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Modeling Uncertainty Project:
Full Permutation Experiment with GCAM

Haewon McJeon and the GCAM Team

Snowmass CCIIA
July 29, 2013

Agenda

- GCAM: The Global Change Assessment Model
- Model Results
  - Population
  - GDP
  - Energy
  - Carbon Dioxide Emissions
  - Carbon Dioxide Concentration
  - Total Forcing
  - Temperature
- Remarks

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GCAM:
The Global Change Assessment Model

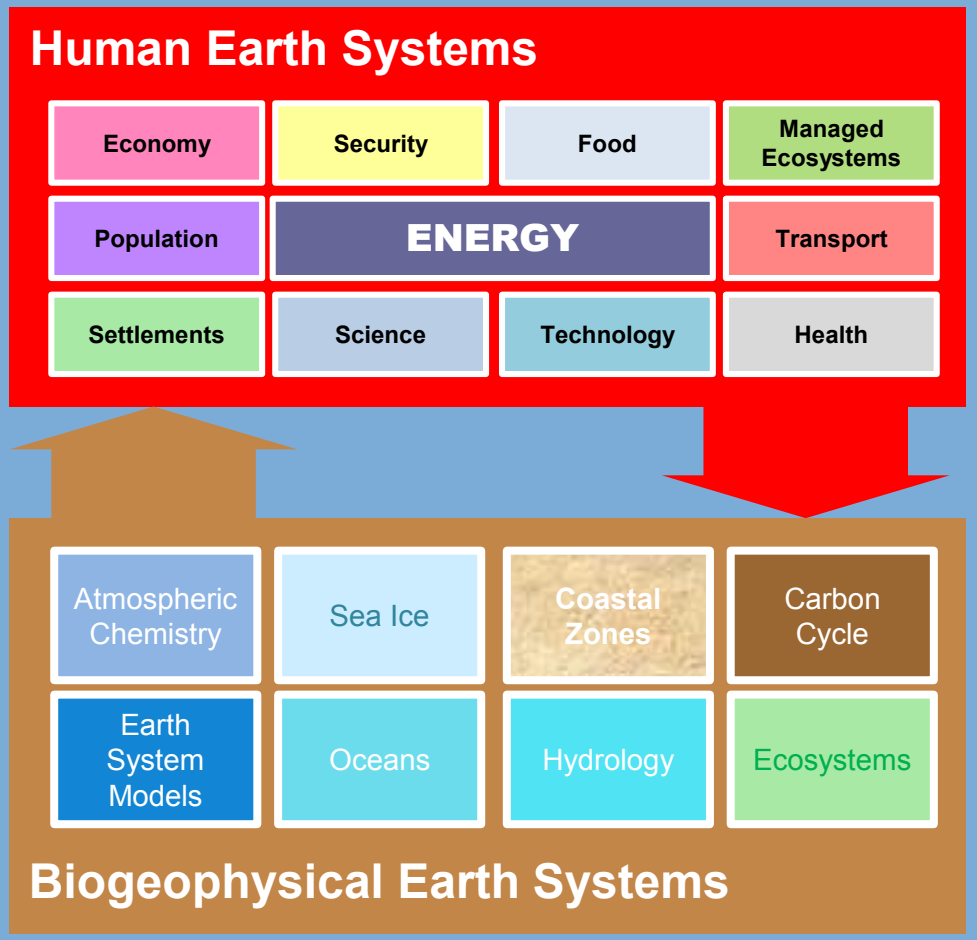
Integrated Assessment Models (IAMs)

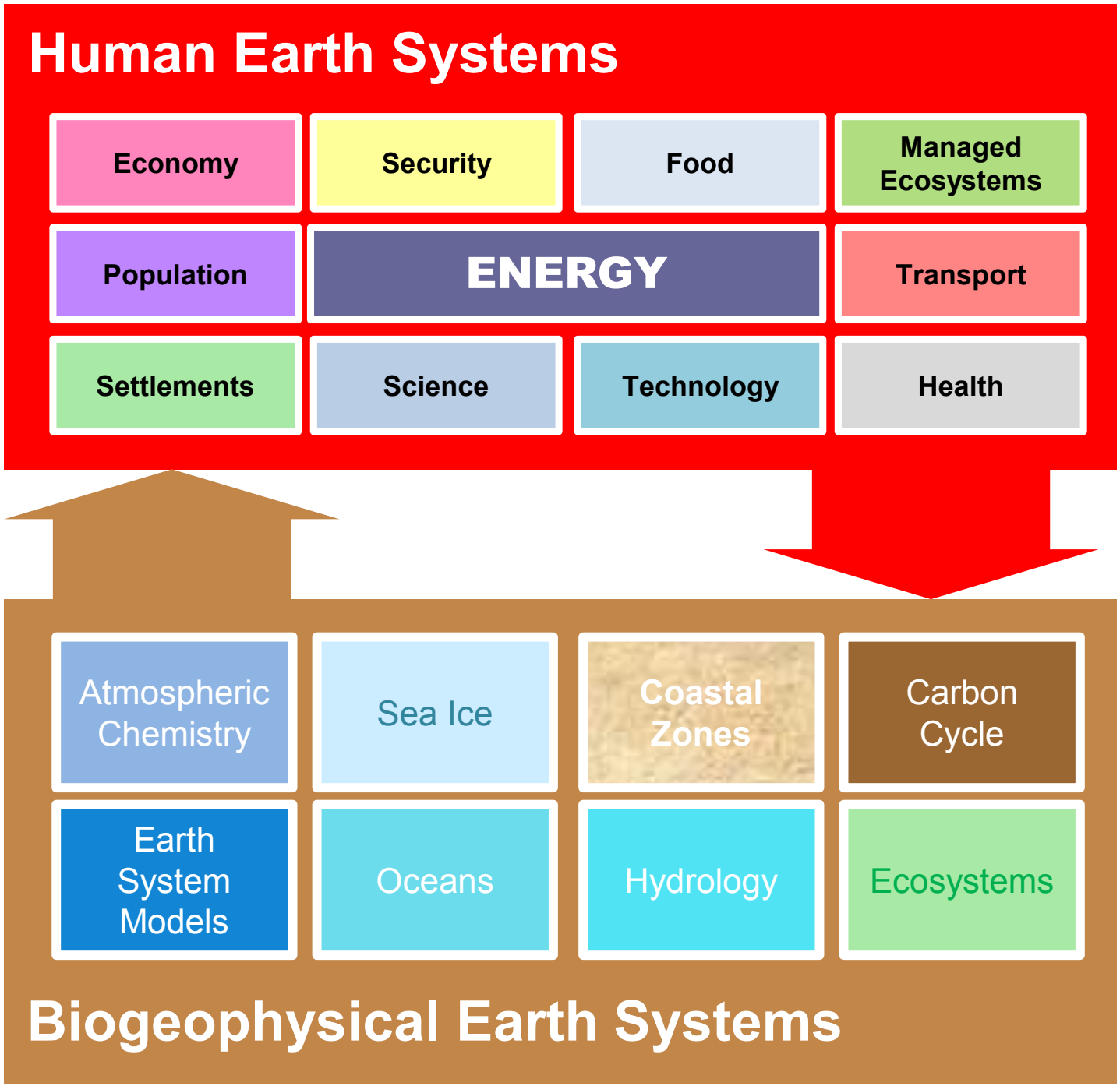
IAMs integrate human and Earth system science.

- IAMs provide insights that would be otherwise unavailable from disciplinary research.
- IAMs capture interactions between complex and highly nonlinear systems.
- IAMs provide Earth system science researchers with information about human systems such as GHG emissions, land use and land cover.

IAMs provide important, science-based decision support tools.

- IAMs support national, international, regional, and private-sector decisions.




Human Earth Systems
Economy
Security
Food
Managed Ecosystems
Population
ENERGY
Transport
Settlements
Science
Technology
Health
Atmospheric Chemistry
Sea Ice
Coastal Zones
Carbon Cycle
Earth System Models
Oceans
Hydrology
Ecosystems
Biogeophysical Earth Systems

GCAM:
The Global Change Assessment Model

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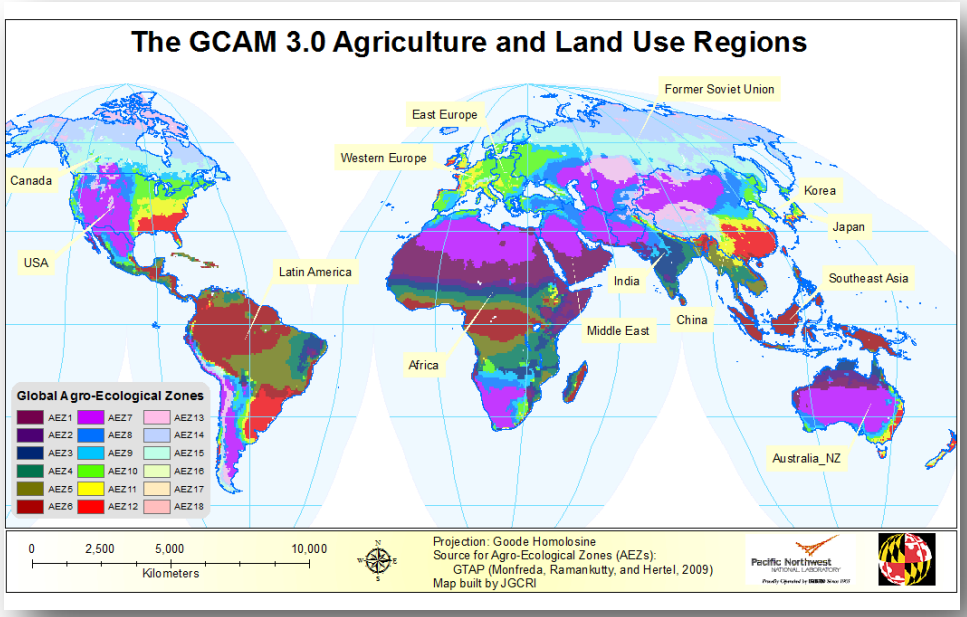
14 Region Energy/Economy Model Regions

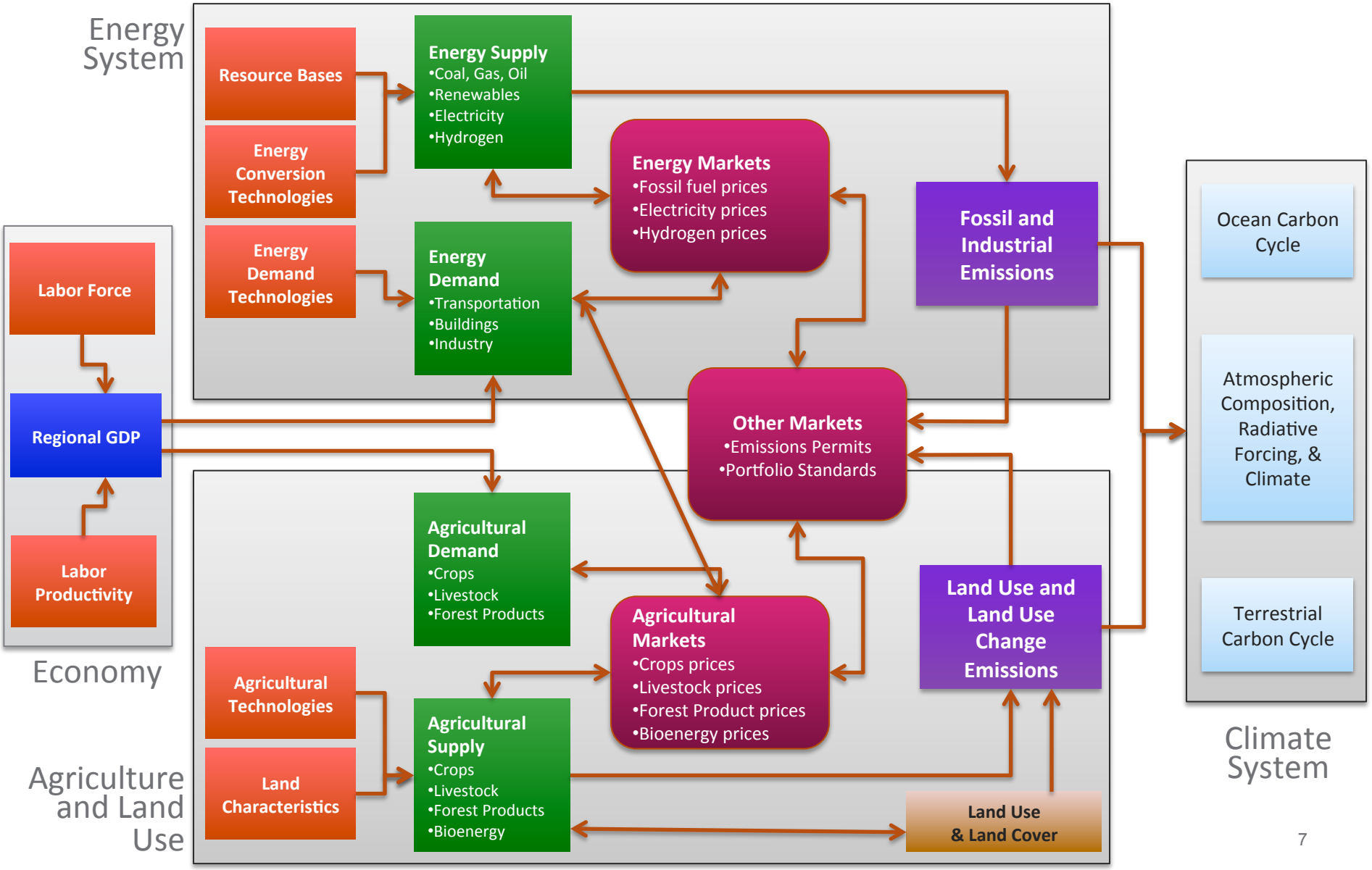
151 Agriculture and Land Use Model Regions



- GCAM is a **global integrated assessment model**
- GCAM links **Economic, Energy, Land-use,** and **Climate** systems
- Emissions of **16 greenhouse gases and short-lived species:** CO_2, CH_4, N_2O, halocarbons, carbonaceous aerosols, reactive gases, sulfur dioxide.
- Runs through **2095** in **5-year time-steps.**
- GCAM is implemented using **object-oriented programming**, providing a robust and flexible platform for future work.
- Documentation available at: **wiki.umd.edu/gcam**

- Started in 1978 – a DOE-SC investment to address the need for an explicit research tool to assess the link between human energy systems and carbon emissions (part of the Carbon Cycle Program back then).
- 1984 first integration of GCAM (then called Edmonds-Reilly) with the DOE carbon cycle model.
- Formerly known as MiniCAM

Overview of Human Systems in GCAM



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Uncertainty Research with GCAM

Uncertainty Analysis of the IEA/ORAU CO_2 Emissions Model (Reilly et al. 1987)

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Table 2. Assumed Correlations

Variables	Parameter	Correlation[a]	Explanation	Justification
Energy/GNP feedback elasticity OECD, non-OECD, Middle East	5,4 5,6	0.8 0.8	Regional E/GNP feedback elasticity	Similar transmission mechanisms, but magnitude of response is uncertain.
Income Elasticity: OECD, USSR, and LDC's	7,8 7,9	0.9 0.7	Regional income elasticities	Similar transmission mechanism. Middle East may be less similar due to dominance of oil production in the economy.
Labor Productivity: LDC's, DC's	31,32	0.9	Regional productivity	Engine of growth hypothesis, growth linked via capital, knowledge flows.
Exogenuous energy efficiency, labor productivity in developed region	12,31	0.9	Labor and energy productivity	Increase in basic knowledge is the driving force and affects all factors equally.
Labor productivity in developed regions, with: technological change in coal supply, technological change in shale oil supply, and technological change in nuclear power	31,60 31,68 31,74	0.6 0.6 0.6	Labor productivity and technological change in energy production	Increase in basic knowledge is the drivign force and affects labor productivity and energy production technologies similarly.
Labor productivity, with environmental cost of shale oil production and environmental cost of nuclear	31,69 31,73	0.9 0.9	Labor productivity and environmental costs	Higher income capita implies higher demands for clean environment.

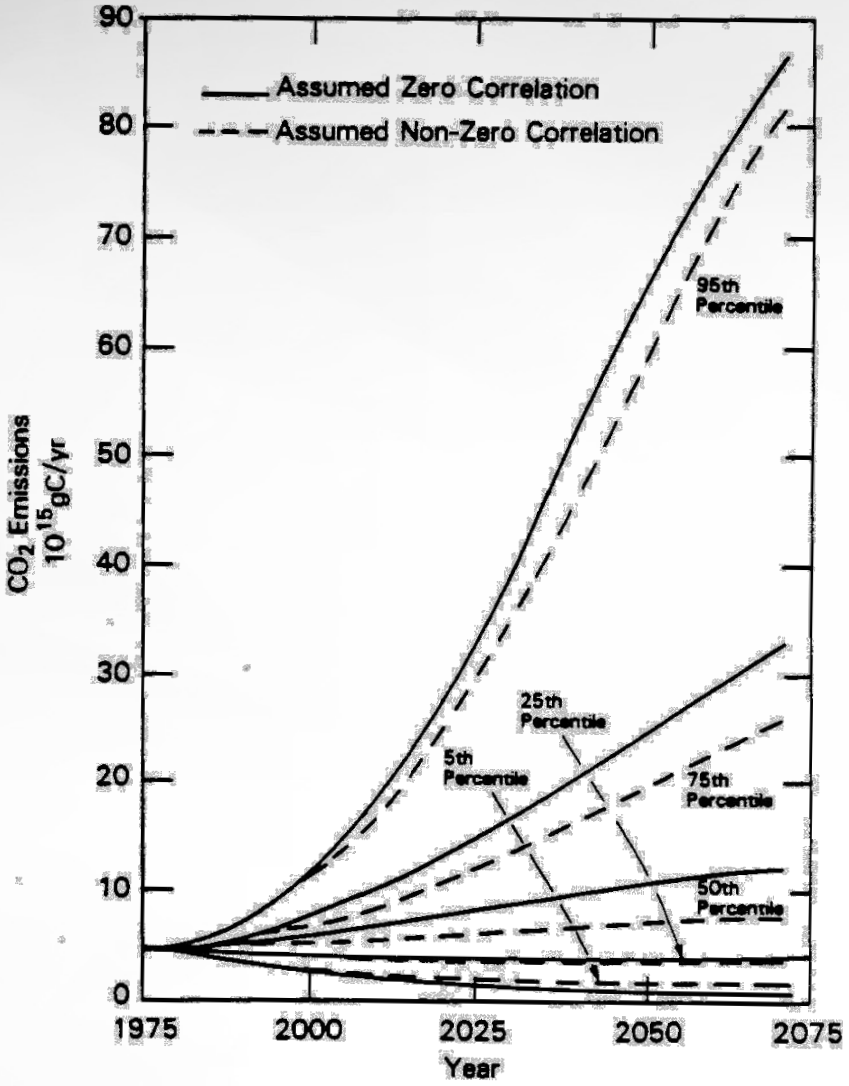

Figure 1. Plot of carbon emission percentiles based on 400 runs.

