A Few Key Results from Recent Model Inter-comparison Projects

John Weyant

(with Elmar Kriegler, Massimo Tavoni and Others as Noted)

Updated forJISEA Annual Cnference

Natonal Renewable Energy Laboratory
Golden Colorado

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Motivation for The Original EMF 24

- **EMF 22 Very Useful Pre-Copenhagen Study**
  - **Global – Ten Models (Clarke)**
    - Alternative climate targets
    - Accession assumptions
    - Overshoot possibilities
  - **US – Six Models (Fawcett)**
    - Alternative emissions pathways
  - **EU – Three Models (Boehringer)**
    - EU ETS, RES, and EE target sensitivities
- **Many Suggestions by Many People for Follow-Ons**
  - **Pershing and Aldy among strongest voices**
  - **Push for more realistic policy architectures**
  - **Strong interest in impacts of advanced technologies**

Three Coordinated EMF Studies

- **EMF 24 Started as one study like EMF 22**
  - **Focus on more realistic policies and advanced technologies**
- **Many scenario ideas and models proposed**
  - **20-30 Scenarios per region**
  - **Over 50 Models**
  - **Too much to do in a single study**
- **Led to three separate studies**
  - **EMF 27: Global (Kriegler/Blanford/Krey) & EU AMPERE Study**
  - **EMF 24: US (Fawcett/Clarke)**
  - **EMF 28: EU (Knopf, Decian, Keppo)**

EMF 27 global technology and GHG mitigation scenario matrix

Policy Dimension	**Technology Dimension**								
Baseline	Base FullTech	Base LowEI		Base NucOff	Base LimSW	Base LimBio	Base Conv	Base EERE	Base LimTech
450 CO_2e	450 FullTech	450 LowEI	450 NoCCS	450 NucOff	450 LimSW	450 LimBio	450 Conv	450 EERE	450 LimTech
550 CO_2e	550 FullTech	550 LowEI	550 NoCCS	550 NucOff	550 LimSW	550 LimBio	550 Conv	550 EERE	550 LimTech
Modified G8 scenario	G8 FullTech							G8 EERE	
Fragmented Policy	FP FullTech							FP EERE	

550 CO2e	550 CO2e concentration in 2100 (3.7 W/m2), pathway not to exceed target
450 CO2e	450 CO2e concentration in 2100 (2.8 W/m2), pathway can overshoot target
Modified G8	G8 targets for participants, fossil fuel exporters not participating (inc. Russia)
Fragmented Policy	Annex 1 (except Russia) 50% reductions by 2050 wrt 2005, non-Annex 1 Copenhagen pledges then slow reduction increases, fossil fuel exporters not participating (inc. Russia)

Technology scenarios

Definition of technology variations	
FullTech	include all technologies represented in models, reference energy intensity improvements
LowEI	low energy intensity: 20-30% lower final energy demand in 2050 and 35-45% in 2100 compared to the reference case
NoCCS	carbon capture and storage excluded from technology portfolio in all sectors
NucOff	phase out of nuclear energy with no new nuclear power plants built beyond those under construction; existing plants operated until end of their technical lifetime
LimSW	share of electricity production from intermittent solar and wind technologies (wind, solar PV and CSP) limited to 20%
LimBio	global primary bio-energy supply – including purpose grown crops, residues and municipal solid waste, but excluding traditional biomass – limited to 100 EJ/yr
Conv	Combined LimSW & LimBio
EERE	Combined LowEI & NoCCS & NucOff
LimTech	Combined NoCCS & NucOff & LimSW & LimBio

