land Degradation | 2030 Precip, 2030 Land Degradation | 2045 Precip, Current Land Degradation | 2045 Precip, 2045 Land Degradation |
|---|---|---|---|---|---|---|---|---|
| Paddy Rice | pdr | 1.97% | 2.11% | 2.31% | 3.28% | 3.42% | 3.39% | 3.51% |
| Refined Oil Production | oil | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Natural Gas Production | gas | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Non-Metallic Minerals: cement, pla | nmm | 0.08% | 0.08% | 0.08% | 0.12% | 0.12% | 0.12% | 0.13% |
| Ferrous metals | i_s | 0.08% | 0.08% | 0.08% | 0.12% | 0.12% | 0.12% | 0.13% |
| Metals nec | nfm | 0.08% | 0.08% | 0.08% | 0.12% | 0.12% | 0.12% | 0.13% |
| Metal products | fmp | 0.08% | 0.08% | 0.08% | 0.12% | 0.12% | 0.12% | 0.13% |
| Motor vehicles and parts | mvh | 0.08% | 0.08% | 0.08% | 0.12% | 0.12% | 0.12% | 0.13% |
| Transmissoin and distribution | TnD | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Water | wtr | 0.56% | 0.60% | 0.65% | 0.91% | 0.94% | 0.93% | 0.97% |
| Human Health and Social Work | hht | 0.07% | 0.07% | 0.08% | 0.11% | 0.12% | 0.12% | 0.12% |
| Coal Production | COL | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Other mining | OMN | 0.01% | 0.01% | 0.01% | 0.01% | 0.02% | 0.01% | 0.02% |
| Agriculture | AGR | 1.97% | 2.11% | 2.31% | 3.28% | 3.42% | 3.39% | 3.51% |
| Crude Oil | CRU | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Food | FOOD | 0.11% | 0.12% | 0.13% | 0.19% | 0.19% | 0.19% | 0.19% |
| Other manufacturing | MANF | 0.57% | 0.60% | 0.65% | 0.91% | 0.96% | 0.93% | 0.99% |
| Chemical, rubber, plastic products | CRP | 0.08% | 0.08% | 0.08% | 0.12% | 0.12% | 0.12% | 0.13% |
| Coal electricty | ecoa | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Gas electrcity | egas | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Hydro electricity | ehyd | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Oil electricity | eoil | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Other electricity | eoth | 0.01% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% |
| Transportation | TRN | 1.76% | 1.76% | 1.77% | 2.29% | 2.35% | 2.35% | 2.45% |
| Services | SER | 0.58% | 0.60% | 0.64% | 0.88% | 0.91% | 0.90% | 0.92% |

## INPUT INTO CGE (from Biophysical Modeling)

### Values of Average Annual LABOR PRODUCTIVITY Loss Relative to Baseline for Flooding

| Climate Change/Land Use Setting | Mean Flood | 50-year Flood |
|---|---|---|
| Baseline Precip, Current Land Degradation | 0.00% | 2.66% |
| Baseline Precip, 2030 Land Degragation | 0.02% | 2.84% |
| Baseline Precip, 2045 Land Degradation | 0.05% | 3.09% |
| 2030 Precip, 2030 Land Degragation | 0.24% | 4.27% |
| 2030 Precip, 2030 Land Degragation | 0.26% | 4.36% |
| 2045 Precip, Current Land Degragation | 0.48% | 4.51% |
| 2045 Precip, 2045 Land Degradation | 0.53% | 4.59% |