Uncertainty in integrated assessment models: modeling with MiniCAM 1.0 (Scott et al. 1999)

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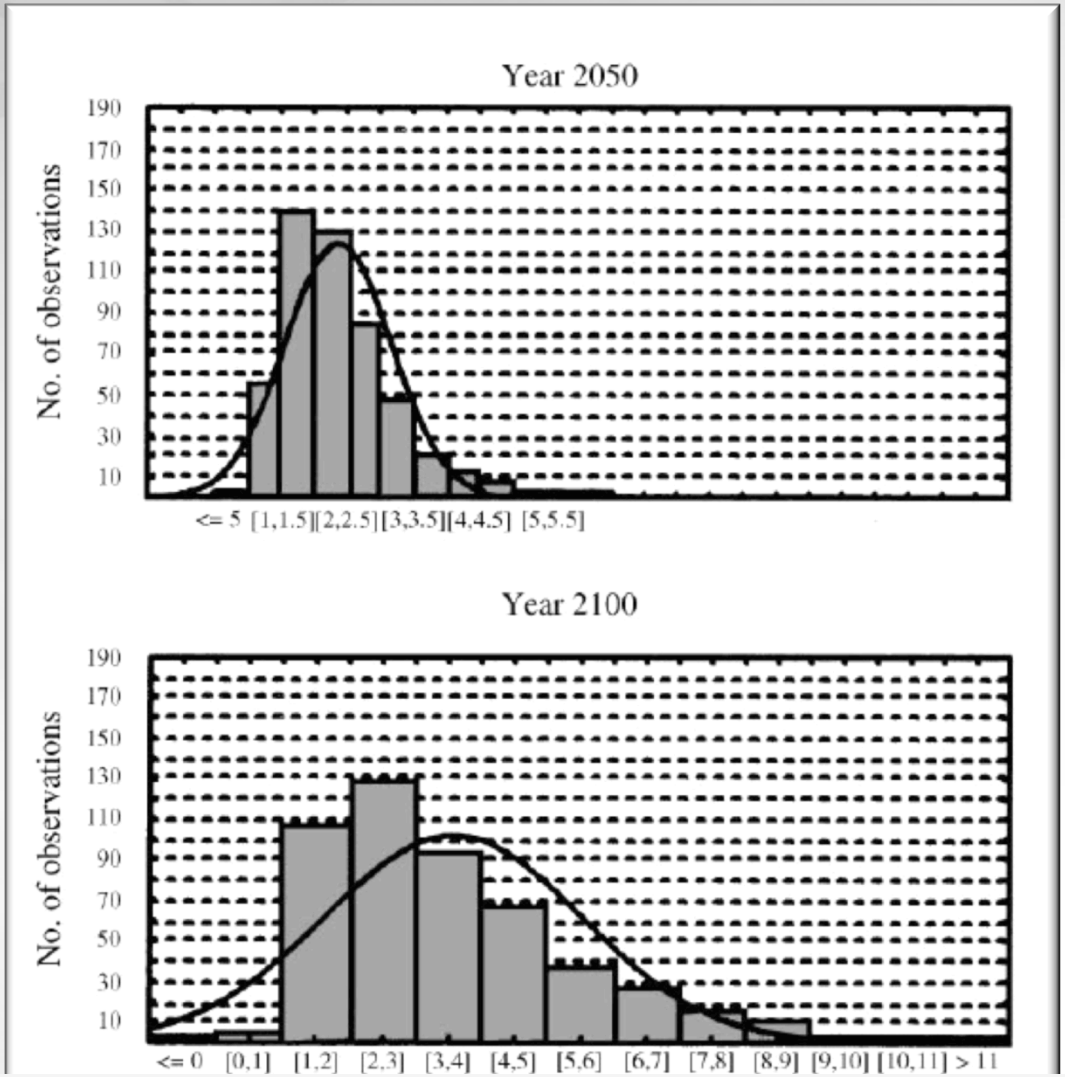
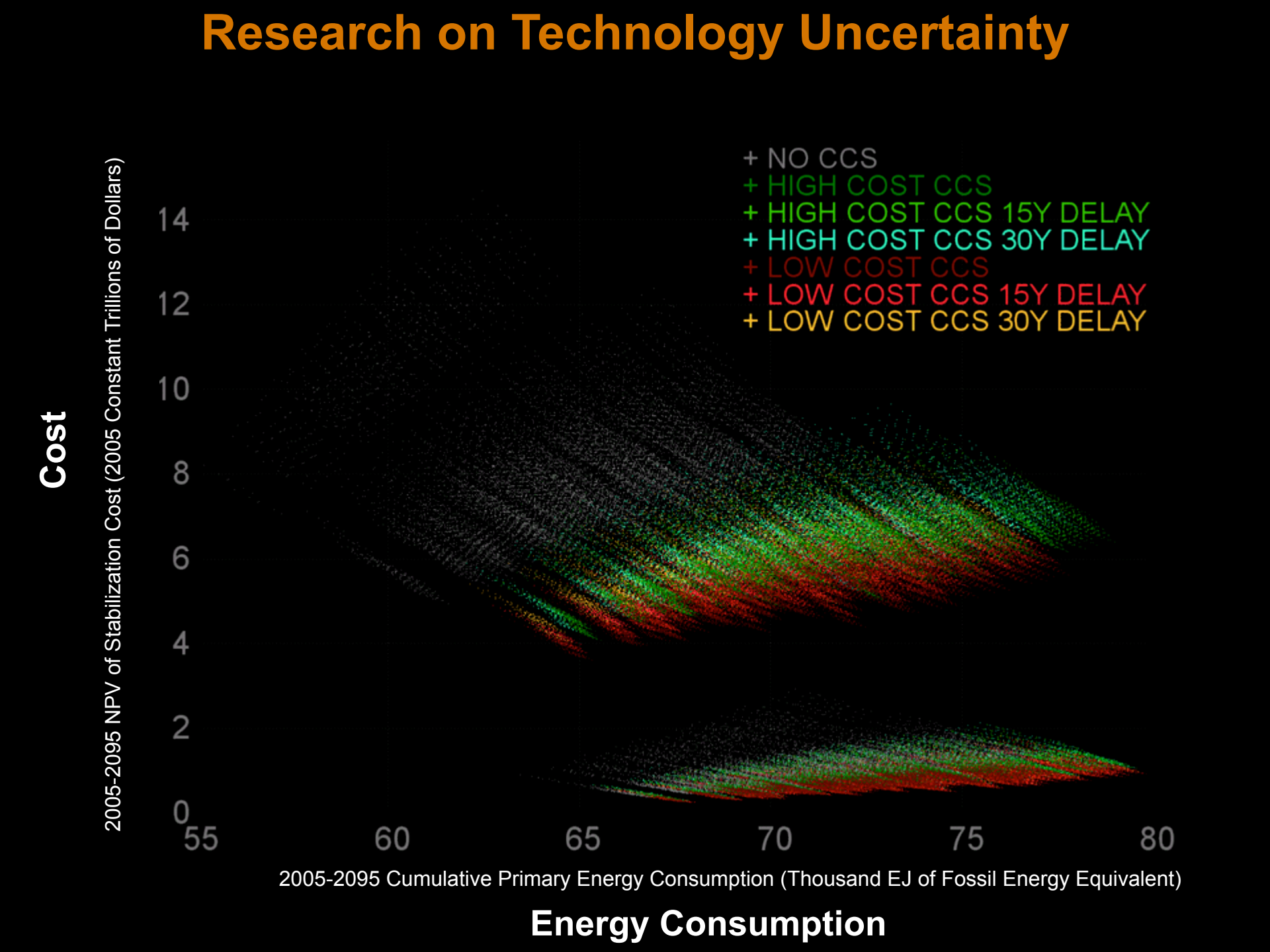
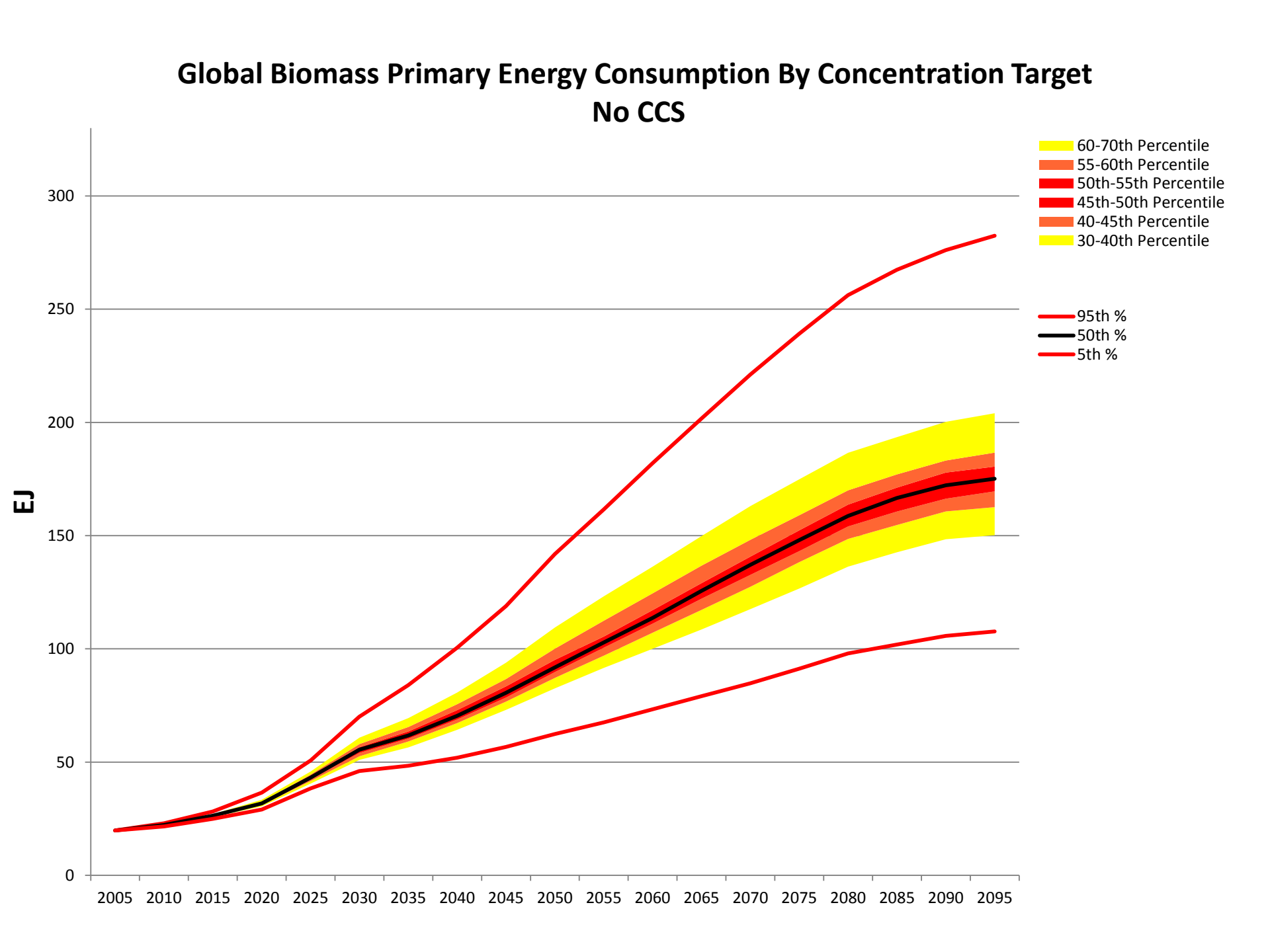
Global Mean Surface Temperature

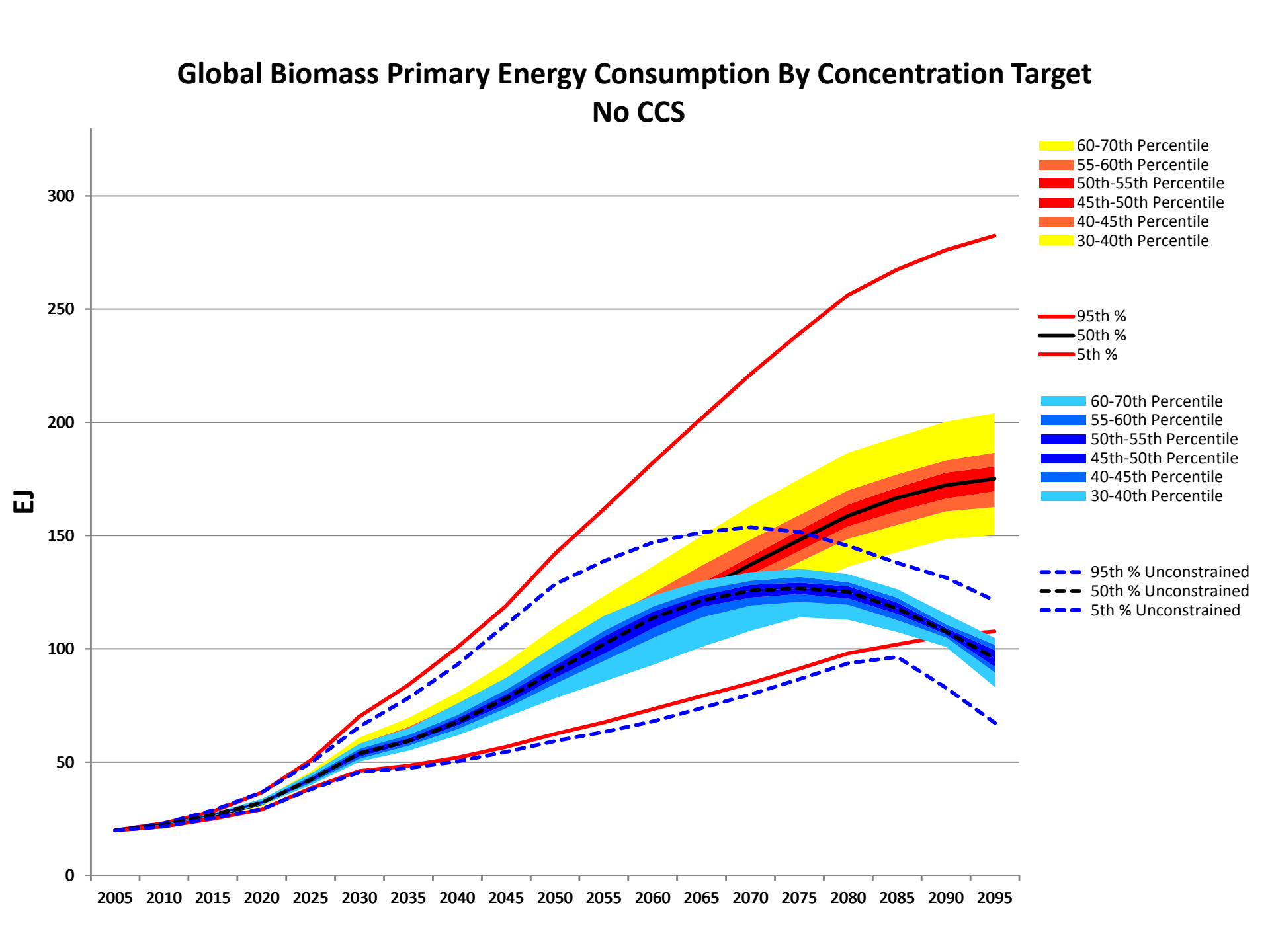


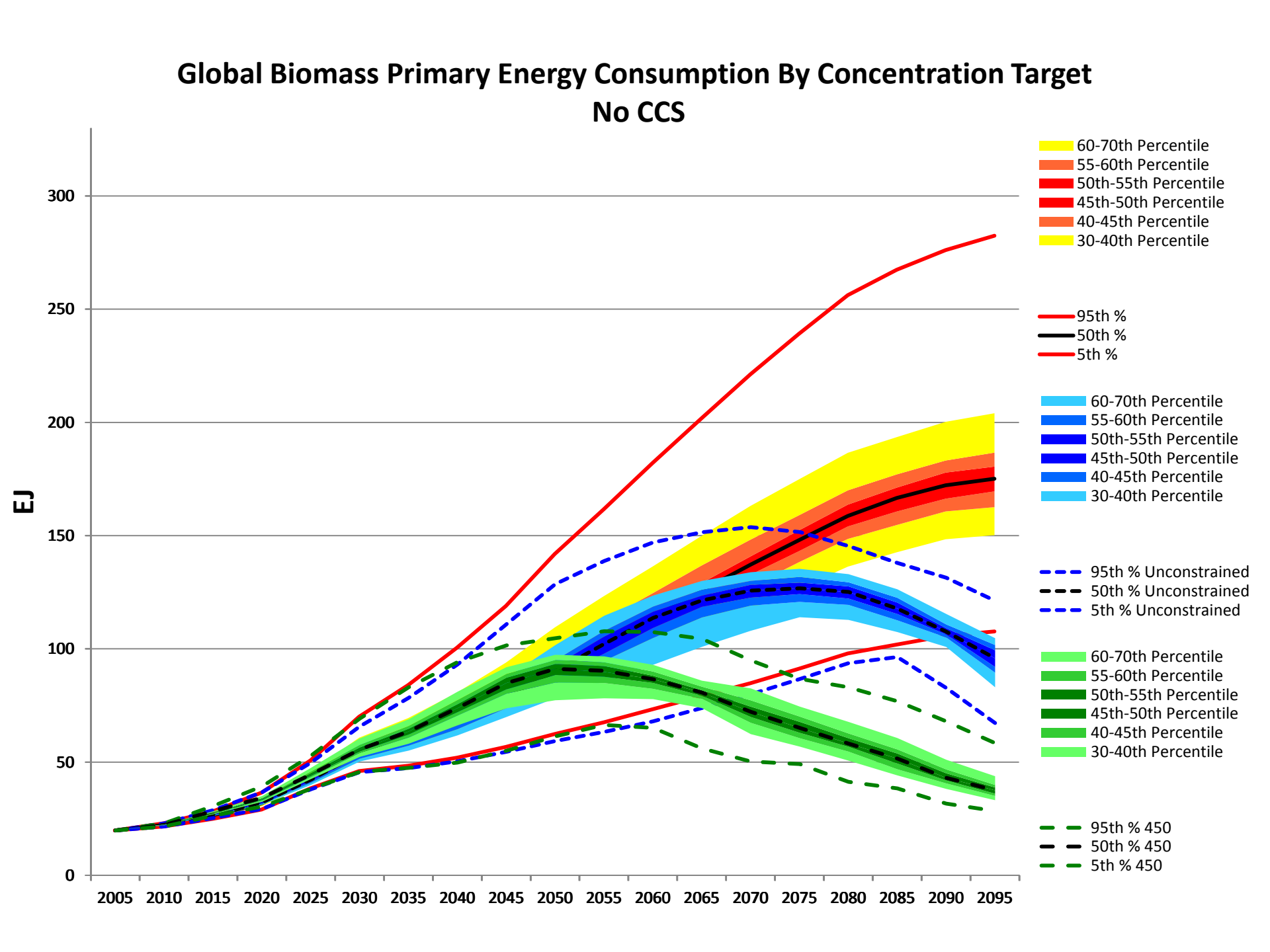
Scott M, R. Sands R, J. Edmonds, A. Liebetrau, D. Engel (1999). Uncertainty in integrated assessment models: modeling with MiniCAM 1.0. Energy Policy 27(14):597

Research on Technology Uncertainty




Global Biomass Primary Energy Consumption By Concentration Target
No CCS
EJ
300
250
200
150
100
50
0
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
60-70th Percentile
55-60th Percentile
50th-55th Percentile
45th-50th Percentile
40-45th Percentile
30-40th Percentile
95th %
50th %
5th %


Global Biomass Primary Energy Consumption By Concentration Target
No CCS
EJ
0
50
100
150
200
250
300
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
60-70th Percentile
55-60th Percentile
50th-55th Percentile
45th-50th Percentile
40-45th Percentile
30-40th Percentile
95th %
50th %
5th %
60-70th Percentile
55-60th Percentile
50th-55th Percentile
45th-50th Percentile
40-45th Percentile
30-40th Percentile
95th % Unconstrained
50th % Unconstrained
5th % Unconstrained