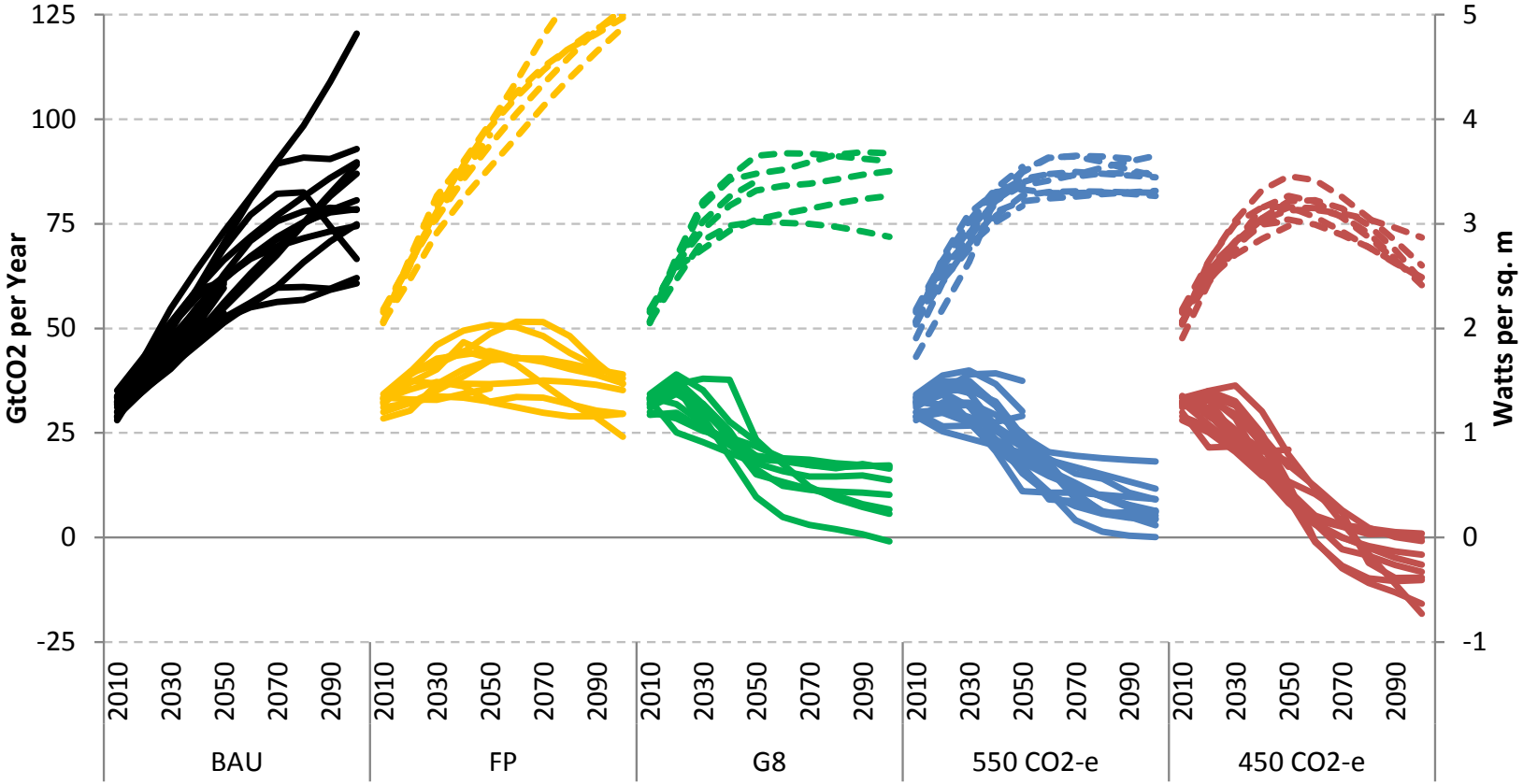
Policy scenarios

	Region	2020	2050	2050-2100
Modified G8	Group I	80% reduction relative to 1990 by 2050		Reductions 2%/yr
	Group II	Copenhagen pledges	Join Group I for combined 50% reductions relative to 1990	Reductions 2%/yr
	Group III	Never joins climate policy regime		
Fragmented Policy	Group I	50% reduction relative to 2005 by 2050		Reductions 2%/yr
	Group II	Copenhagen pledges	Slowly increasing reductions, limited trading	Reductions 2%/yr
	Group III	Never joins climate policy regime		