## OUTPUT FROM CGE

### GDP Impacts of Flooding as Percent Deviations from the Base Case

| Setting | Mean Flood 2030 | Mean Flood 2045 | 50-yr Flood Compared to: Mean Flood Base 2030 | 50-yr Flood Compared to: Mean Flood Base 2045 | 50-yr Flood Compared to: 50-yr Flood Base 2030 | 50-yr Flood Compared to: 50-yr Flood Base 2045 |
|---|---|---|---|---|---|---|
| **JUST CAPITAL** | | | | | | |
| Baseline Precip, Baseline Land Degradation | 0% | 0% | -0.17% | -0.10% | 0% | 0% |
| Baseline Precip, Changing Land Degradation | 0.00% | 0.00% | -0.18% | -0.11% | -0.01% | -0.01% |
| Changing Precip, Baseline Land Degradation | -0.01% | -0.01% | -0.27% | -0.15% | -0.09% | -0.06% |
| Changing Precip, Changing Land Degradation | -0.01% | -0.01% | -0.27% | -0.16% | -0.10% | -0.06% |
| **JUST LABOR** | | | | | | |
| Baseline Precip, Baseline Land Degradation | 0% | 0% | -0.83% | -0.51% | 0% | 0% |
| Baseline Precip, Changing Land Degradation | -0.01% | -0.01% | -0.89% | -0.59% | -0.06% | -0.08% |
| Changing Precip, Baseline Land Degradation | -0.07% | -0.09% | -1.35% | -0.87% | -0.51% | -0.36% |
| Changing Precip, Changing Land Degradation | -0.08% | -0.10% | -1.38% | -0.89% | -0.54% | -0.38% |
| **CAPITAL AND LABOR** | | | | | | |
| Baseline Precip, Baseline Land Degradation | 0% | 0% | -1.01% | -0.61% | 0% | 0% |
| Baseline Precip, Changing Land Degradation | -0.01% | -0.01% | -1.07% | -0.70% | -0.06% | -0.09% |
| Changing Precip, Baseline Land Degradation | -0.08% | -0.10% | -1.62% | -1.03% | -0.61% | -0.42% |
| Changing Precip, Changing Land Degradation | -0.09% | -0.11% | -1.65% | -1.05% | -0.64% | -0.44% |

# Indonesia Example: Overall Impacts of Threats on GDP and Benefits of Action

| Threat | Scenario | Impact on GDP vs. Base Case | | | | Benefits of Action | |
|---|---|---|---|---|---|---|---|
| | | Without Action | | With Action | | | |
| | | 2030 | 2045 | 2030 | 2045 | 2030 | 2045 |
| **Development-Related Threats** | | | | | | | |
| Inadequate WASH coverage | Full coverage by 2045 | 0% | 0% | 0.12% | 0.64% | 0.12% | 0.64% |
| Insufficient water storage | No Climate Change | -0.47% | -1.04% | 0.26% | -0.23% | 0.74% | 0.82% |
| Peatland and lowland development | Considering NDCs | 1.70% | -0.53% | | | | |
| Groundwater over-extraction | Low end subsidence | -0.77% | -1.01% | -0.25% | -0.49% | 0.52% | 0.52% |
| | High end subsidence | -1.33% | -1.32% | -0.25% | -0.49% | 1.08% | 0.83% |
| **Climate-Change Driven Threats** | | | | | | | |
| Sea level rise | Median climate | -0.69% | -1.98% | | | | |
| | High warming | -0.77% | -2.40% | | | | |
| Flooding | Wet climate; mean | -0.09% | -0.11% | -0.08% | -0.10% | 0.01% | 0.01% |
| | Wet climate; 50-yr | -1.65% | -1.05% | -1.62% | -1.03% | 0.04% | 0.02% |
| Insufficient water storage | Dry climate | -0.93% | -2.50% | 0.04% | -1.35% | 0.97% | 1.15% |
| | Wet climate | -0.44% | -0.59% | 0.32% | 0.13% | 0.77% | 0.72% |

**Framework can:**

- **Quantify/identify greatest threats to growth**
- **Quantify trade-offs of different policy and investment decisions**

# Impact Channels for this Partnership

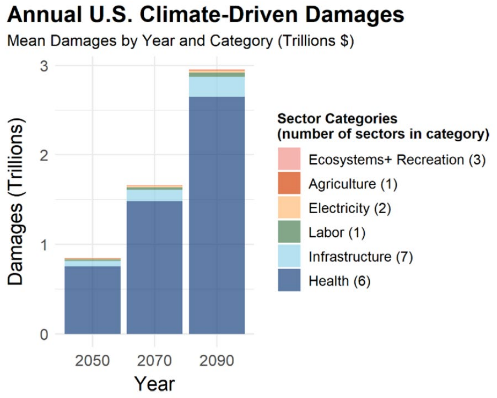
| Nº | CHANNEL OF IMPACT | DESCRIPTION AND MACRO HOOK |
|---|---|---|
| | | |
| **Water, Agriculture, Energy, and Land Use** | | |
| 1 | **Rainfed Crop production** | **Agricultural productivity shocks**. Based on crop yield responses to water availability from monthly temperature and precipitation. |
| 2 | **Irrigated crops** | **Agricultural productivity shocks**. Based on crop yield responses to water availability from monthly temperature and precipitation |
| 3 | **Water availability** | **Capital investments**. Uses a water systems model to evaluate changes in water availability to municipal and industrial uses, and resulting implications for water supply infrastructure investments. |
| 4 | **Hydropower production** | **Hydropower shocks**. Impacts on energy generation resulting from changes in river runoff. Requires a more involved modeling approach and a water systems model. |
| 5 | **Livestock production** | **Livestock productivity shocks**. Based on relationships between temperature and livestock growth and death rates. Also assess rangeland production losses due to climate change. |
| **Human Capital and Development** | | |
| 6 | **Heat and labor productivity** | **Labor productivity shocks**. Labor type-specific curves based on sectoral work intensities from temperature. |
| 7 | **Human health and labor supply** | **Labor supply shocks**. Damage to total labor supply based on statistically modeled effects of temperature on the spread of disease, and the resulting losses in labor supply. |
| 8 | **Water supply and sanitation: Labor supply** | **Labor supply shocks.** Water borne diseases negatively affect the economy by reducing labor supply/productivity. |
| **Infrastructure** | | |
| 9 | **Inland flooding** | **Capital damages**, considering floodplains, design flood events, and spatial distribution of capital. Precipitation events routed through the TR-20 model. |
| 10 | **Roads and bridges: Capital** | **Capital damages**. Impacts to road and bridges infrastructure due to temperature, precipitation, and flooding effects across paved, gravel, and dirt roads. |
| 11 | **Roads and bridges: Labor** | **Labor disruptions**. Impacts to road and bridges infrastructure due to temperature, precipitation, and flooding effects across paved, gravel, and dirt roads. |
| 12 | **Grid Infrastructure** | **Capital damages.** Impacts of climate events to the infrastructure components of the electrical grid, including transmission and distribution lines, transformers, substations, and power poles. |
| 13 | **Sea level rise** | **Capital damages**. Coastal flooding due to sea level rise. A reduced form approach using temperature and proxies (e.g., road density) to represent coastal capital. |