Global Biomass Primary Energy Consumption By Concentration Target
No CCS
EJ
0
50
100
150
200
250
300
2005
2010
2015
2020
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2050
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2065
2070
2075
2080
2085
2090
2095
60-70th Percentile
55-60th Percentile
50th-55th Percentile
45th-50th Percentile
40-45th Percentile
30-40th Percentile
95th %
50th %
5th %
60-70th Percentile
55-60th Percentile
50th-55th Percentile
45th-50th Percentile
40-45th Percentile
30-40th Percentile
95th % Unconstrained
50th % Unconstrained
5th % Unconstrained
60-70th Percentile
55-60th Percentile
50th-55th Percentile
45th-50th Percentile
40-45th Percentile
30-40th Percentile
95th % 450
50th % 450
5th % 450

Research on Regional Building Energy Use Uncertainty

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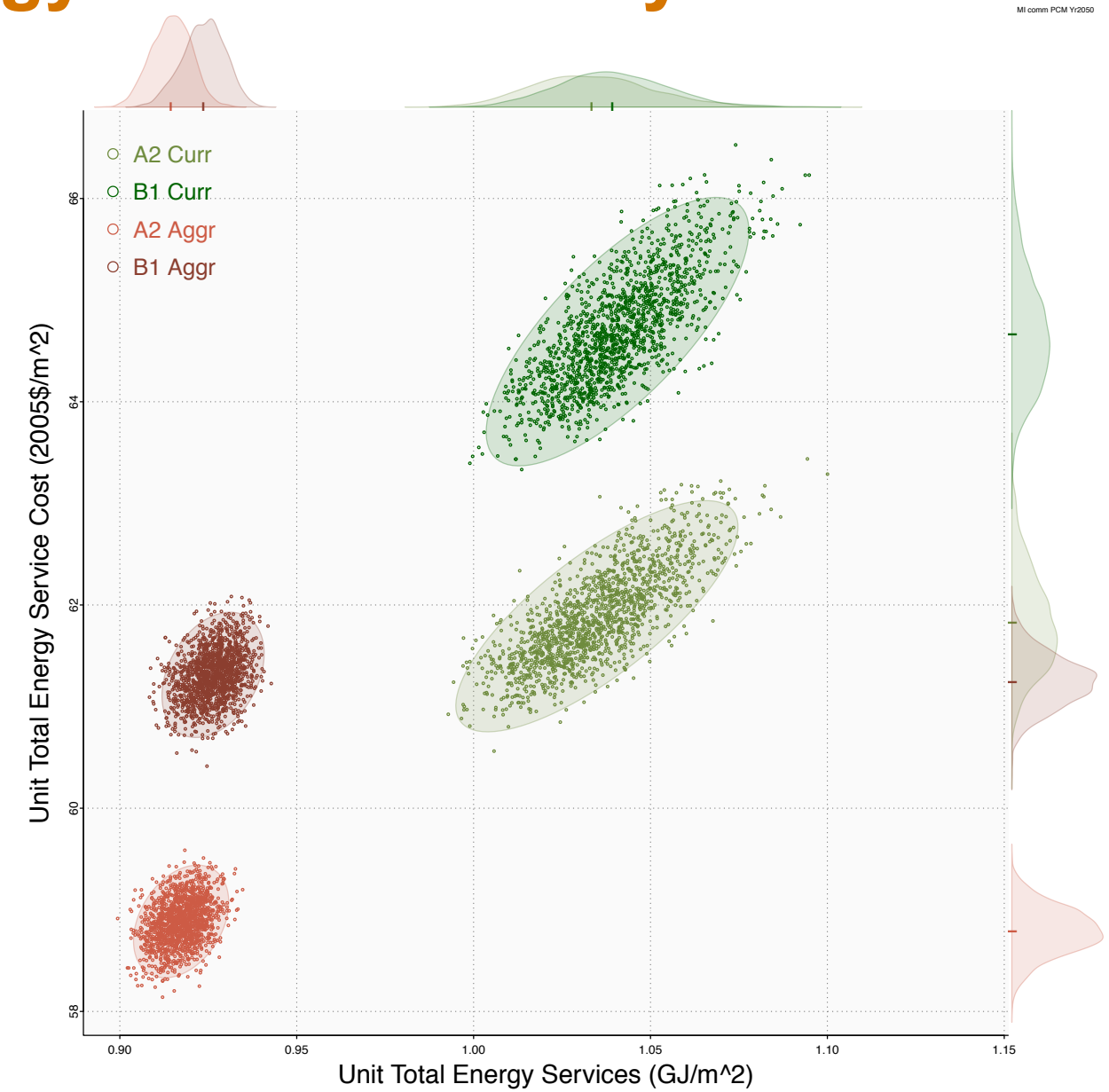
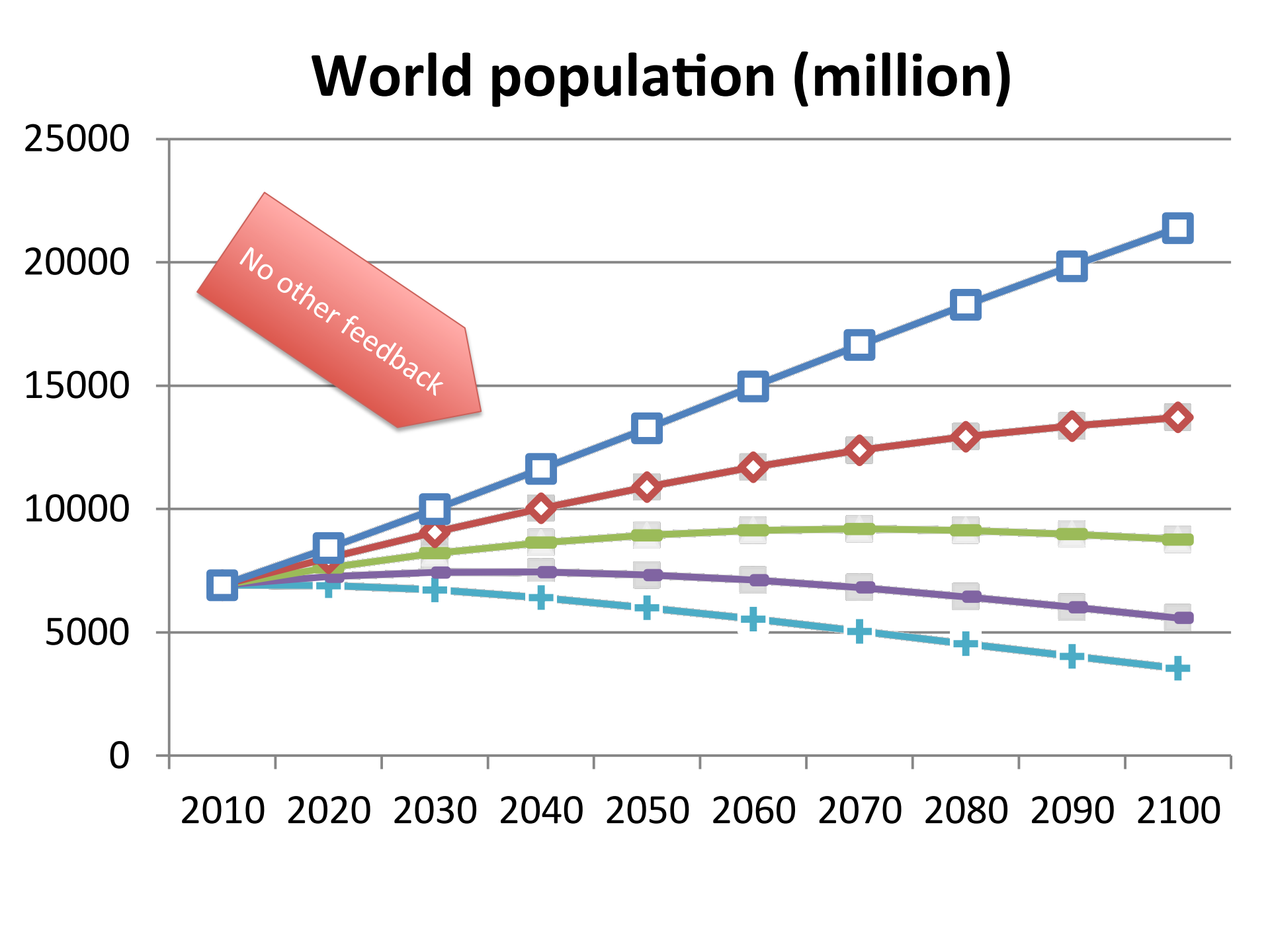


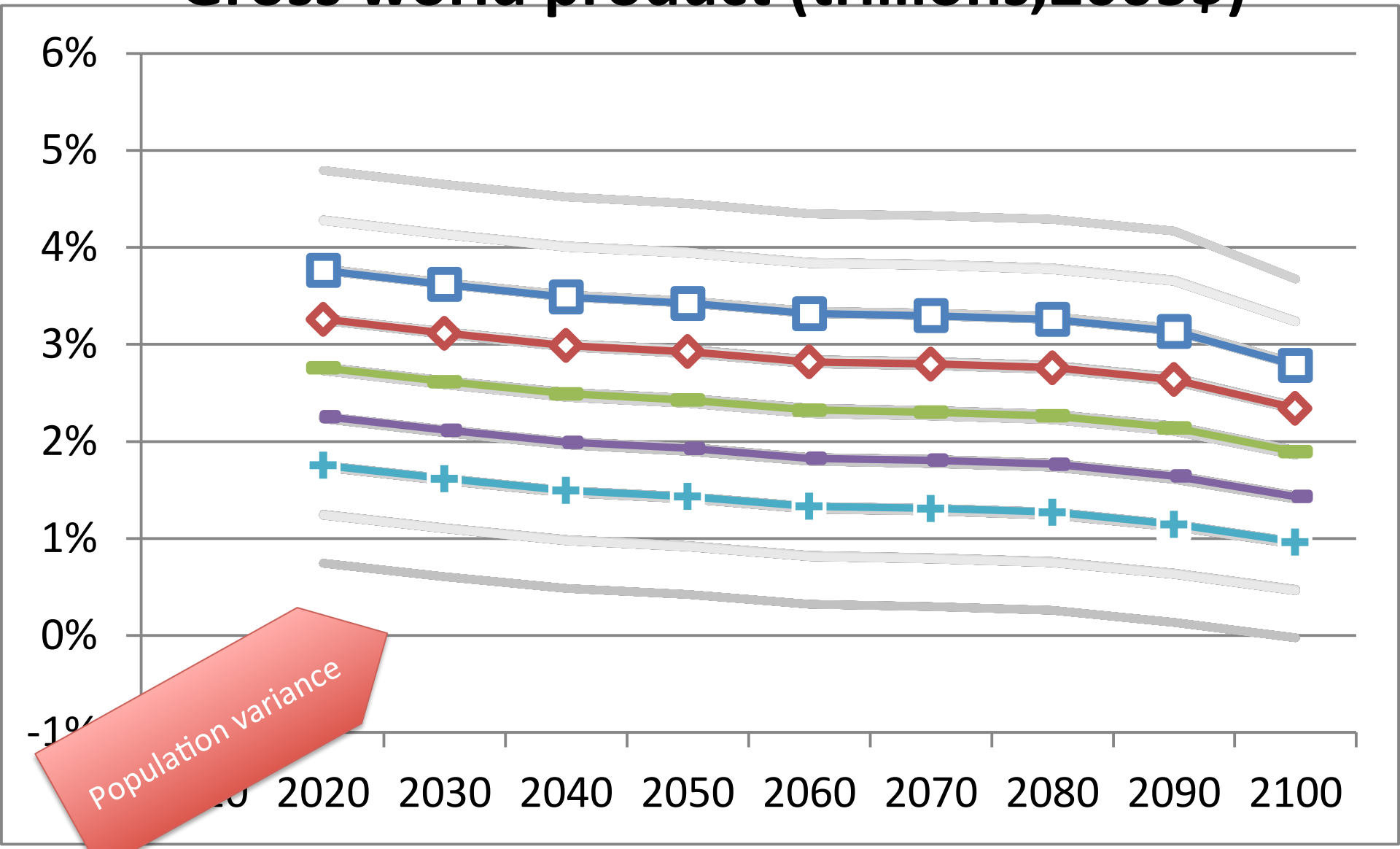
Model Results


World population (million)
25000
20000
15000
10000
5000
0
No other feedback
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

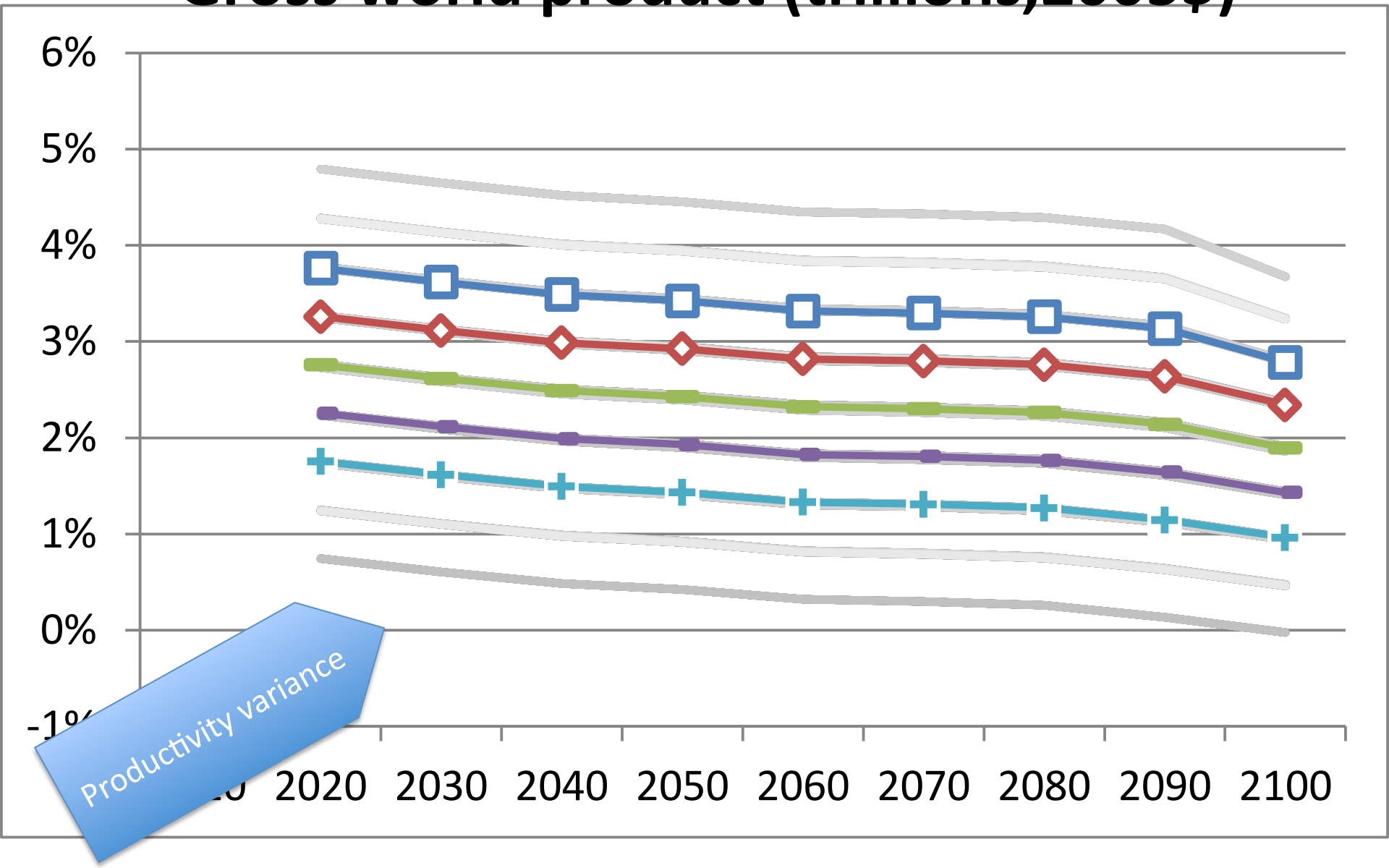
World population (million)

- How wide is the uncertainty range of the future population?
- Benefits and costs of heavy focus on the tails.
  - Broader coverage. Avoid unexpected surprise.
  - Loss of statistical power.
- Considering small number of samples, better to narrow the focus range?

Gross world product (trillions,2005$)



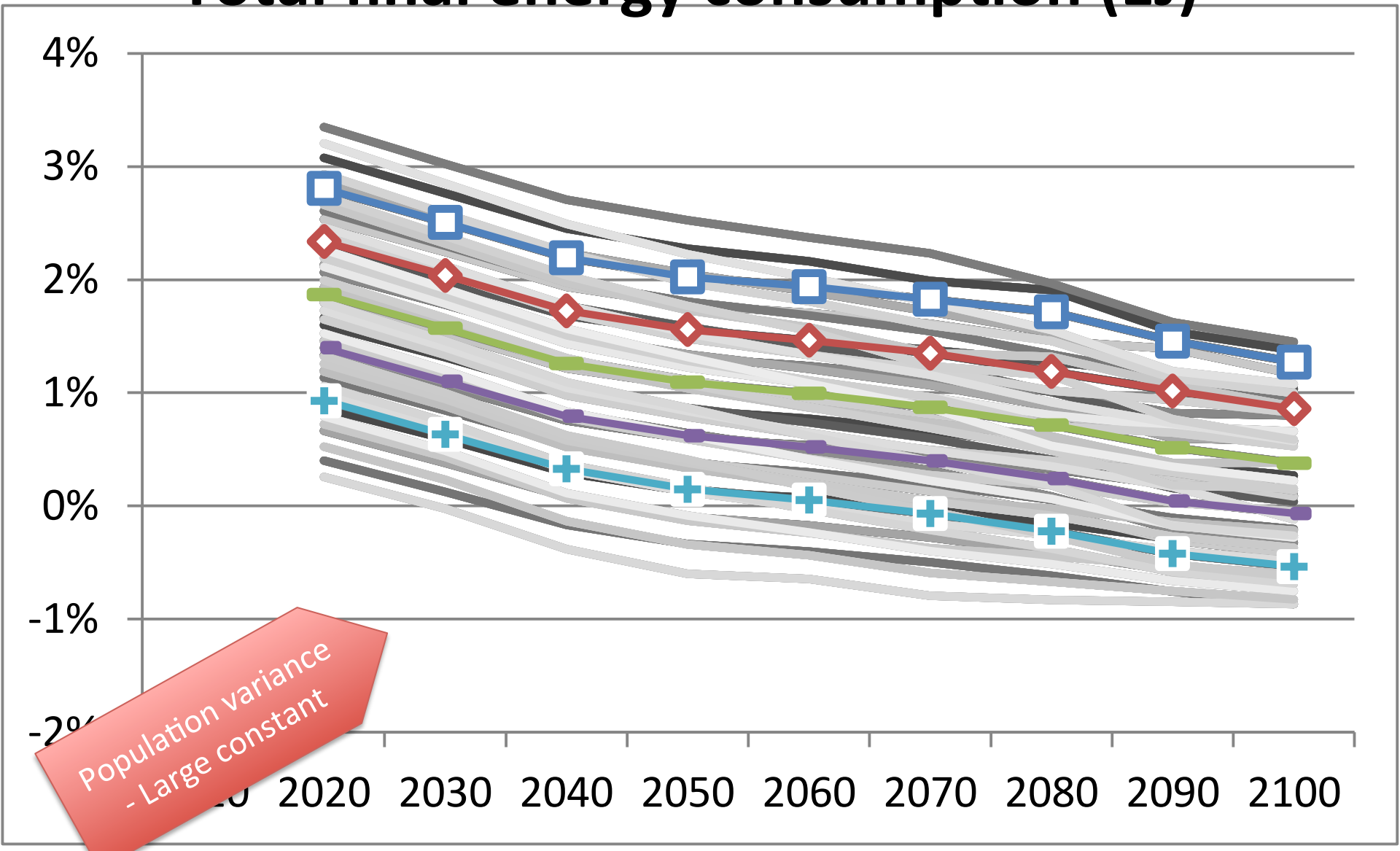
Gross world product (trillions,2005$)