EMF 27: Participating global models

- AIM/End Use (Japan)
- BET (Japan)
- DNE 2100 (Japan)
- EC-IAM (Canada)
- ENV-Linkages (OECD)
- FARM (US)
- GCAM (US)
- GCAM-IIM (India)
- GRAPE (Japan)
- IMACLIM (France)
- IMAGE (Netherlands)
- MERGE (US)
- MESSAGE (IIASA)
- Phoenix (US)
- POLES (France)
- REMIND (Germany)
- TIAM-World (Canada)
- WITCH (Italy)

EMF27 emissions scenarios



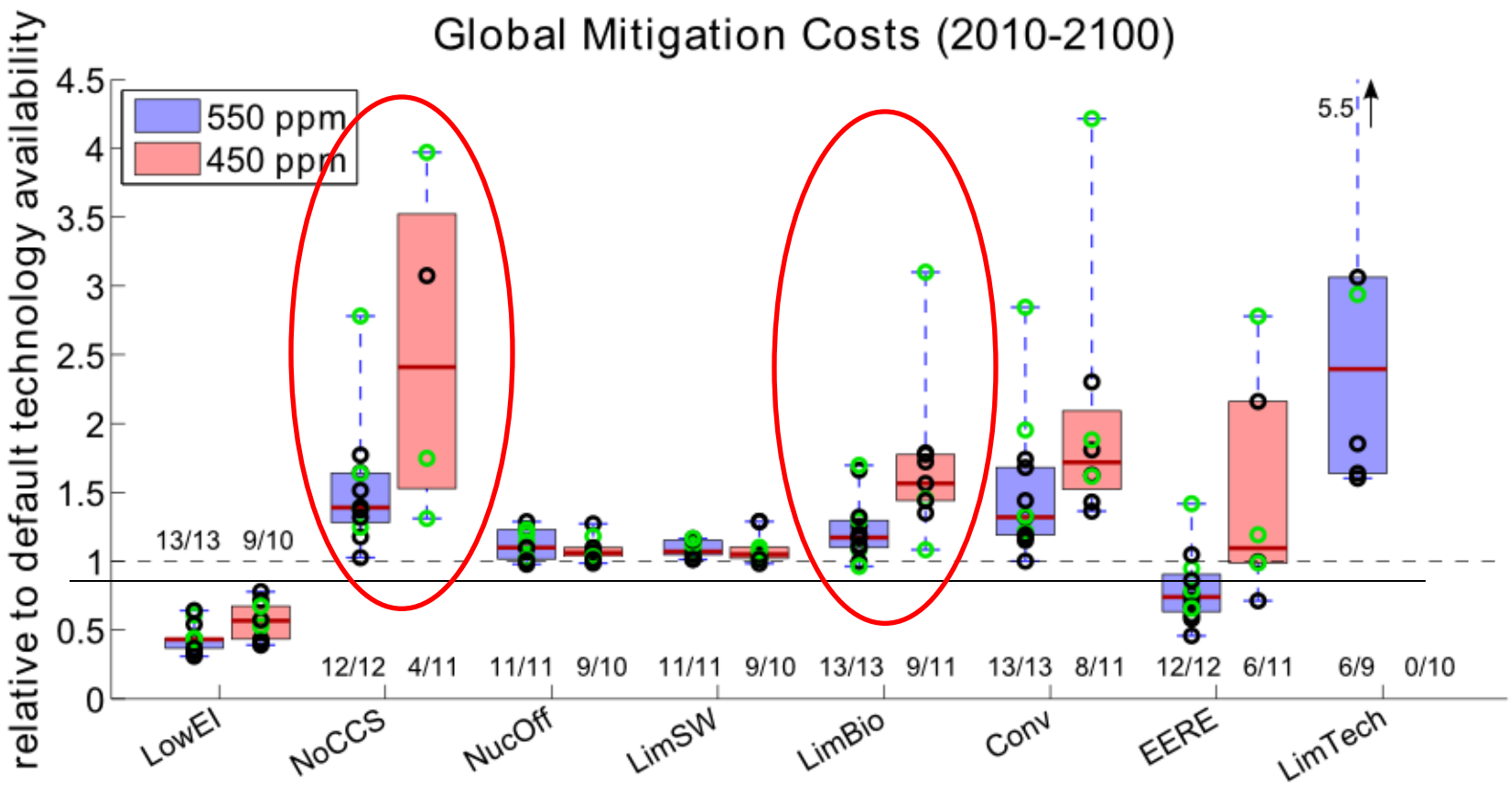
Shown are FF&I CO2 emissions and radiative forcing