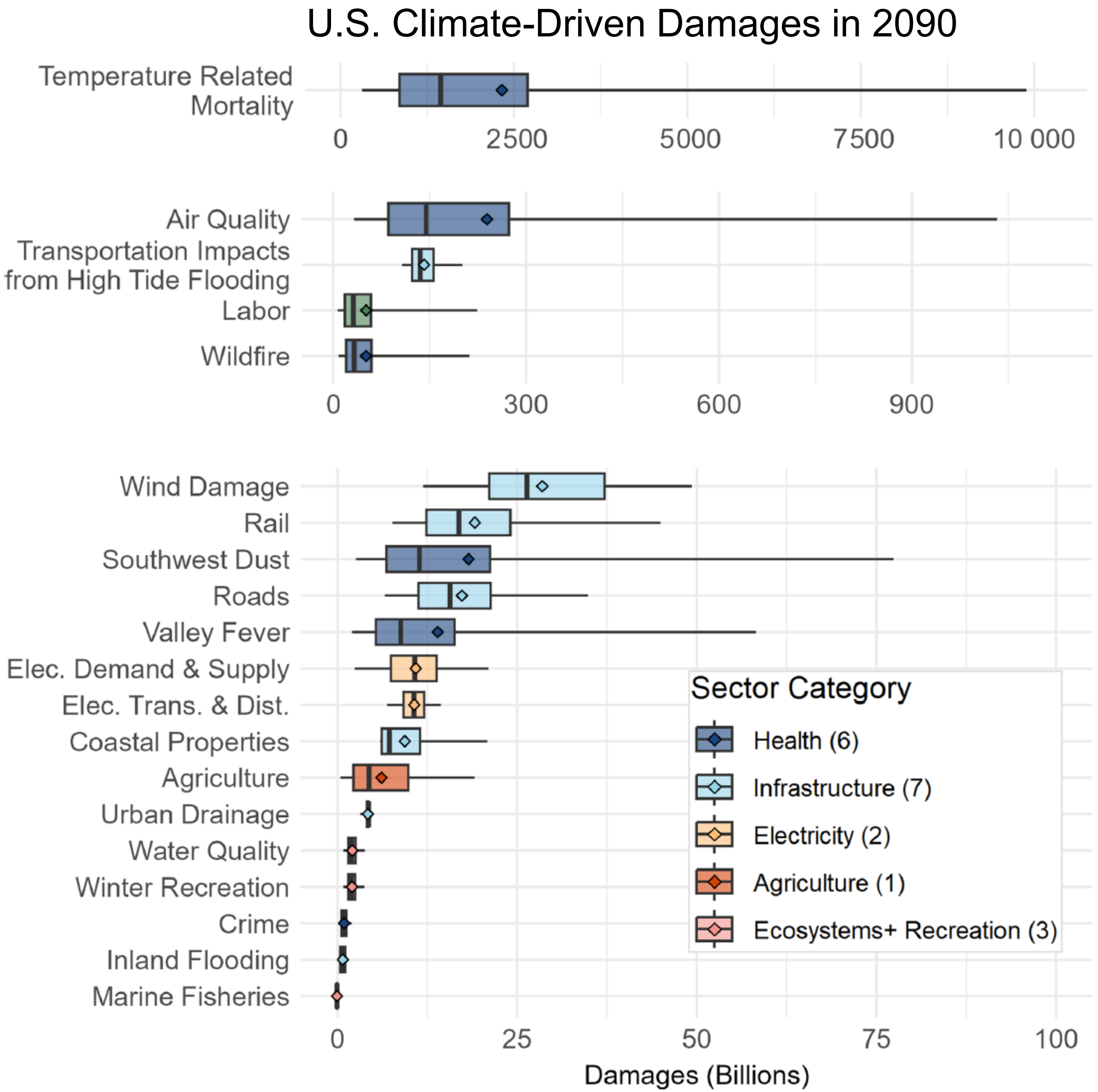
# USREP-FrEDI

EPA's Framework for Evaluating Damages and Impacts (FrEDI)

- Draws on over 30 climate change impact models from peer-reviewed studies to develop relationships between mean surface temperature change and climate-driven impacts across 20 sectors within U.S. borders through the end of the 21st century

Incorporate these impacts into USREP, our state-level CGE model of the U.S.



**MAIN MESSAGE 2:**

# We do not have robust estimates of global climate change mitigation costs

Despite abundance of research efforts, estimates are highly uncertain

# Cost of Achieving Climate Targets

## IPCC (2022) costs range from 0-10% of GDP in 2100

Global GDP loss compared to baselines (not accounting for climate change damages) in 2030, 2050 and 2100 for mitigation pathways **with immediate global action**.