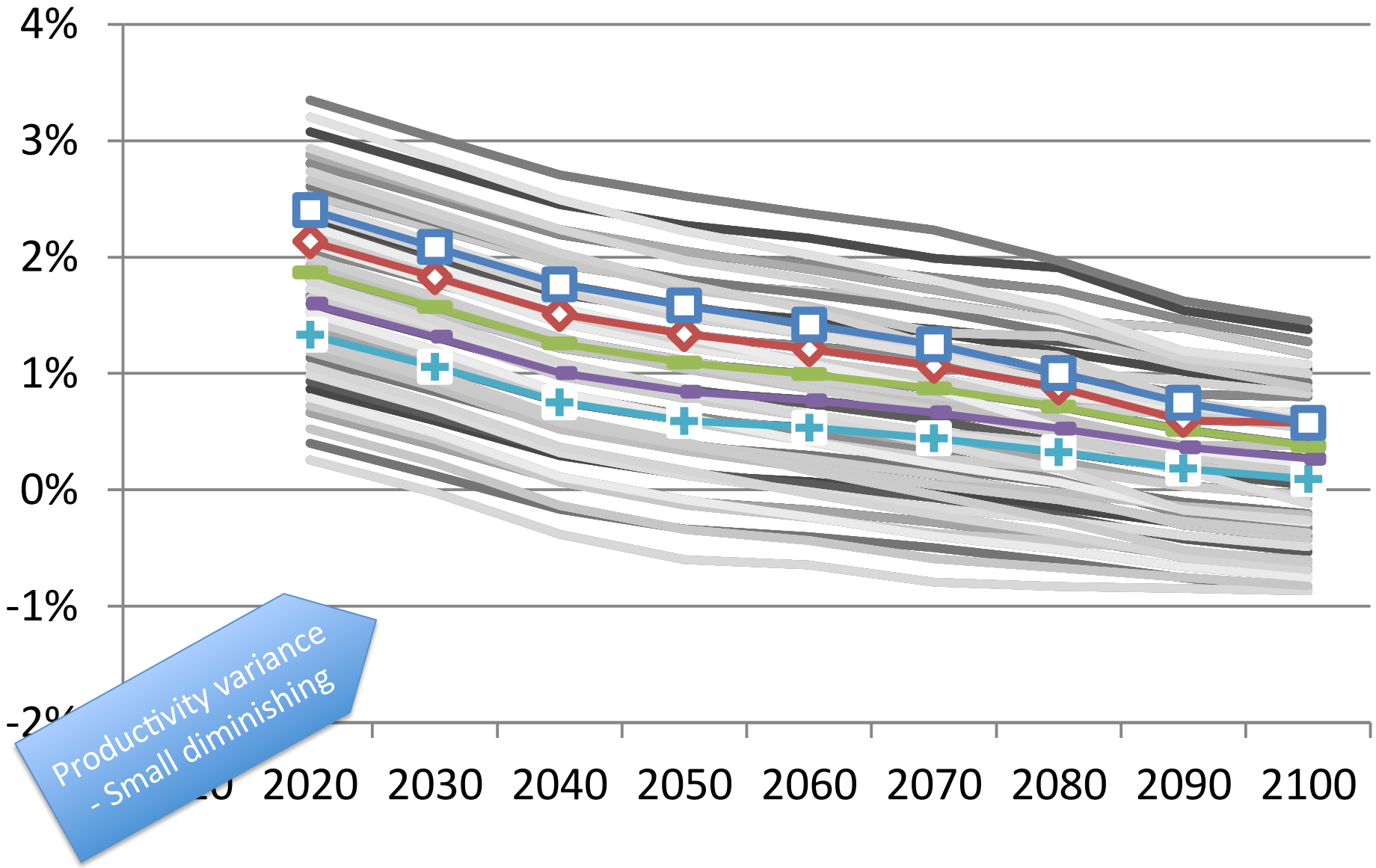
Gross world product

- Population variance and productivity variance are identical by design.
- Covariance between age structure and productivity will be a complicated issue.

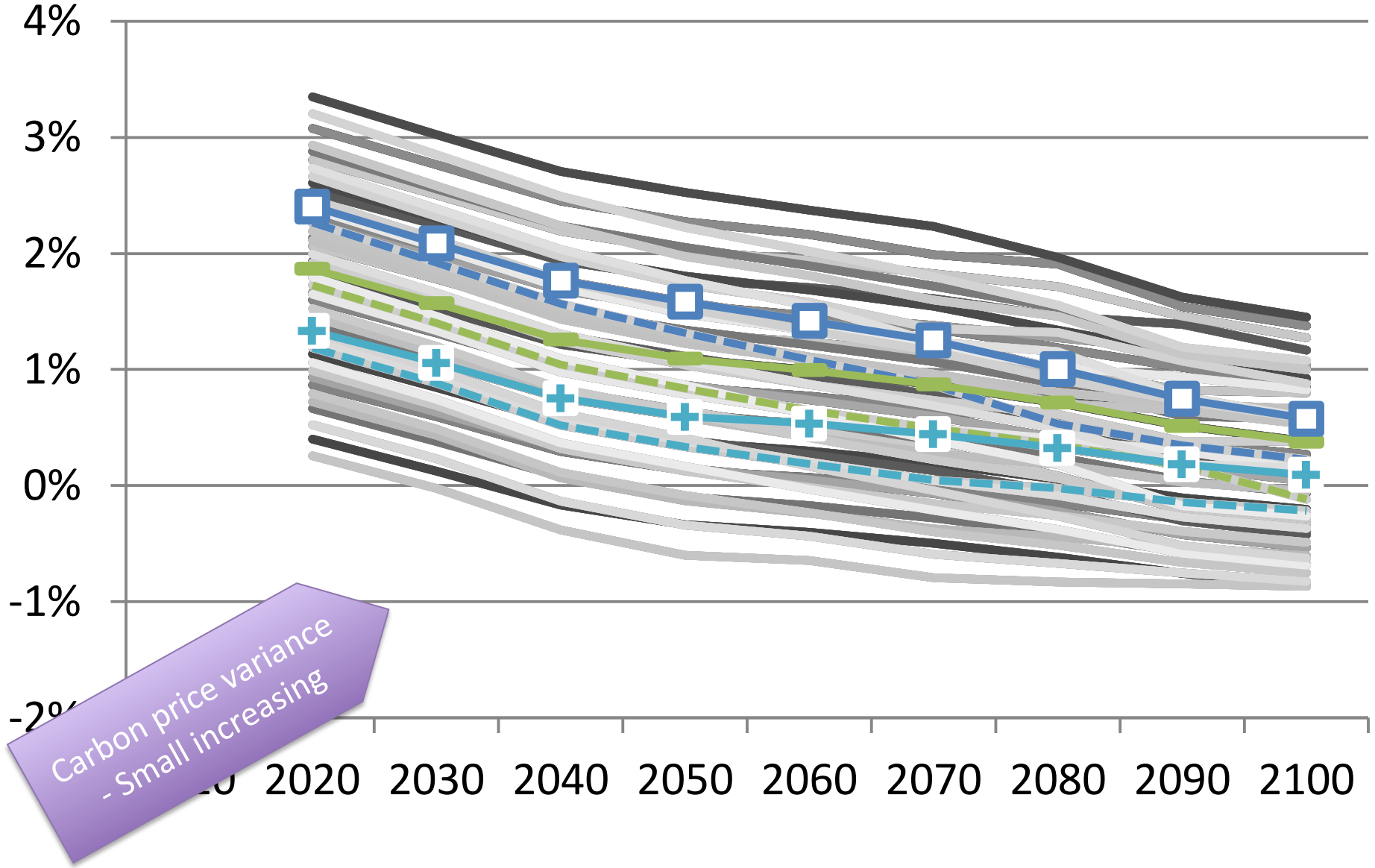
Total final energy consumption (EJ)



Total final energy consumption (EJ)



Total final energy consumption (EJ)

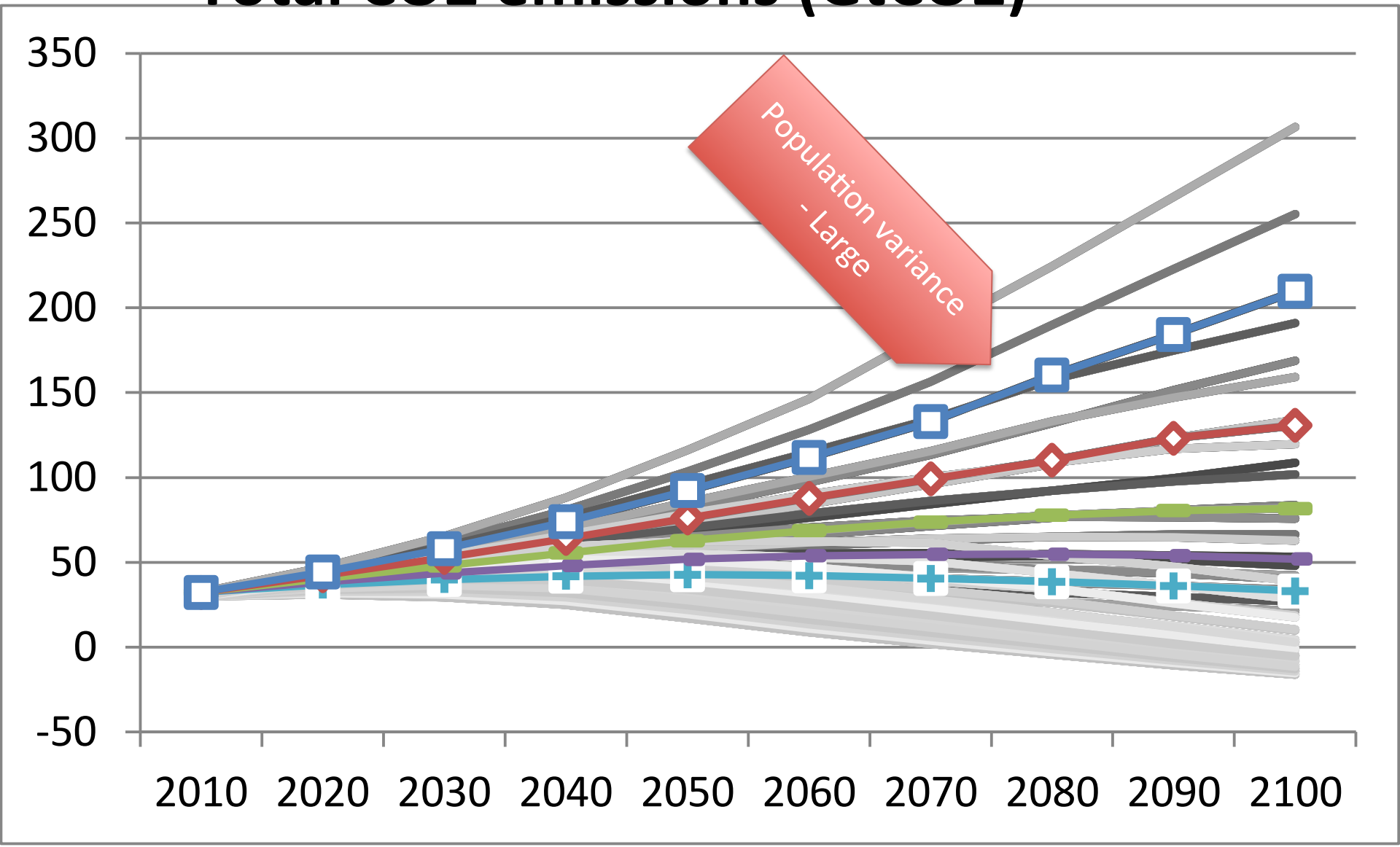


Total final energy consumption

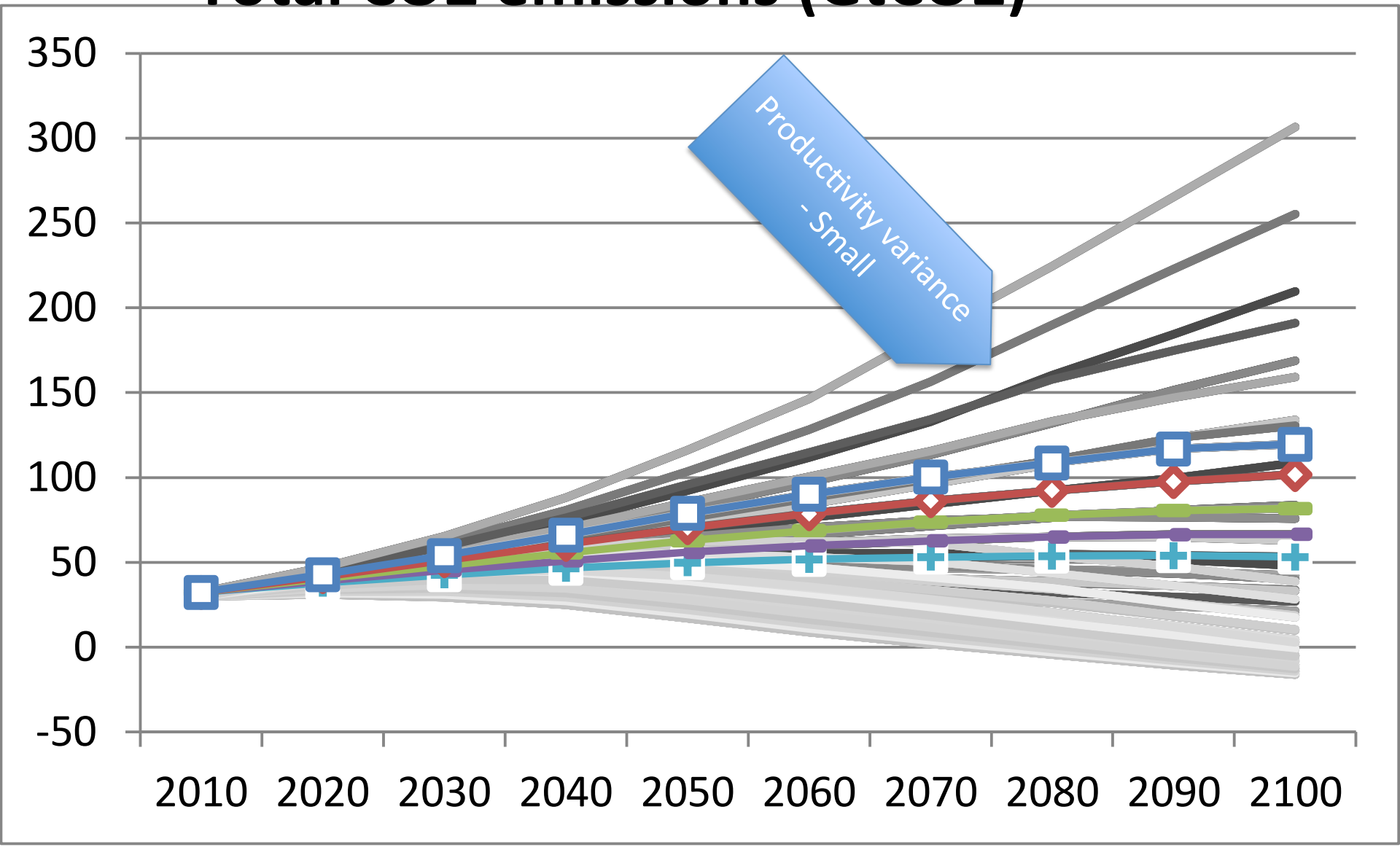
- Population variance has larger impact than productivity variance by model construction.
  - Subsistence level energy consumption.
  - Energy consumption satiation.

- Primary energy (fossil equivalent) may be a better measure for overall scale of energy system.

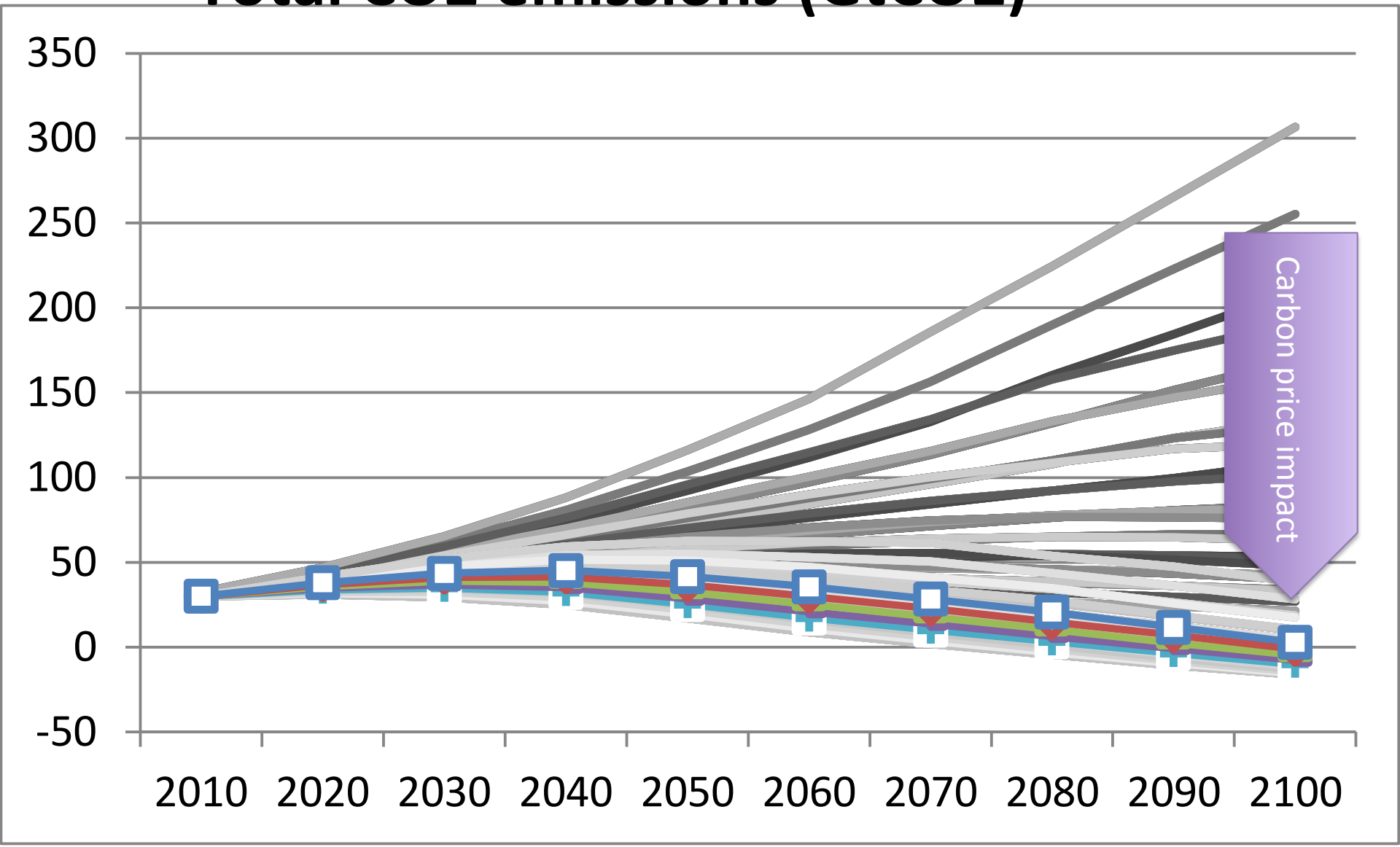
Total CO2 emissions (GtCO2)