Blanford, Kriegler, Tavoni, Climatic Change, forthcoming

Kriegler, Weyant et al, Climatic Change, forthcoming

EMF27 – The role of technology for mitigation

BECCS is very valuable mitigation strategy, particular for 450 ppm



Krey, Luderer et al, Climatic Change, forthcoming

Kriegler, Weyant et al, Climatic Change, forthcoming

AMPERE Project on … a lot of things

Established a European Modeling Platform

- **Global models from the EU:** GEM-E3, IMACLIM, IMAGE, MERGE-ETL, MESSAGE, POLES, REMIND, WITCH, WorldScan
- **EU models:** Green-X, PRIMES, NEMESIS, TIMES-PanEU
- **International partner models:** AIM-Enduse, DNE21+, GCAM

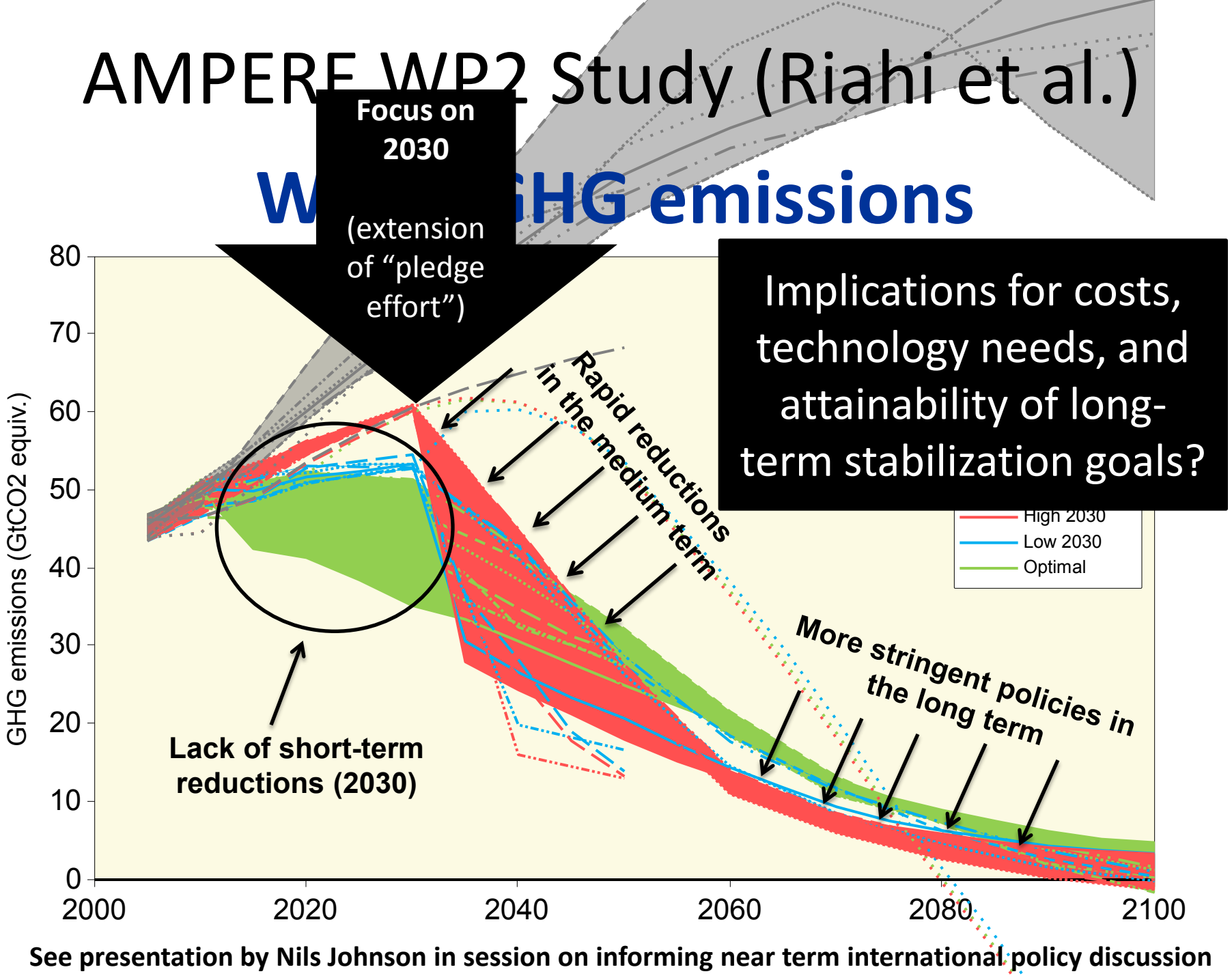
Special issue in Technological Forecasting and Social Change on delayed and fragmented action scenarios of climate policy