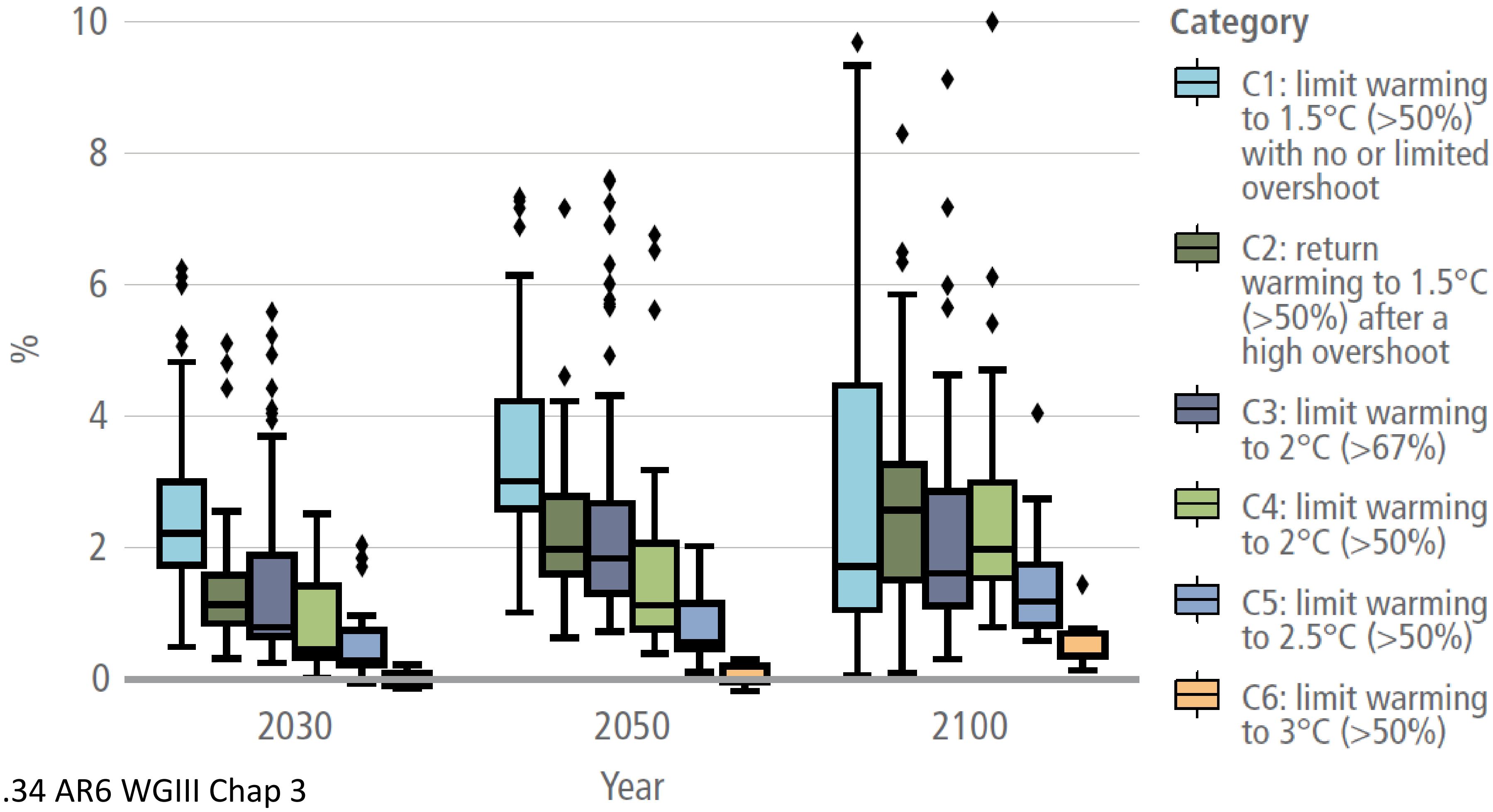


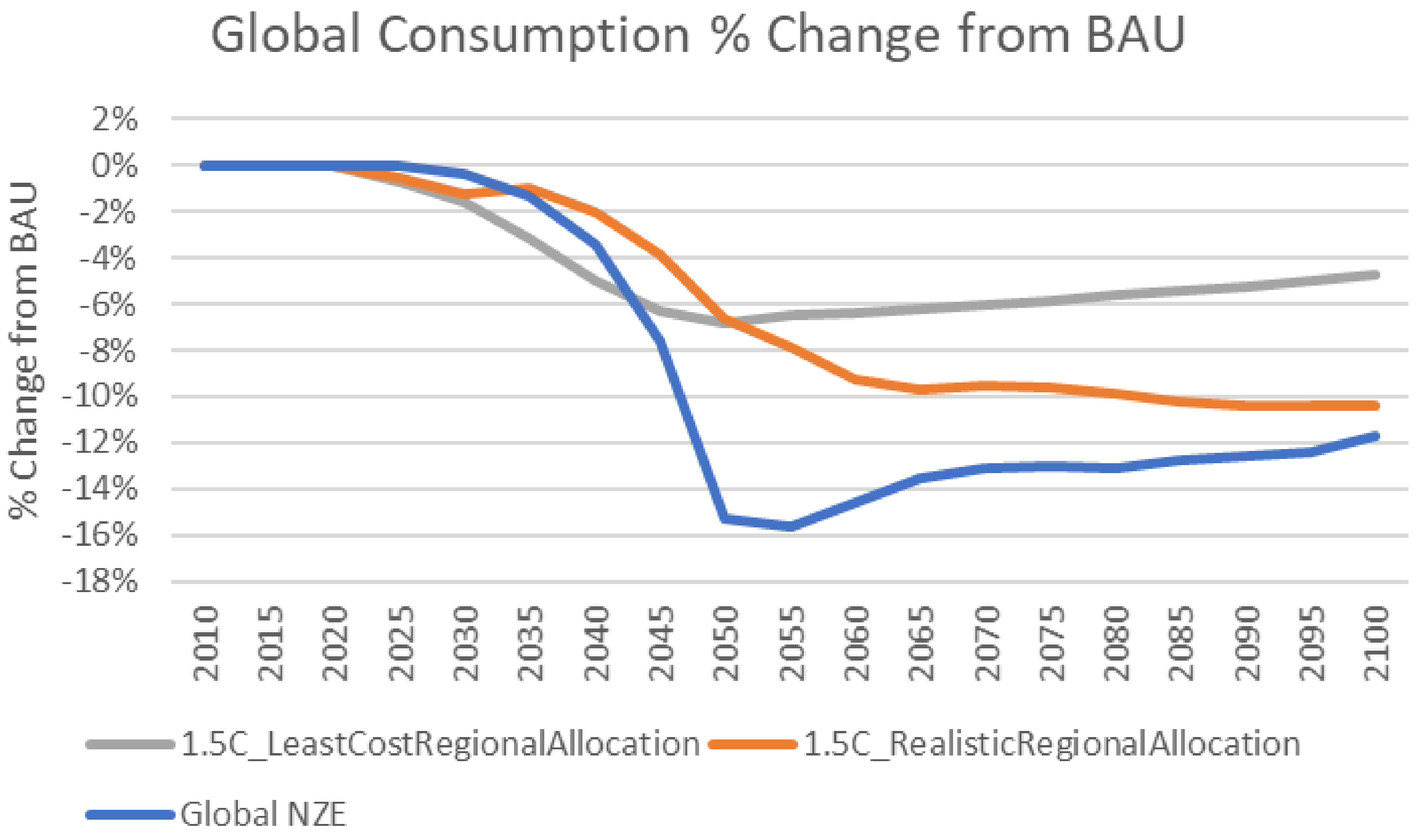

Fig 3.34 AR6 WGIII Chap 3

**NOT a full range: limited set of models, scenarios and assumptions**

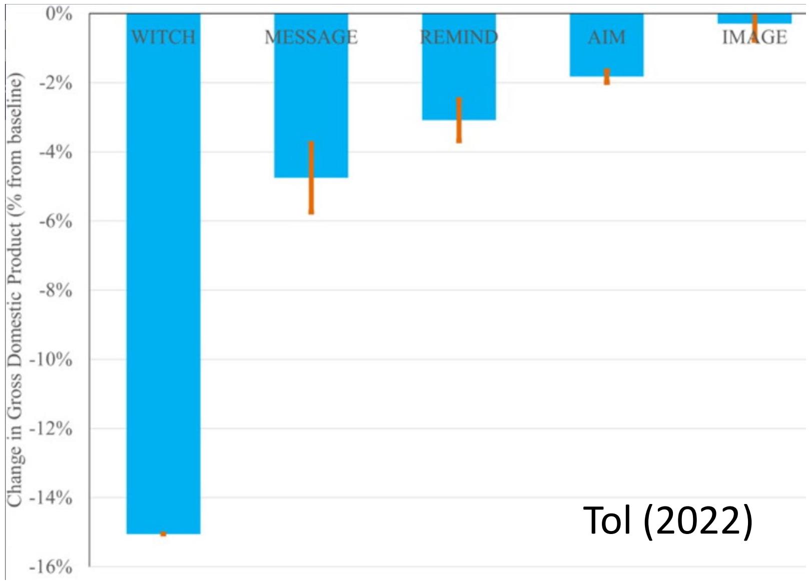
# Cost of Achieving Climate Targets

**Specific assumptions matter immensely**

**EPPA:**




Costs of reducing carbon dioxide emissions by 95% or more (from baseline) by 2050 according to five models