Total CO2 emissions (GtCO2)



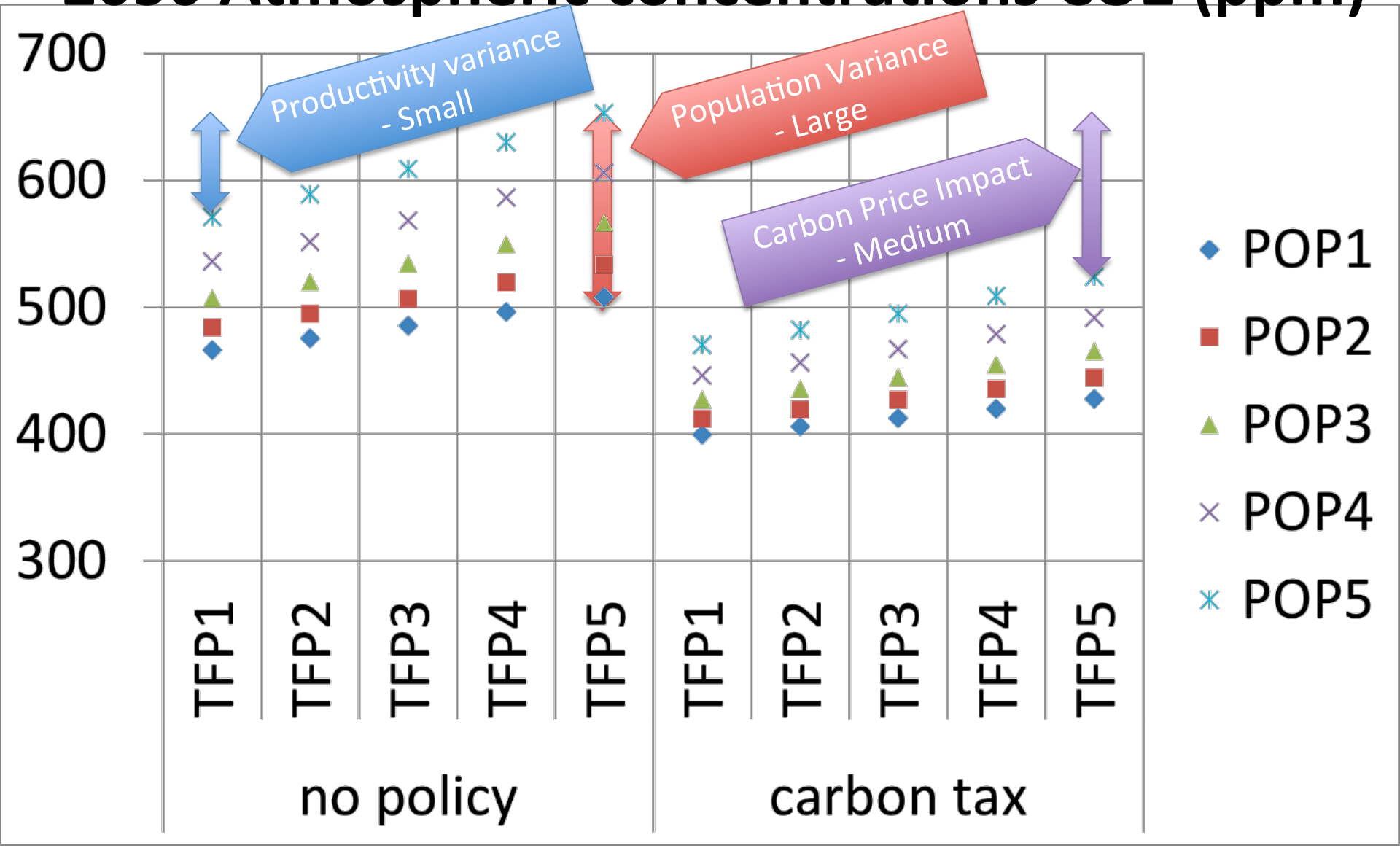
Total CO2 emissions (GtCO2)



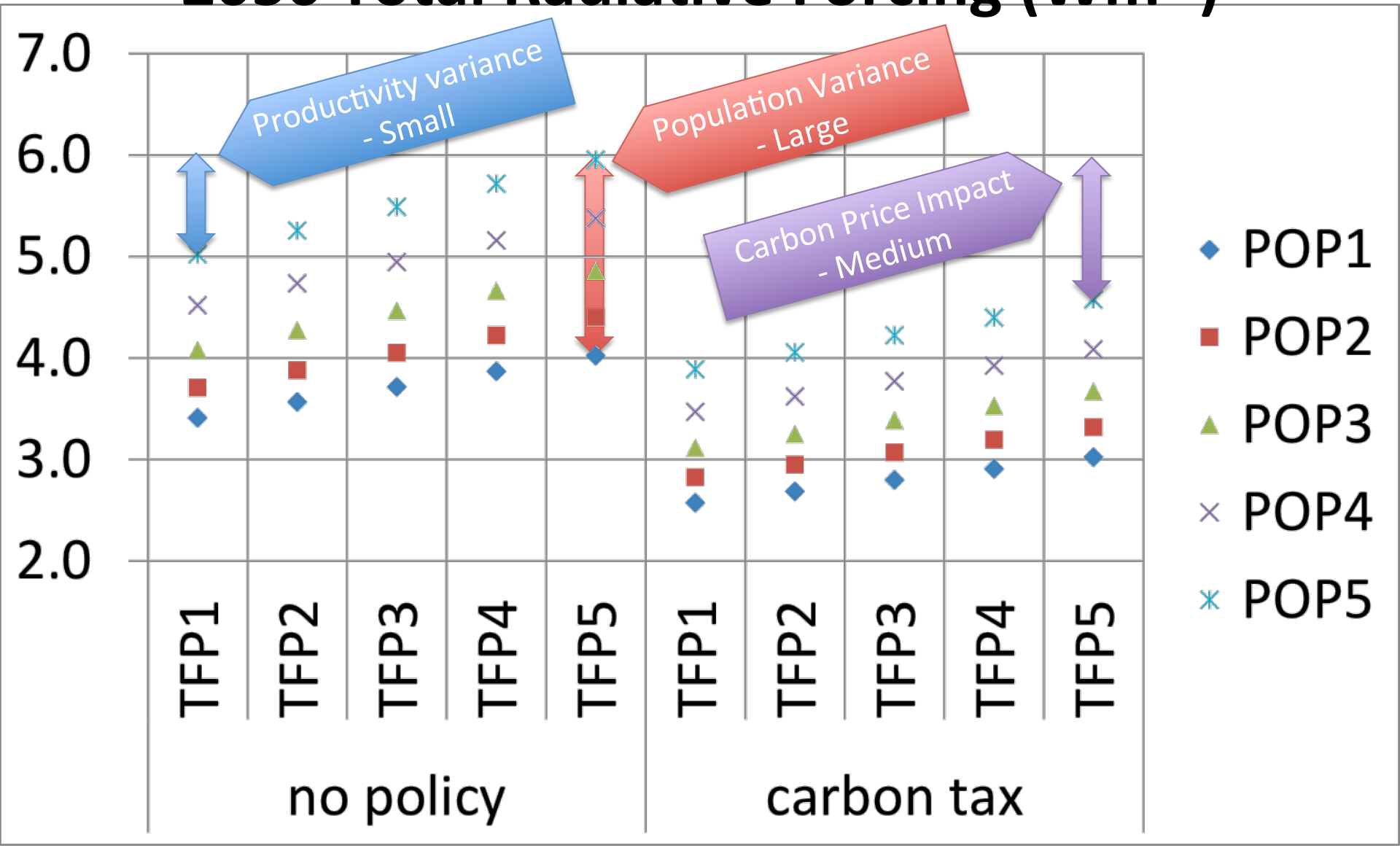
Total CO2 emissions (GtCO2)

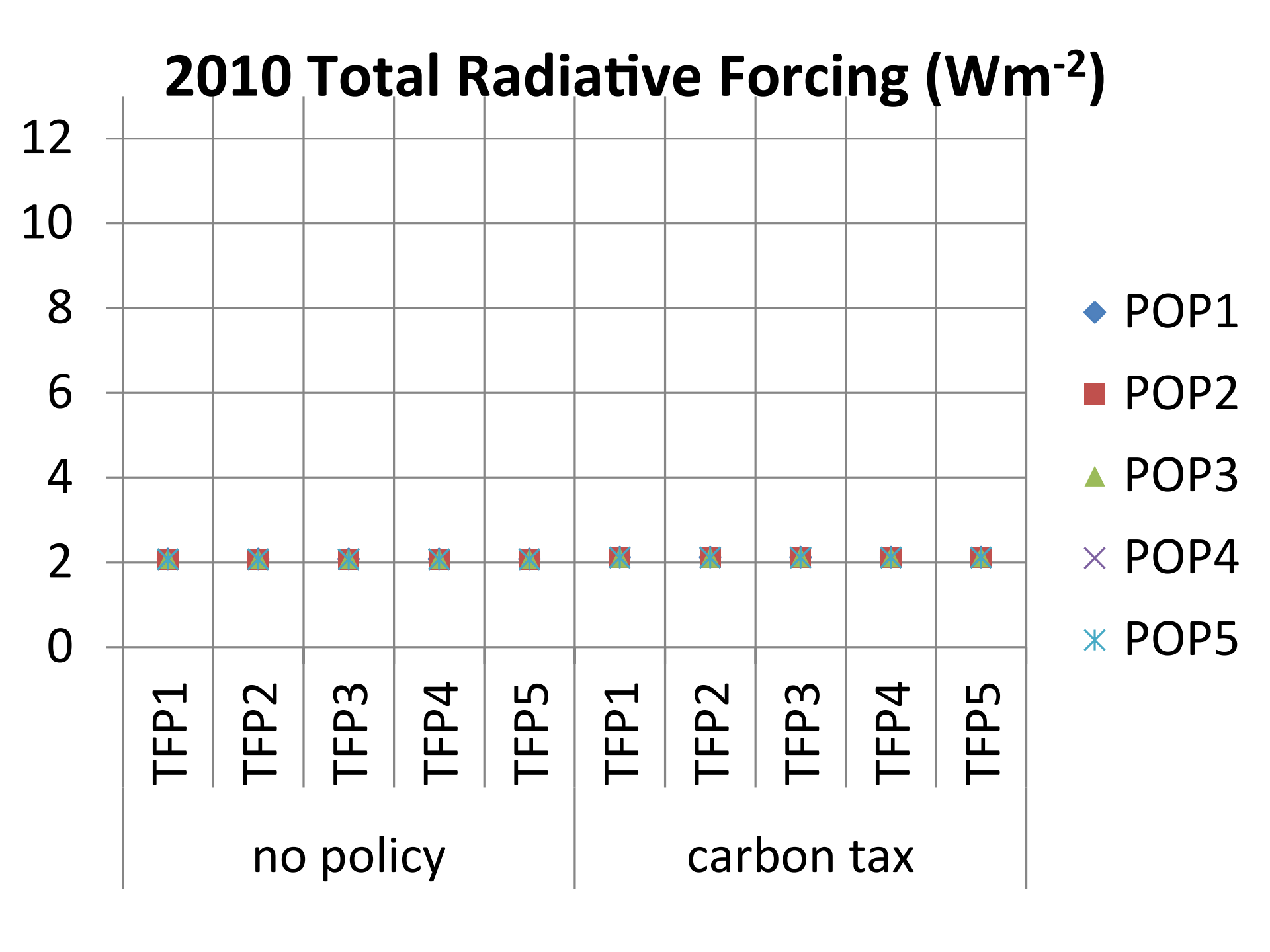
- Carbon Price has disproportionate impact by design.
- Recommend adding more carbon price paths for mapping out the mitigation space.
  - At least two price paths to get curvature.
  - More for assessing threshold effects.
- The dual problems of climate change mitigation:
  - How much can be mitigated at a given price? – current approach
  - How much does it cost to mitigate a given quantity? – RCP approach

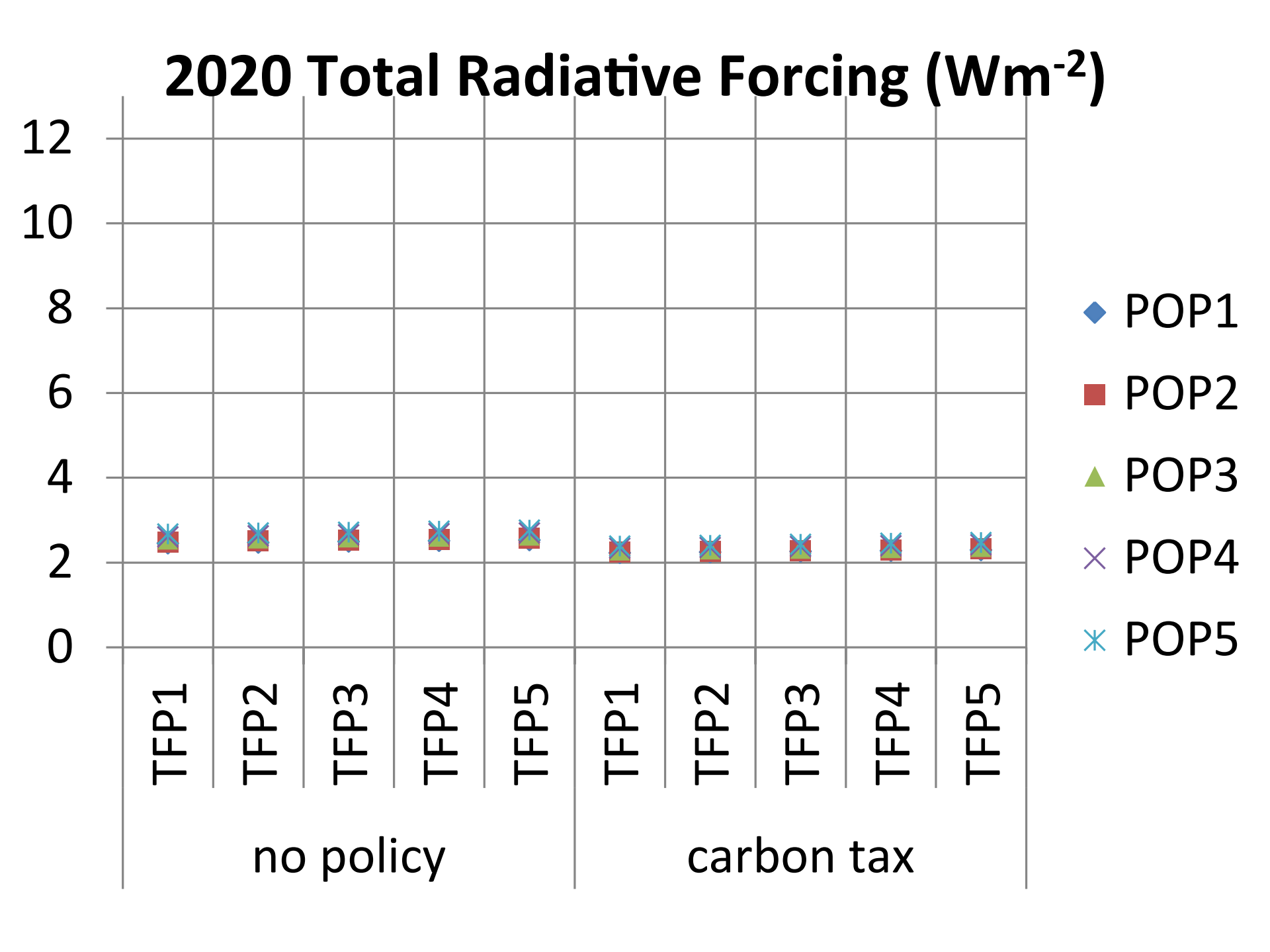
2050 Atmospheric concentrations CO2 (ppm)