- Implications of short term targets for the costs and feasibility of long term targets (Riahi et al., Bertram et al., Eom et al.)
- Staged accession to global climate regime (Kriegler et al.)
- X-cuts on climate outcomes (Schaeffer et al.), impact of delay and fragmentation on fossil fuel markets (Bauer et al.), EU roadmap (Schwanitz et al.)
- Diagnostic indicators for integrated assessment models (Kriegler et al.)
- Individual modeling team papers on carbon leakage (industry, land use, energy channel), technology diffusion, energy efficiency, energy system transformation

Funded by the EU 7th Framework Programme

AMPERE WP2 Study (Riahi et al.)

W GHG emissions



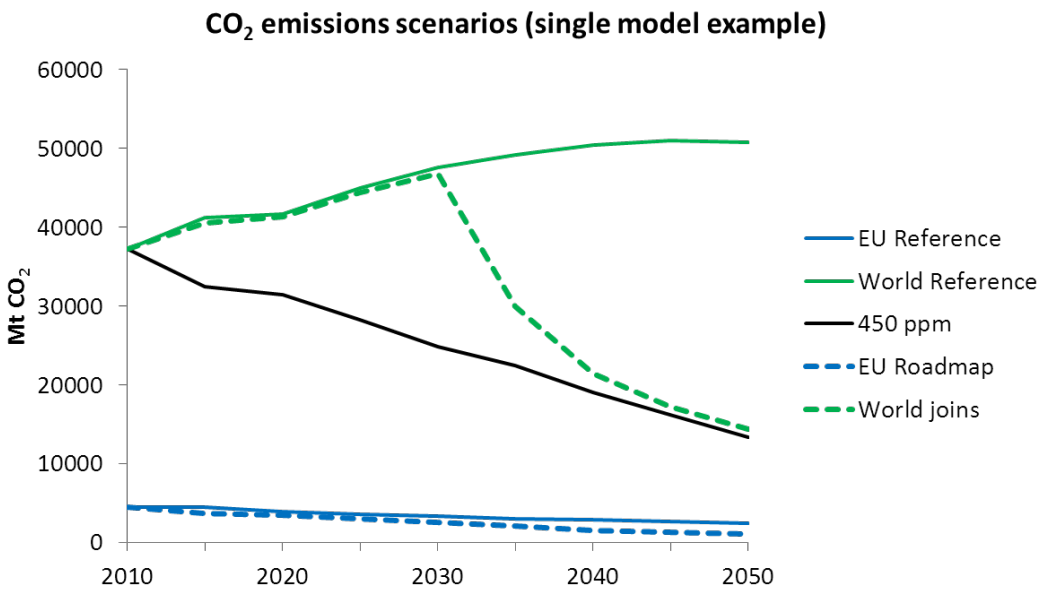
See presentation by Nils Johnson in session on informing near term international policy discussion

AMPERE WP3 study on fragmented action and staged accession

What implications for front runners (EU27; EU27 & China) and late adopters in an international climate policy regime?