# Implications of Socio-Economic and Policy Design Uncertainty

**5 Policy Levels**

Reference
Above2C
2C
Almost1.5C
1.5C

**3 Policy Design Assumptions**

Each policy under optimistic, pessimistic, pessimistic+ BECCS assumptions

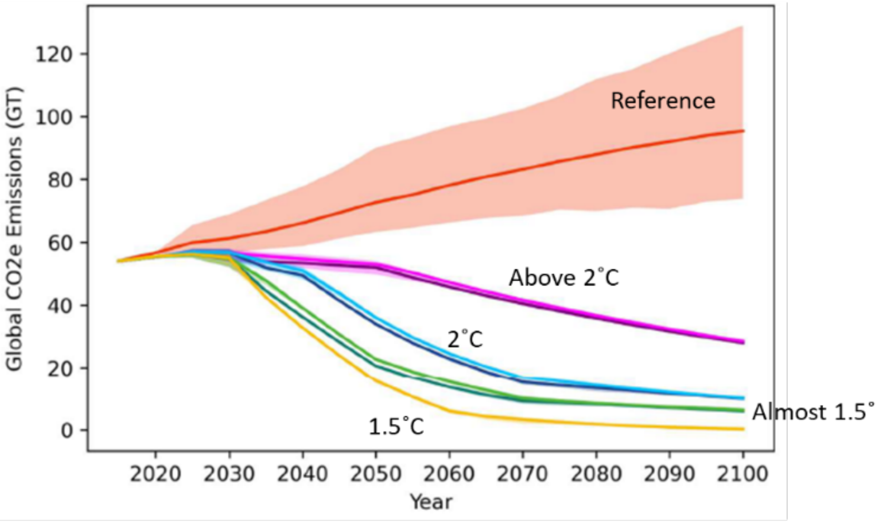
**12 Scenarios**

Ref
Above2C_opt
Above2C_pes
Above2C_med
2C_opt
2C_pes
2C_med
Almost1.5C_opt
Almost1.5C_pes
Almost1.5C_med
1.5C_opt
1.5C_med
(Note: 1.5_pes cannot solve)

**Each run as an ensemble sampling from distributions for key uncertain socio-economic parameters**

- **Labor/Capital Productivity**
- **Population**
- **Energy Technology Costs**
- **Energy Efficiency Improvements**
- **Fossil Fuel Resource Availability**
- **Rate of Technology Penetration**
- **Elasticities of Substitution**