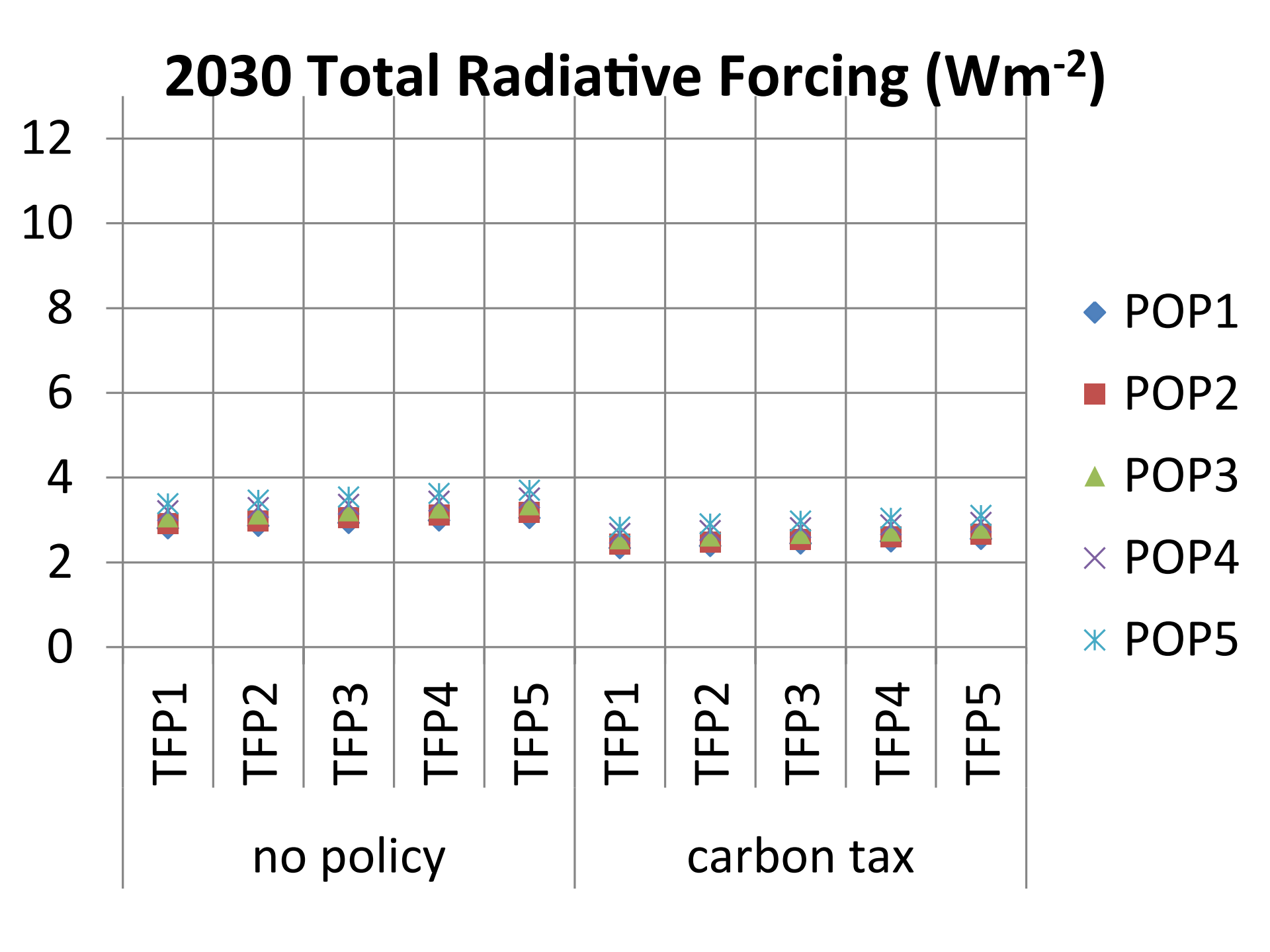


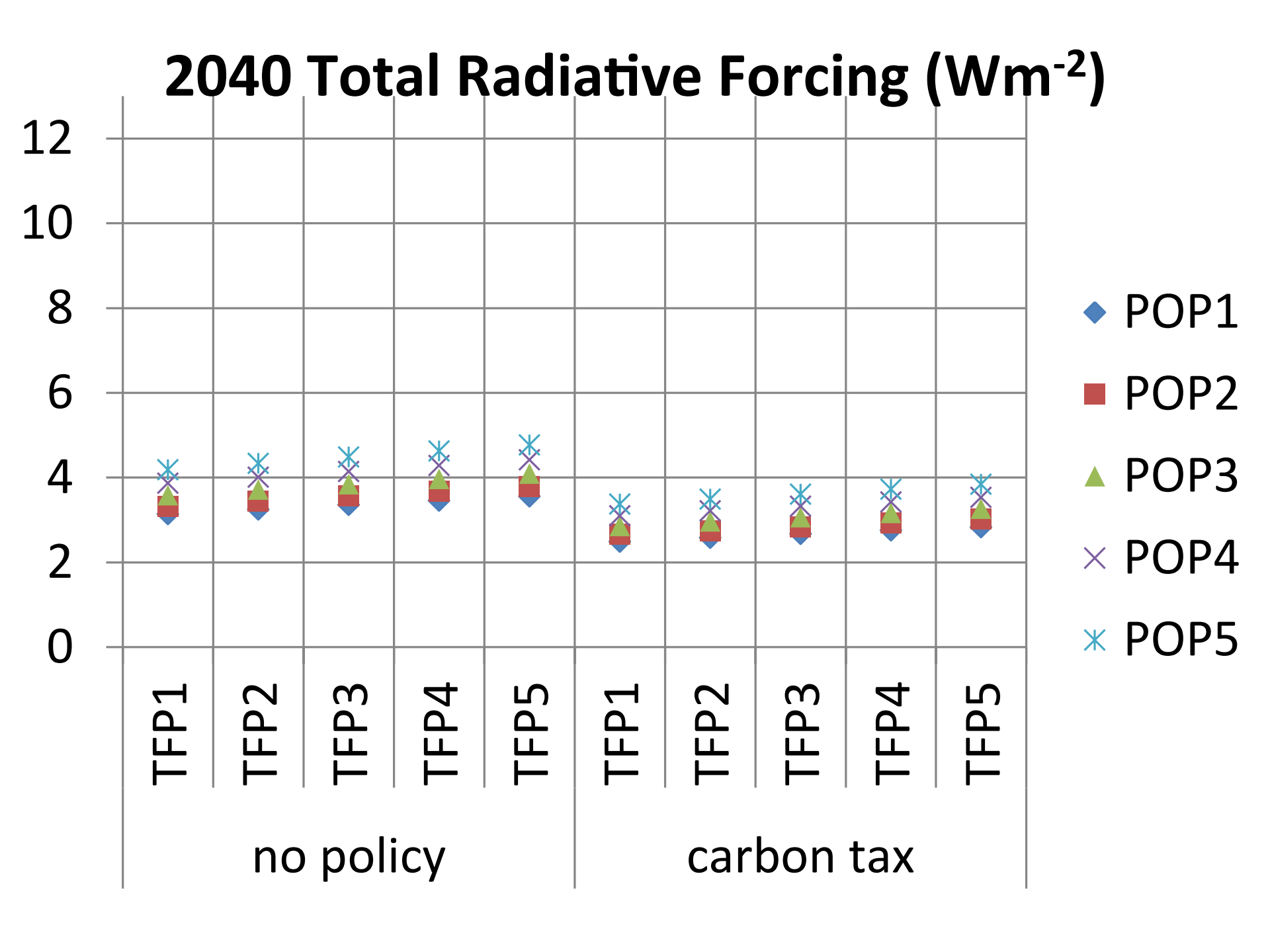
2050 Total Radiative Forcing (Wm^{-2})