- What climate outcome can still be achieved if early movers are joined by the rest of the world after 2030?
- How large are inefficiencies, e.g. from carbon leakage, in the initial period of fragmented action?

Study design:
Excess emissions until 2050 are not compensated in the 2nd half of the century



Key findings

- **High 2030 emissions (~60 GtCO2e) pose a triple-challenge:**
  - Fossil fuel lock-in (+50% compared to today by 2030)
  - Stranded assets (100s of coal power plants globally)
  - Requires doubling the "upscaling pace" of low-carbon energy
- **Implications for the transformation:**
  - Increased risks that low stabilization targets become unattainable
  - Higher costs (particularly in the medium term)
  - "Overshoot" reduces chances to stay below 2C
- **<u>Energy Efficiency</u> critical for keeping options open**
- **Results are being published as a Special Issue of TFSC and open-access databases**

(https://secure.iiasa.ac.at/web-apps/ene/AMPEREDB)

EMF 24
U.S. Technology and Climate Policy Strategies
An Overview

Allen Fawcett, Sebastian Rausch

Leon Clarke, John Weyant, Yuyu Zhou, Vaibhav Chaturvedi, James McFarland

Overview of Scenarios

Technology Dimension								
	Optimistic	Single Technology Sensitivities				Combined Sensitivities		Pessimistic
End Use Technology	Optimistic	Pessimistic	Optimistic	Optimistic	Optimistic	Optimistic	Pessimistic	Pessimistic
CCS	Optimistic	Optimistic	Pessimistic	Optimistic	Optimistic	Pessimistic	Optimistic	Pessimistic
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Scenario Name	**Hi Tech**	**Low EE**	**Low CCS**	**Now Nuc**	**Low Renew**	**Low CCS/Nuc**	**Low EERE**	**Low Tech**

Policy Dimension								
Baseline								
50% Cap & Trade								
80% Cap & Trade								
Transportation (CAFE)								
Electricity (RPS)								
Electricity (CES)								
Sectoral Policies (RPS & CAFE)								
Sectoral Policies + 50% Cap & Trade								