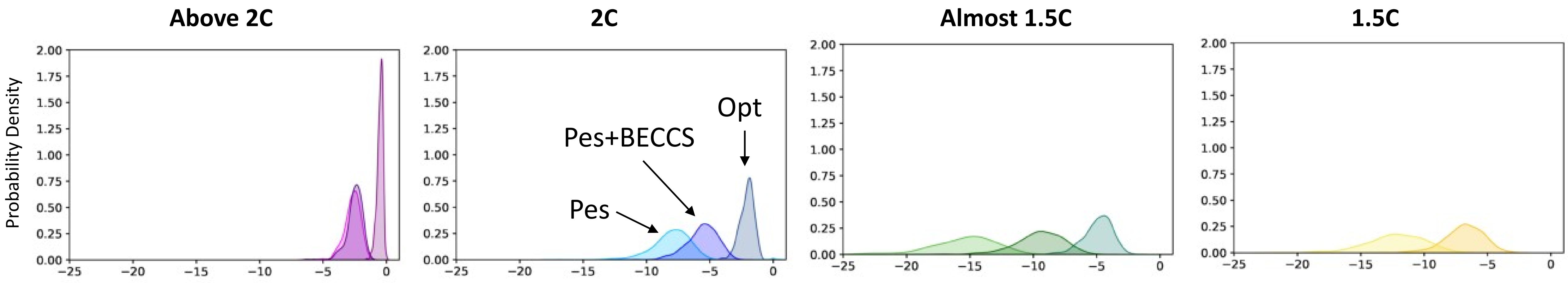
Global $CO_2$e emissions
(reference and global policy, mean and 1st to 99th)




| | | CDR (BECCS & afforestation) | Land Mitigation Covered | International Permit Trading |
|---|---|---|---|---|
| _opt | Optimistic | Yes | Yes | Yes |
| _pes | Pessimistic | No | No | No |
| _med | Pessimistic+BECCS | BECCS | No | No |

# Implications of Socio-Economic and Policy Design Uncertainty

**2050 Global Consumption Loss Relative to Reference**




- **Substantial cost uncertainty:** increases with policy ambition and driven by socio-economic uncertainty and policy design uncertainty- more realistic policy designs = higher costs
- Costs are estimated based on technologies we know of today... in 30 to 100 years there will likely be considerable innovation that will bring costs down
- Even under high cost estimates, economy still growing relative to today

EPRI

**MAIN MESSAGE 3:**

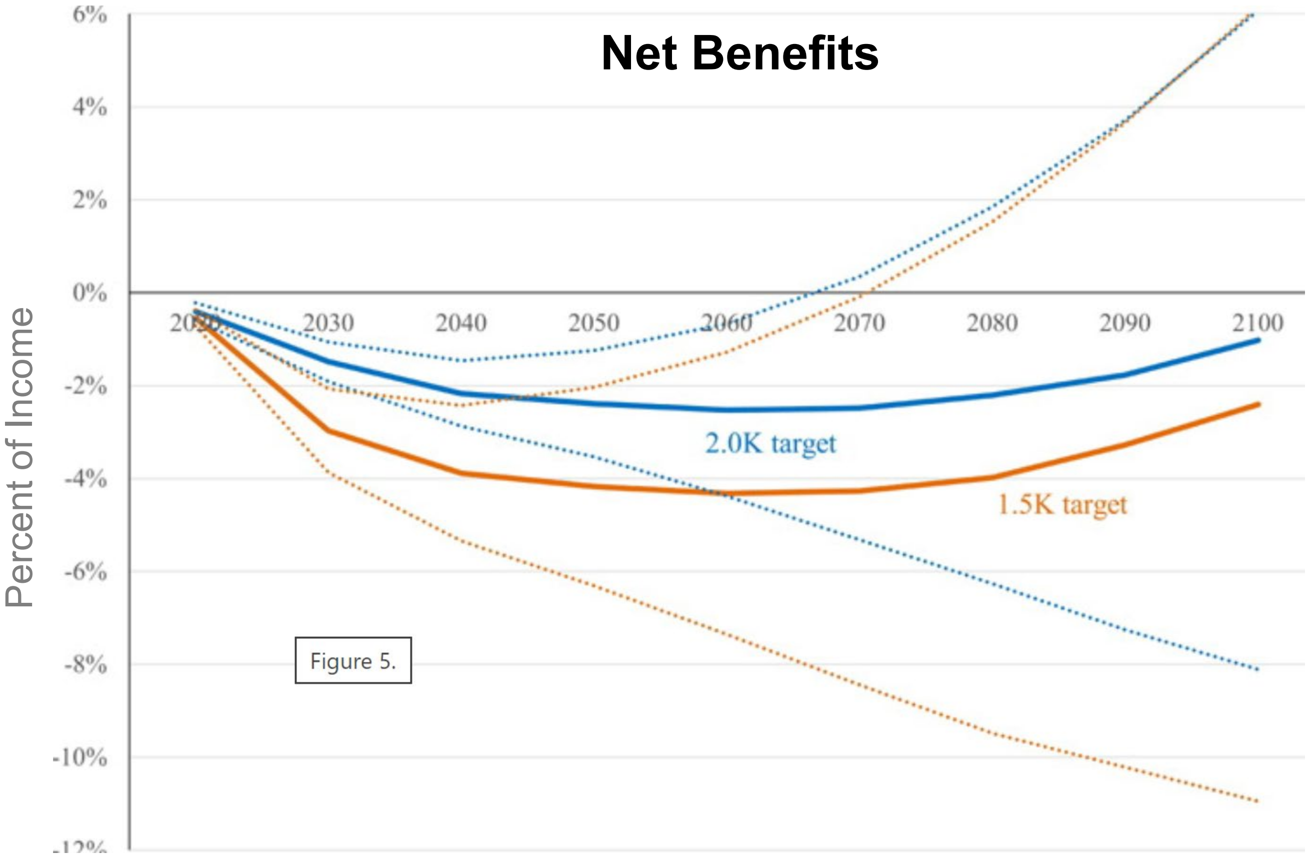
# Caution is needed in how economic impact and mitigation cost estimates are interpreted