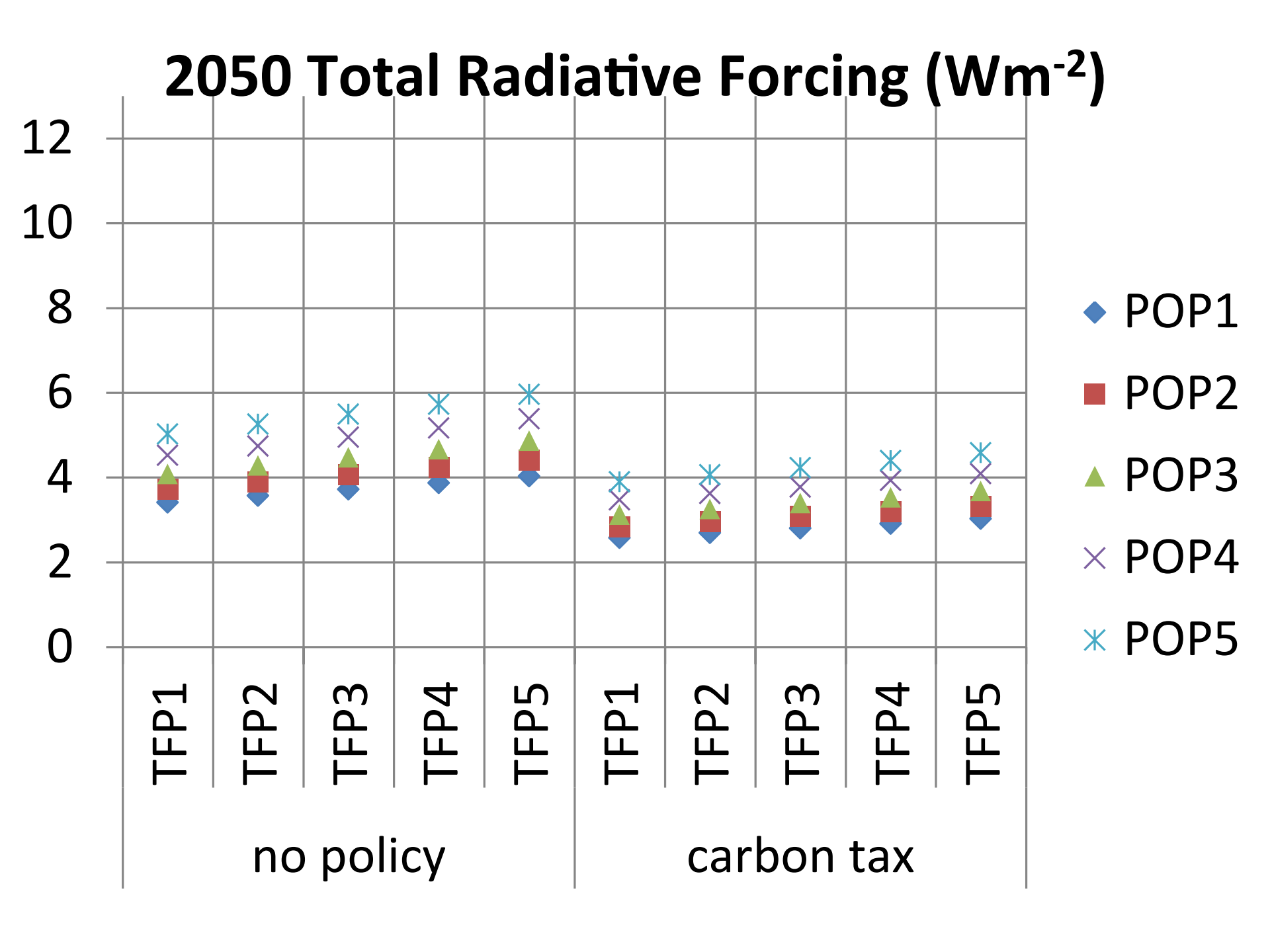


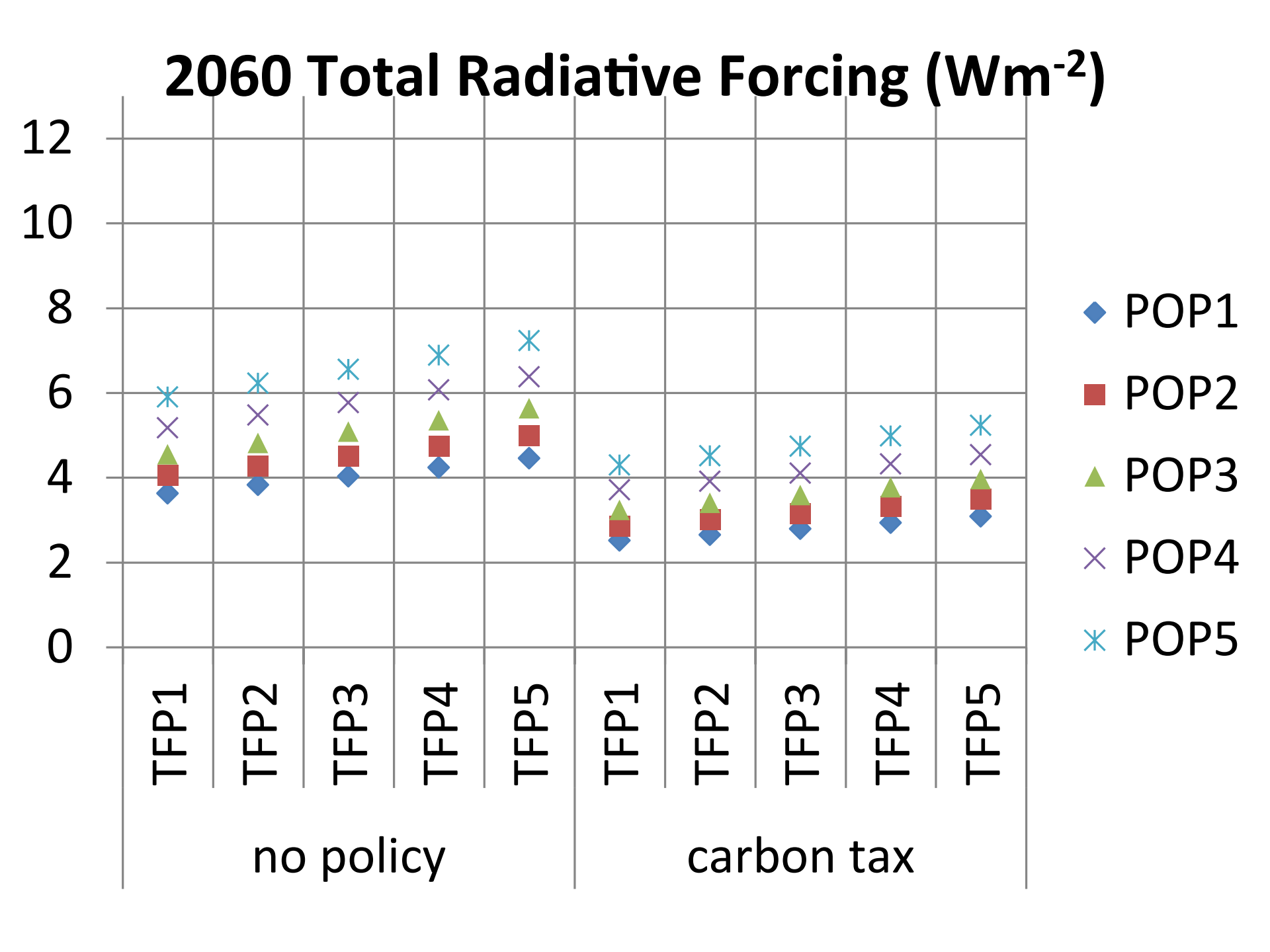

2010 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5

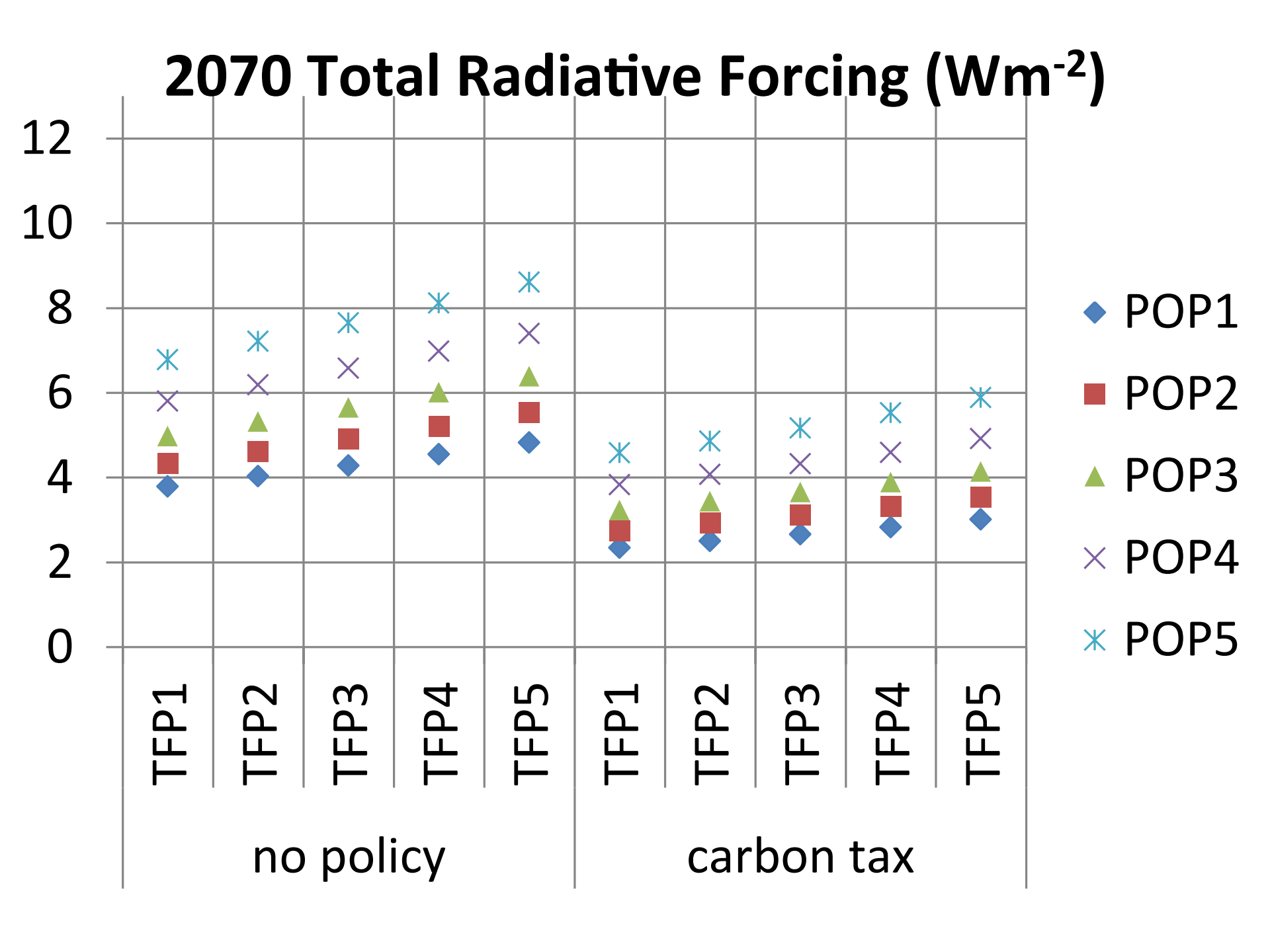

2020 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5

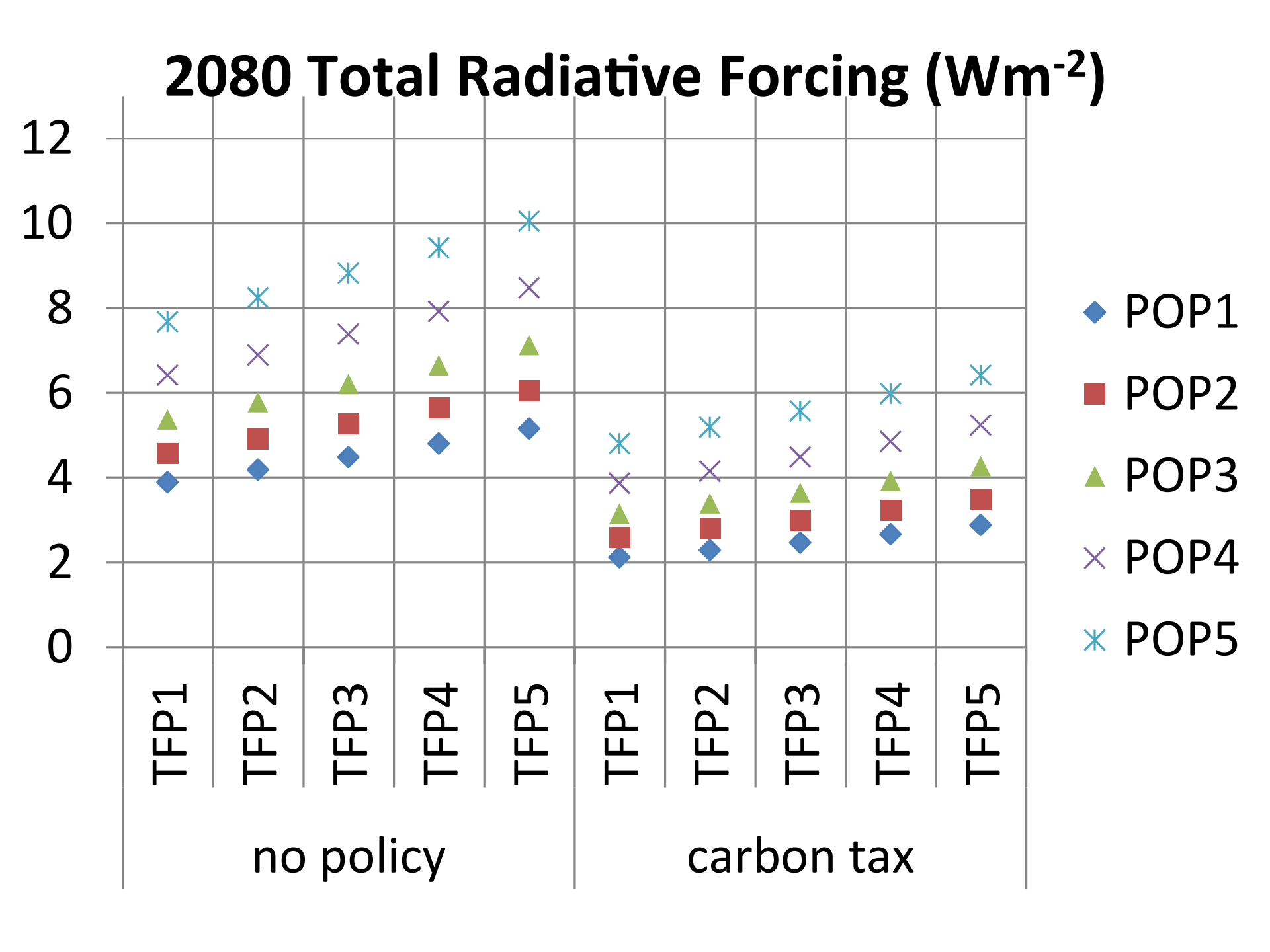

2030 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5

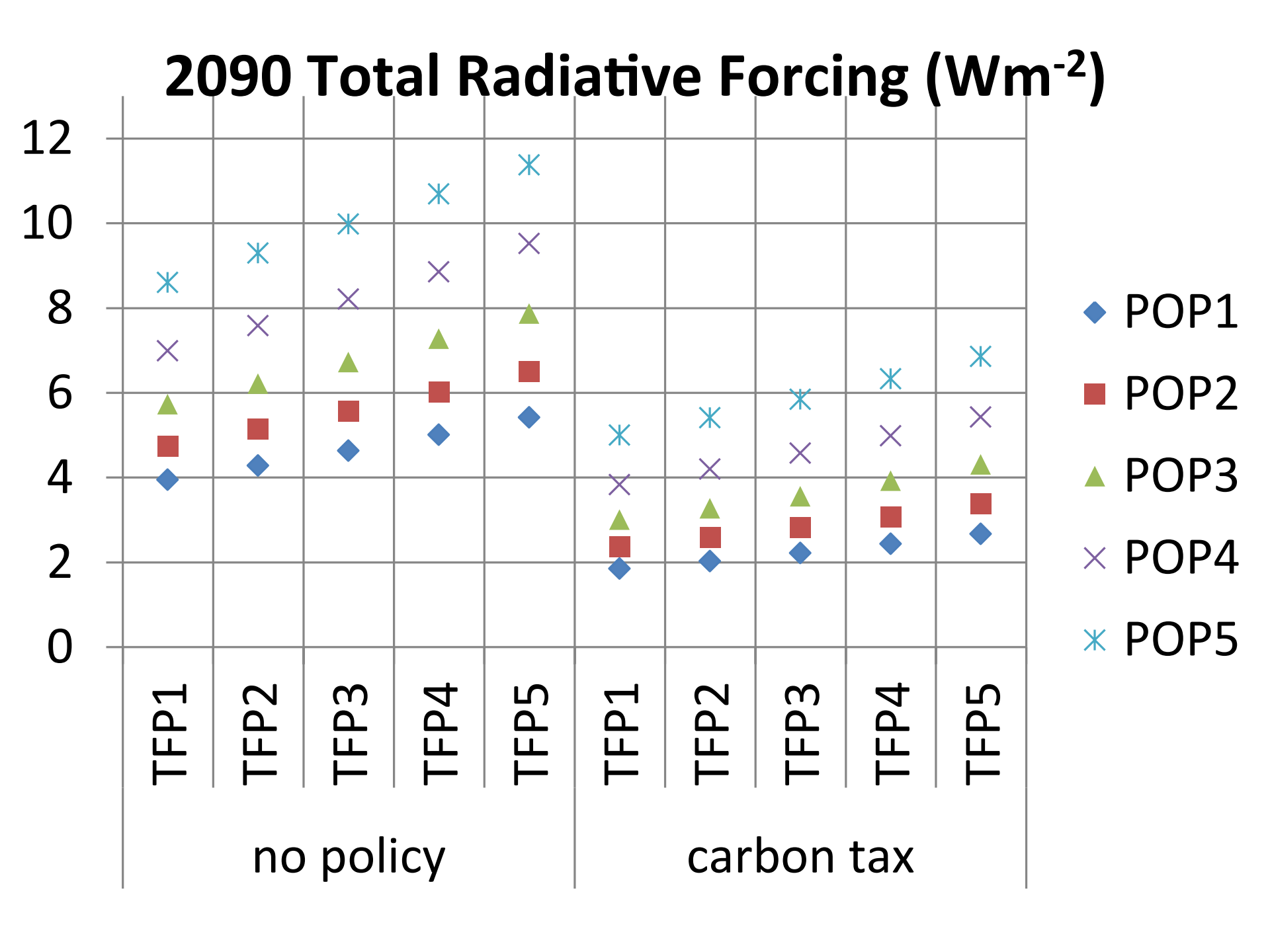

2040 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5

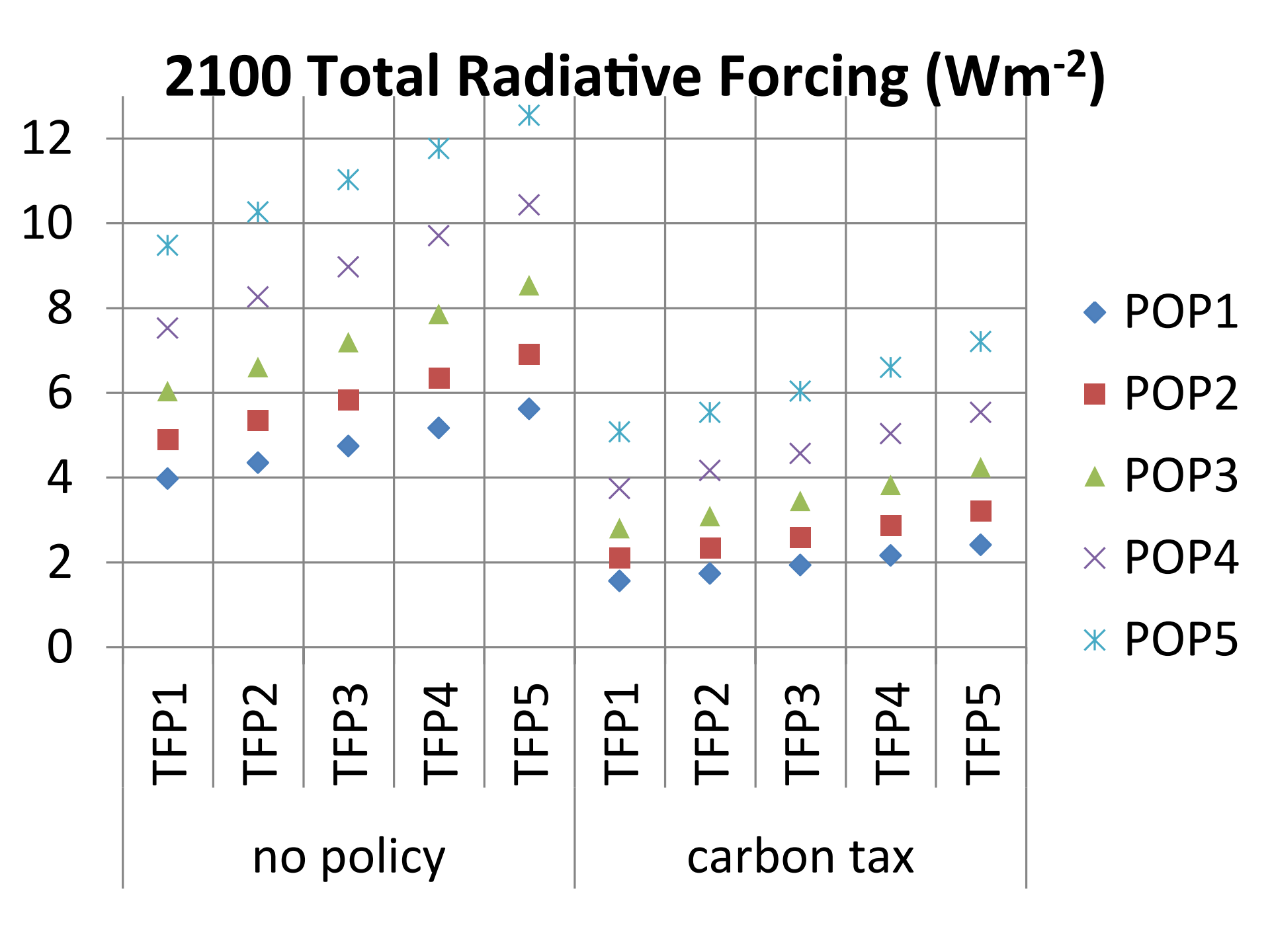

2050 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5


2060 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5


2070 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5


2080 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5

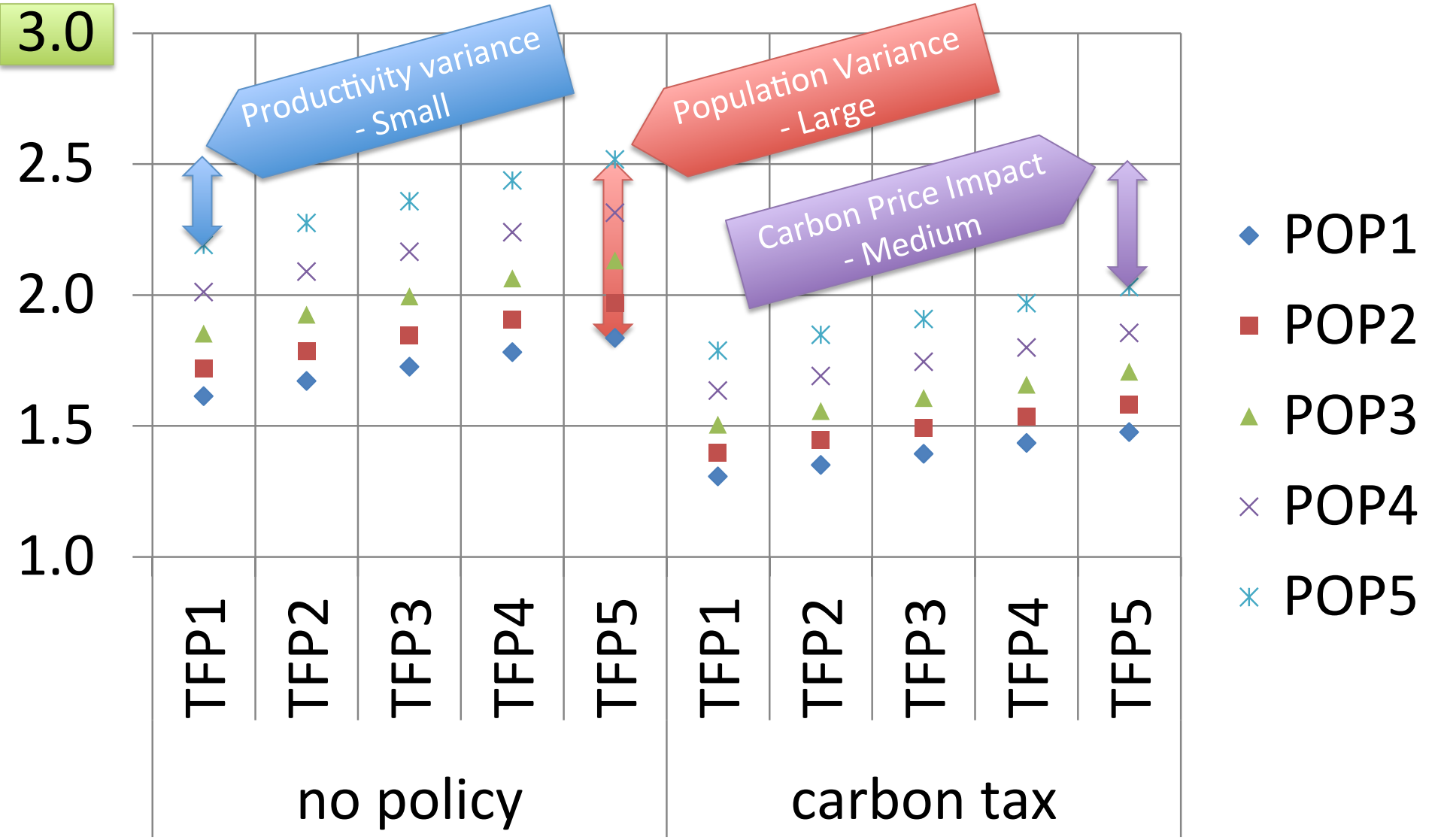

2090 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5


2100 Total Radiative Forcing (Wm-2)
12
10
8
6
4
2
0
TFP1
TFP2
TFP3
TFP4
TFP5
TFP1
TFP2
TFP3
TFP4
TFP5
no policy
carbon tax
POP1
POP2
POP3
POP4
POP5

Total Radiative Forcing (Wm^{-2})

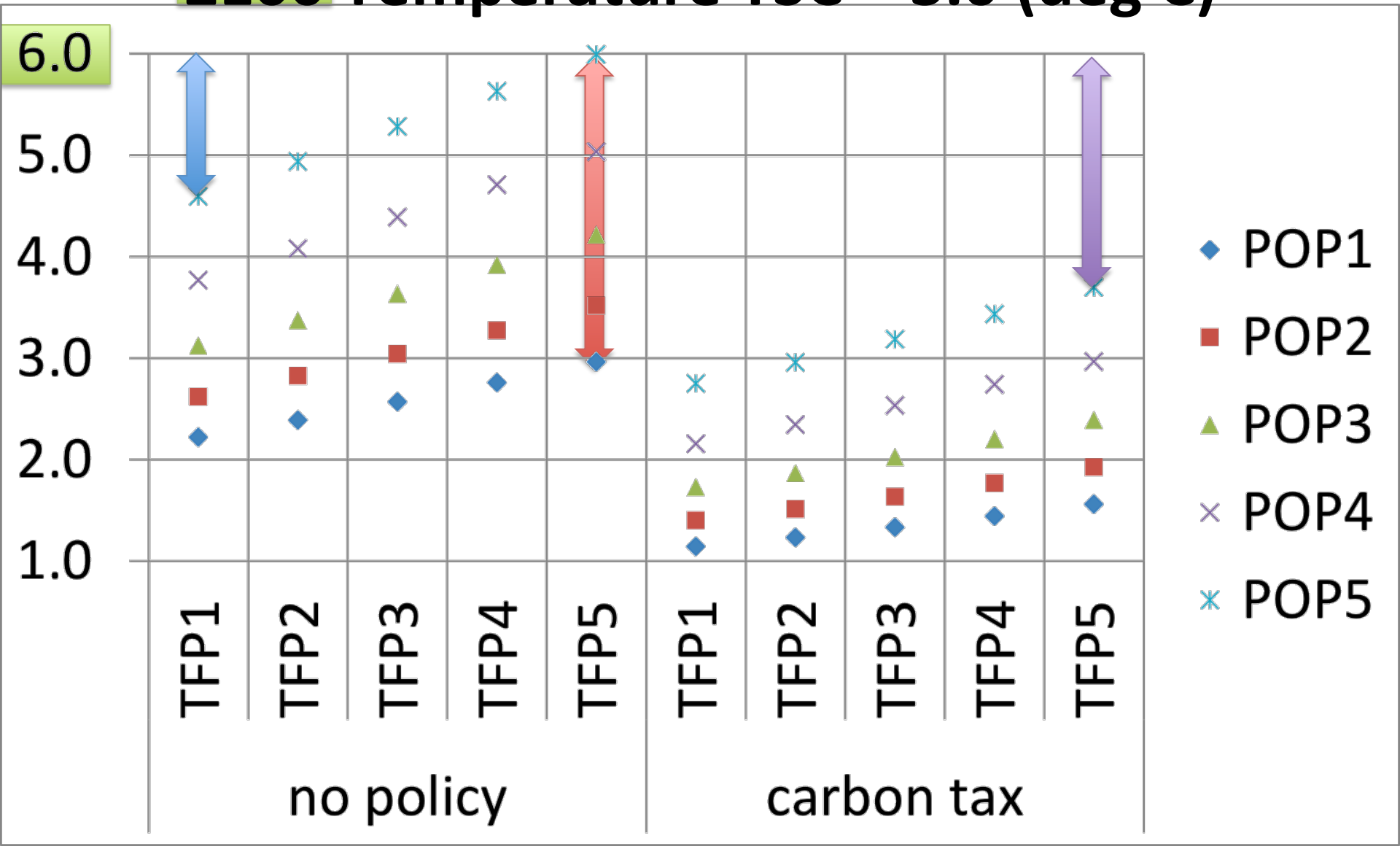
- Uncertainty exacerbates over time.
- Stock accumulation effect.