Technology Scenarios

Policy Scenarios

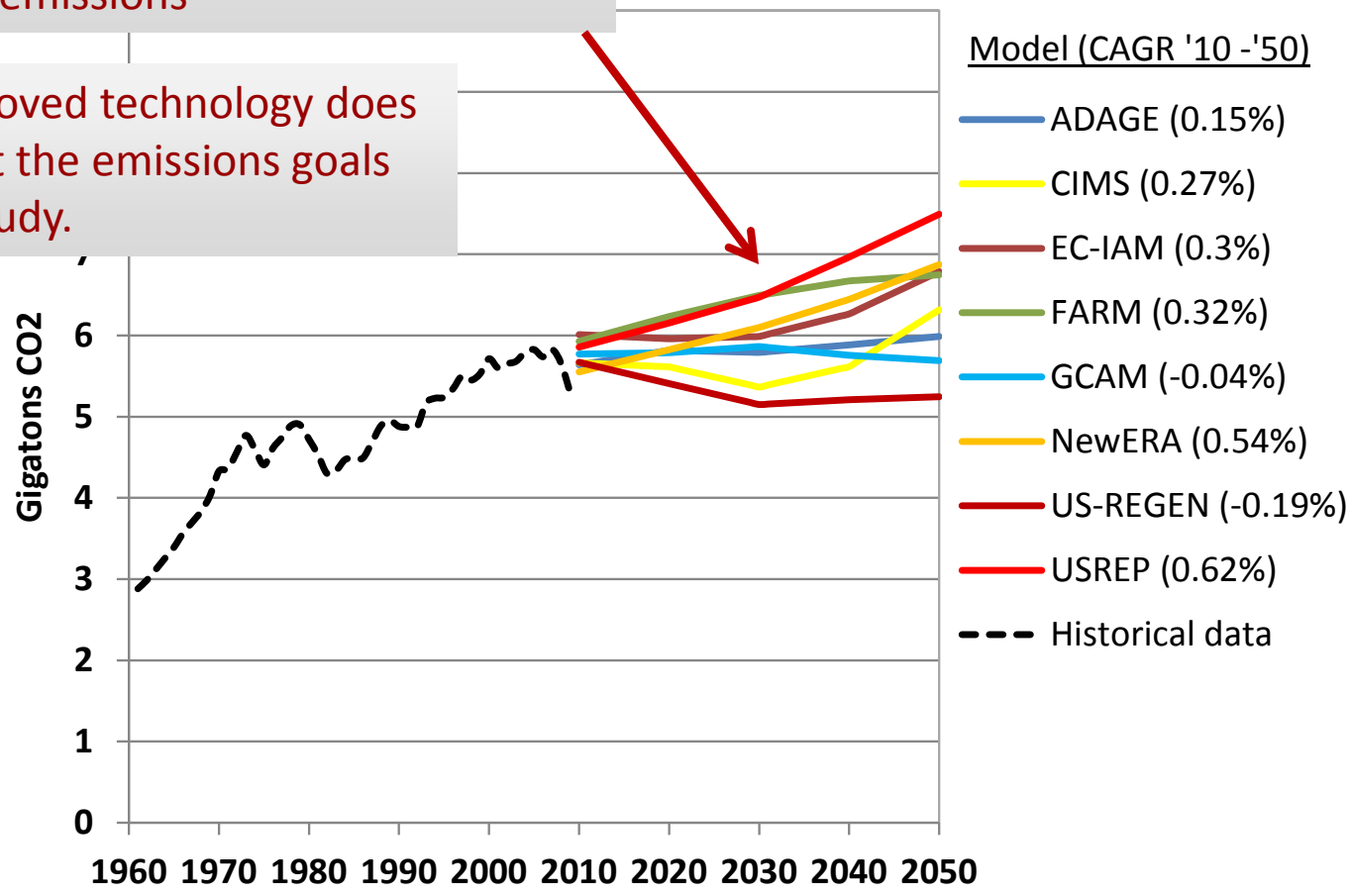
Technology Assumptions

Technology	High Tech	Low Tech
End Use	End use assumptions regarding technology that lead to a **20% decrease in final energy consumption in 2050 relative to the low-tech, no policy case.**	**Evolutionary progress.** Precise assumptions specifed by individual modeling teams specificed by each individual modeler.
Carbon Capture and Storage (CCS)	**CCS is available.** Cost and performance assumptions specifeed by individual modeling teams	**No implementation of CCS.**
Nuclear	**Nuclear is fully available.** Cost and performance specified by each modeling team.	**Nuclear is phased-out after 2010.** No new construction of plants beyond those under construction or planned. Total plant lifetime limited to 60 years.
Wind and Solar Energy	**Plausibly optimistic technology development.** Cost and performance assumptions specified by individual modeling teams.	**Evolutionary technology development.** Cost and performance assumptions specified by individual modeling teams
Bioenergy	**Plausibly optimistic level of sustainable supply.** Supply assumptions specified by individual modeling teams.	**Evolutionary technology development representing the lower end of sustainable supply.** Supply assumptions specified by individual modeling teams.

US CO_2 Emissions in the HiTech Scenarios

Improved technology – largely reductions in energy use – reduce baseline emissions

But improved technology does not meet the emissions goals of this study.