Beware cost-benefit analysis

# Tol (2023): “The Paris targets do not pass the cost-benefit test unless risk aversion is high and discount rate low.”

Central estimate of costs of climate policy (Rogelj et al., 2018): 3.8–5.6% of GDP in 2100

Central estimate of benefits of climate policy (Toll, 2022): 2.8–3.2% of GDP in 2100



# Tol (2023): “The Paris targets do not pass the cost-benefit test unless risk aversion is high and discount rate low.”

**Central estimate of costs of climate policy (Rogelj et al., 2018): 3.8–5.6% of GDP in 2100**
**Central estimate of benefits of climate policy (Toll, 2022): 2.8–3.2% of GDP in 2100**

- **Uncertainty about the benefits is larger** than the uncertainty about the costs
- **Uncertainty about benefits is skewed toward higher benefits**: Negative climate surprises are more likely than positive surprises of similar magnitude
- **Estimates are incomplete:** Some impacts are omitted altogether because they resist quantification, others are dropped because they do not fit the method
- **Assumptions about adaptation are stylized**: either overly optimistic (e.g. rational agents with perfect expectations in markets without distortions) or overly pessimistic (e.g. dumb farmers)
- **Valuation of nonmarket impacts is problematic**
- **Extrapolation** of observed (or rather inferred) values to unobserved situations has proven difficult

→ **Comparing the sectoral coverage of various estimates, Tol (2022) finds an average underestimate of 63%**

Rising, J., Tedesco, M., Piontek, F. *et al.* (2022). The missing risks of climate change. *Nature* 610, 643–651. https://doi.org/10.1038/s41586-022-05243-6

# IPCC (2022): "Comparing economic costs and benefits of mitigation raises a number of methodological and fundamental difficulties. Monetising the full range of climate change impacts is extremely hard, if not impossible, as is aggregating costs and benefits over time and across individuals when values are heterogeneous."

- **"A complete appraisal of economic effects and welfare effects at different temperature levels would include the macroeconomic impacts of investments in low-carbon solutions and structural change away from emitting activities, co-benefits and adverse side effects of mitigation, (avoided) climate damages, as well as (reduced) adaptation costs, with high temporal, spatial and social heterogeneity using a harmonised framework."**
- Recommend **cost-effectiveness** approaches that analyze how to achieve a defined mitigation objective at least cost or while also reaching other societal goals.
- Financial **value of health benefits from improved air quality** from mitigation alone is projected to be greater than the costs of meeting the goals of the Paris Agreement (high confidence).

# Closing Points

- Much more research is needed on the economic impacts of climate change
    - Existing global estimates are incomplete and underestimates
    - Many useful insights from country-level / impact specific research
- Mitigation cost assessments should consider a greater variety of assumptions, especially about policy design
- Many studies are simply not comparable (different methods, scales, impacts, scenario assumptions, etc.)
- Heterogeneity of costs across space, time, groups, etc. matters
- More representation of uncertainty and adaptation is needed
- Be wary of cost-benefit assessments
- More attention to irreversible damages and tipping points is needed
    - Weitzman: mean estimates of damages are largely irrelevant to cost-benefit assessment
- Need to move toward more integrated modeling/scenarios
- Uncertainty shouldn’t stop action

# Thank You

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SCIENCE POLICY
GLOBAL CHANGE

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