2050 Temperature TSC = 3.0 (deg C)

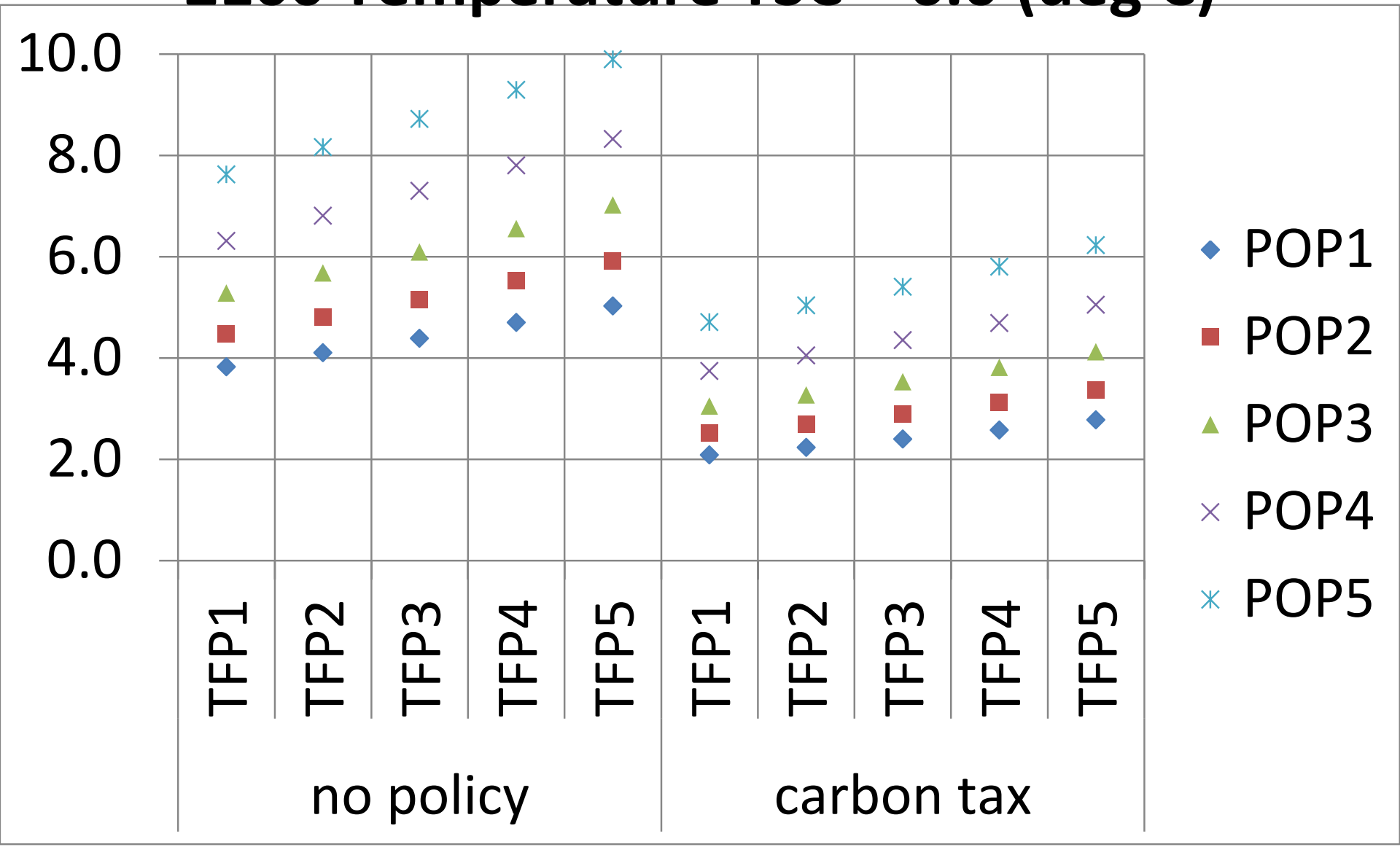


*TSC: Temperature Sensitivity Coefficient

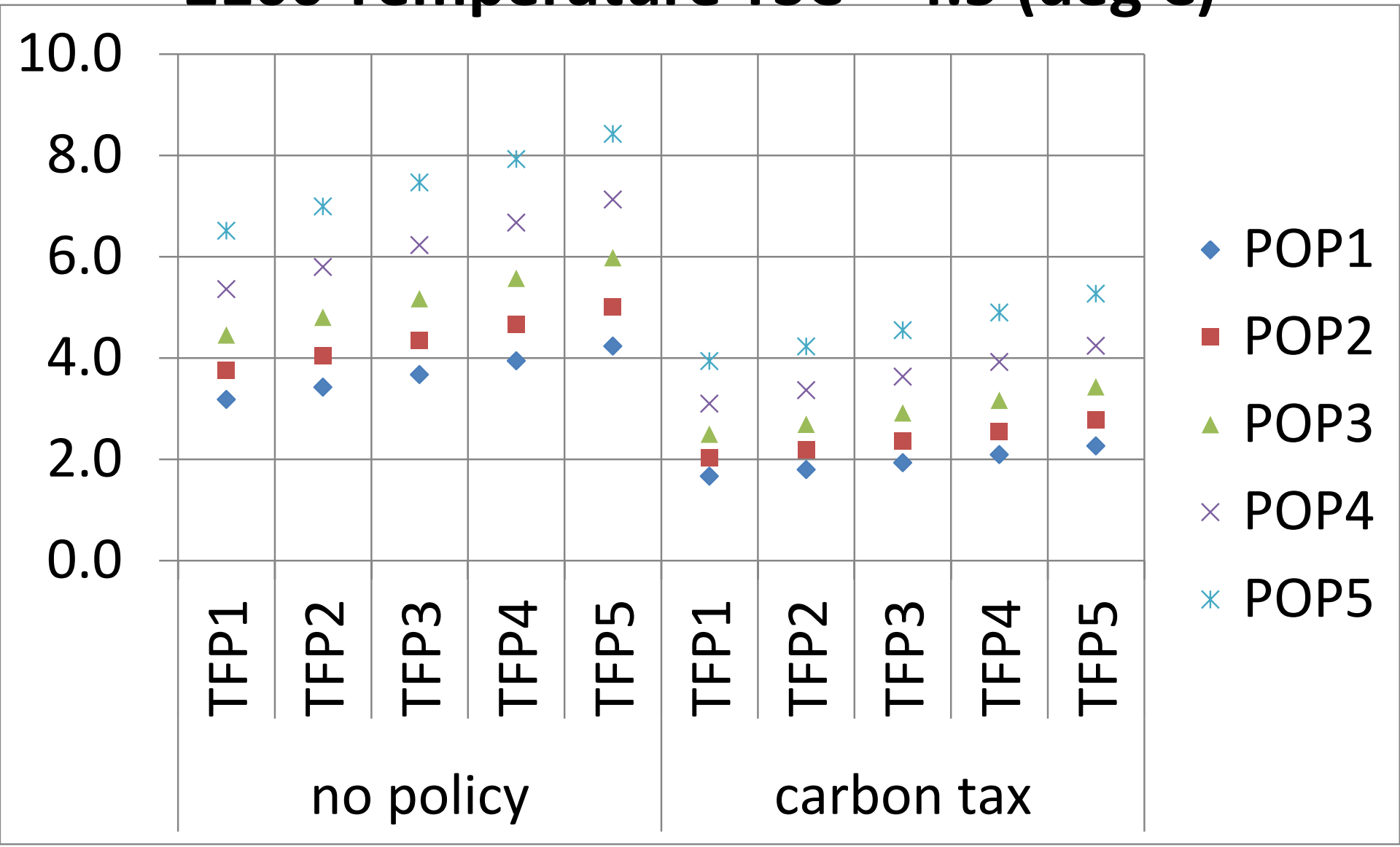
2100 Temperature TSC = 3.0 (deg C)



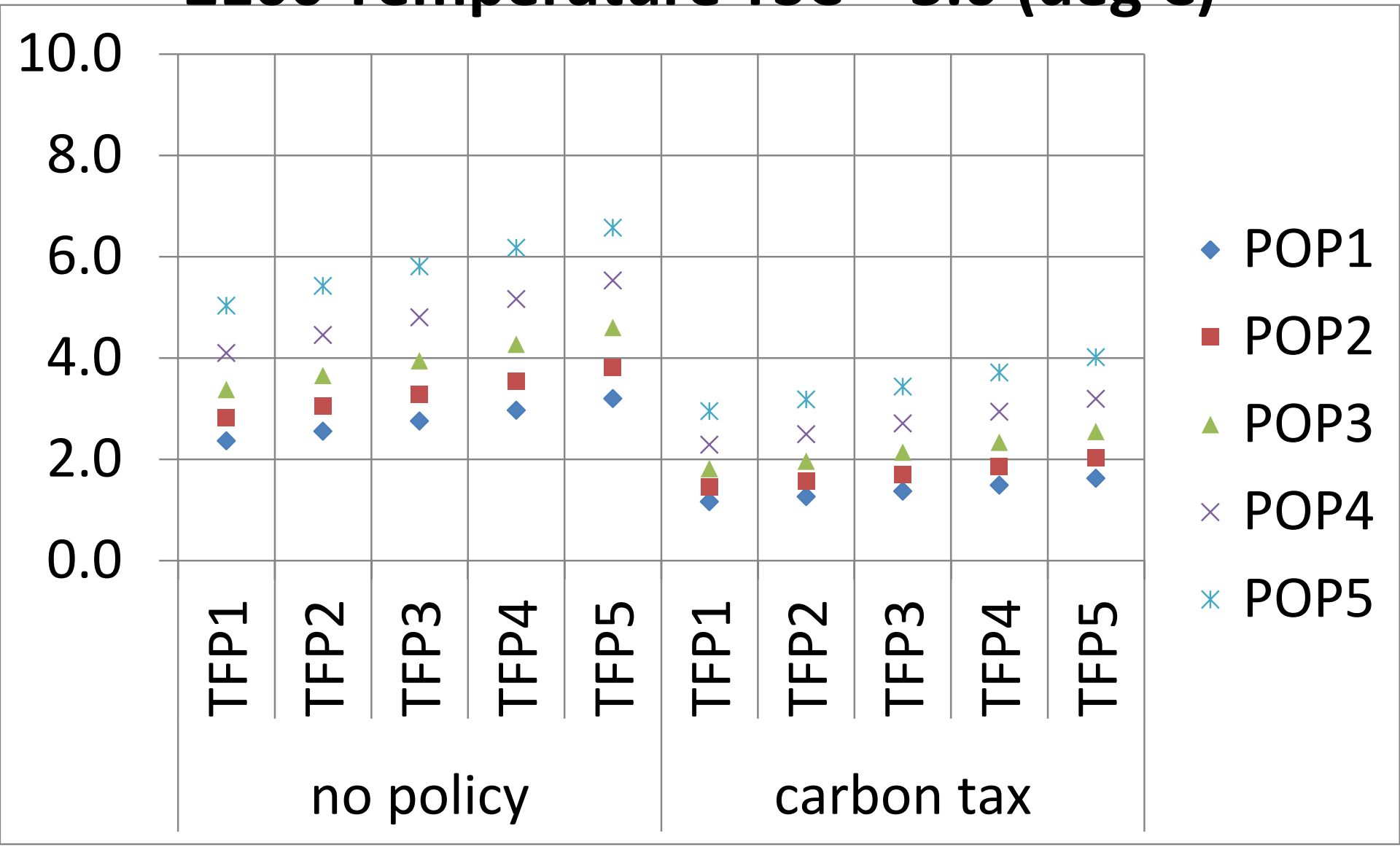
2100 Temperature TSC = 6.0 (deg C)



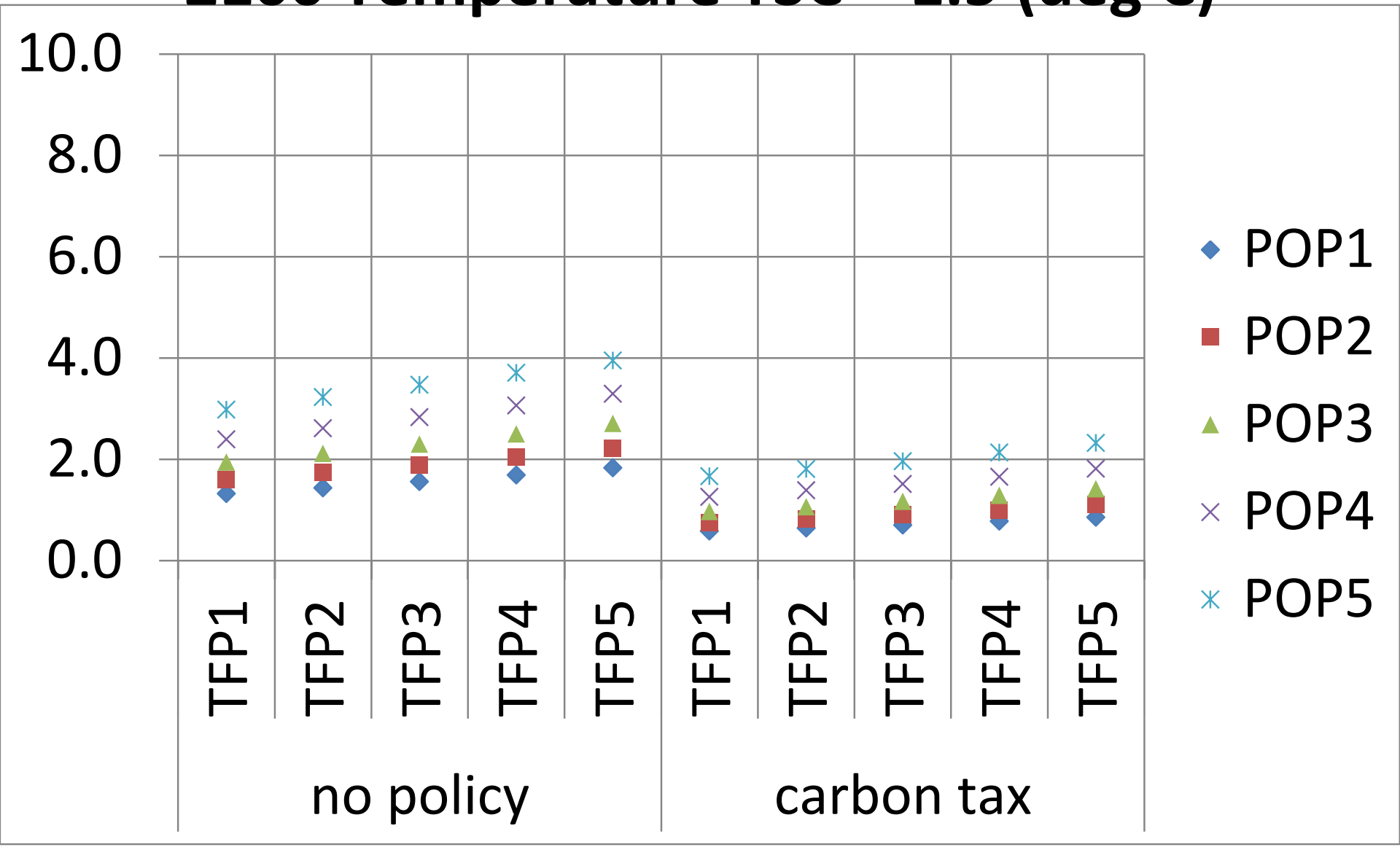
2100 Temperature TSC = 4.5 (deg C)



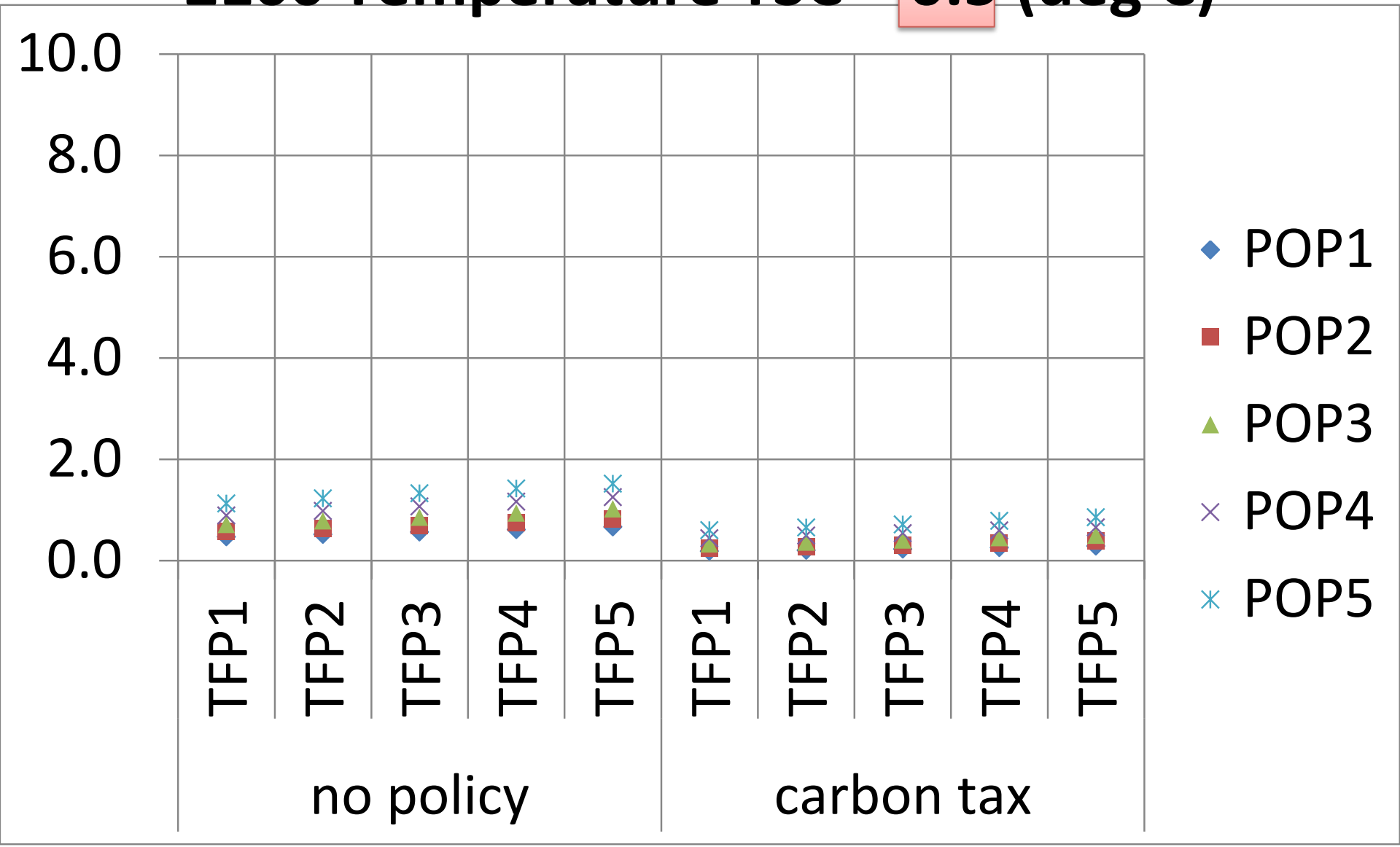
2100 Temperature TSC = 3.0 (deg C)



2100 Temperature TSC = 1.5 (deg C)



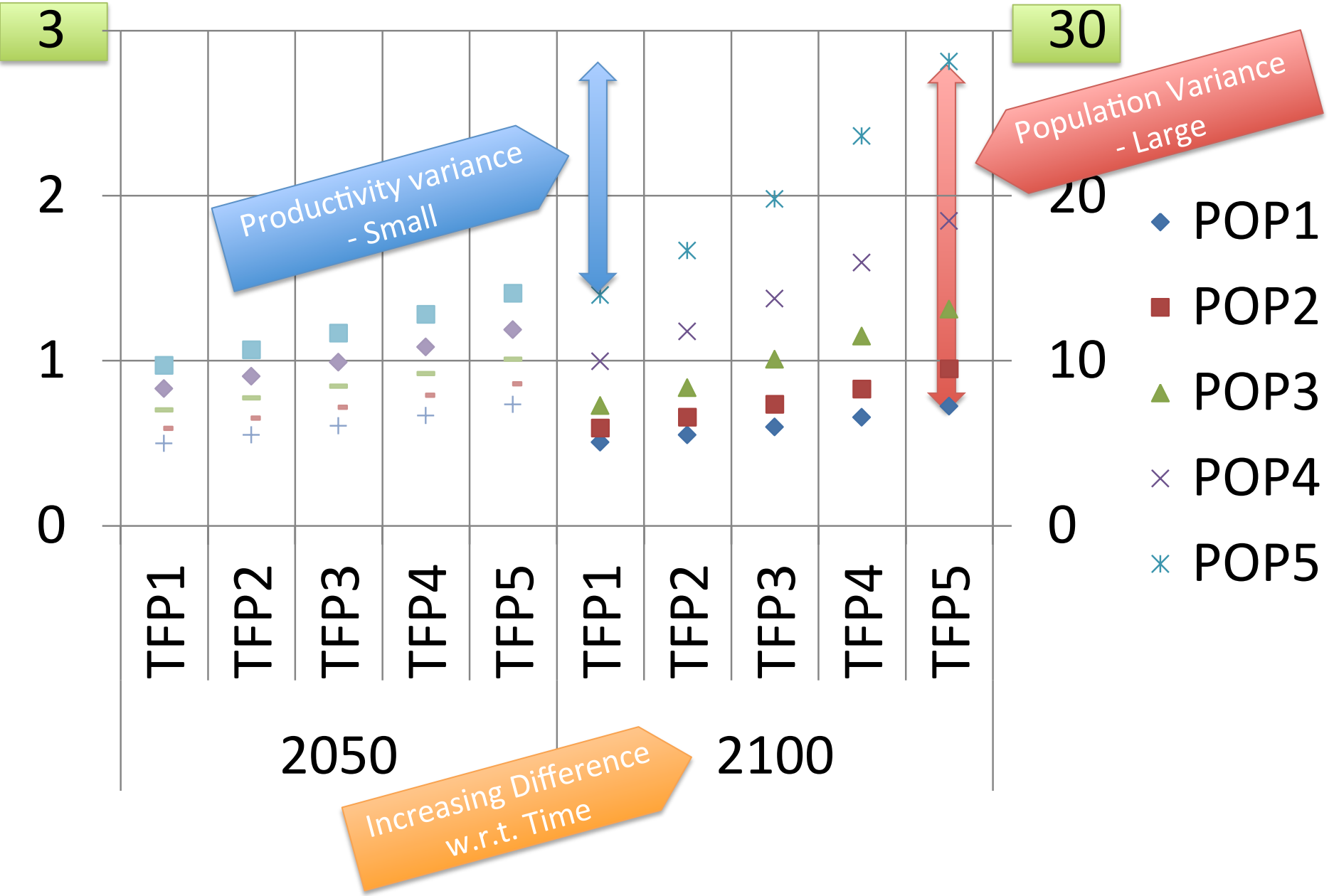
2100 Temperature TSC = 0.5 (deg C)



Temperature (deg C)

- To be focusing on extreme TSC, or not to be…

Mitigation costs (trillions, 2005$)



Remarks

- Second trial of MUP model sensitivity analysis.
- Population has larger variance than productivity.
  - Subsistence level energy consumption.
  - Energy consumption satiation.
- Carbon Price is treated differently, but shows large impact.
- Uncertainty tend to exacerbate over time. Multi-level stock accumulation effect.
- Limits to scenario growth:
  - More focus on extremes for scholarly interest,
  - Or more focus on the “probable” region?
  - Other efficient sampling method?
- Other uncertain variables:
  - Natural Gas and other fossil fuel resources.
  - Technology: TEaM project
  - Behavior: ADVANCE

The End