Overview of EMF 24 Policy Scenarios: Motivating Questions

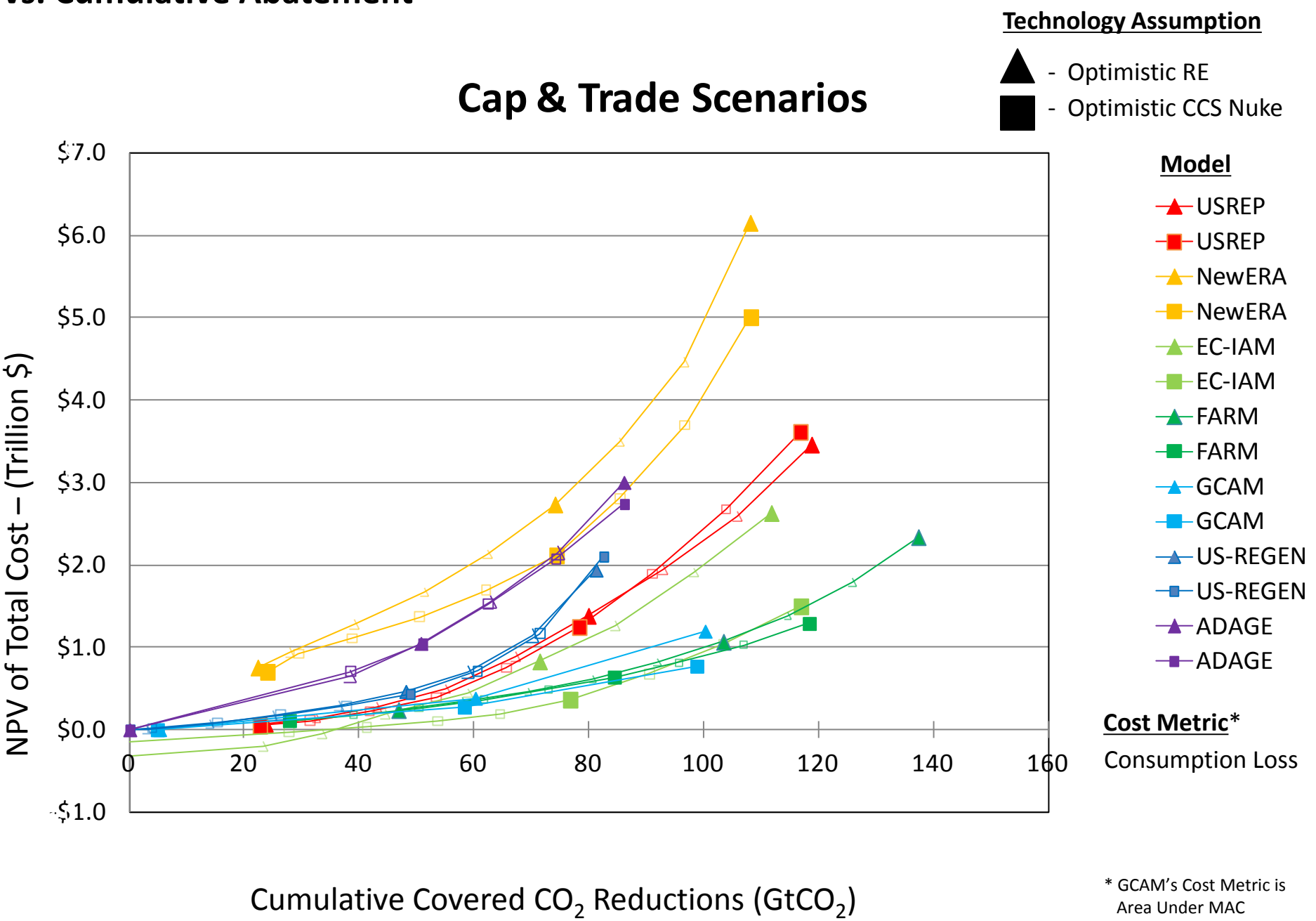
- **What are the potential implications of sectoral approaches to GHG emissions reductions?**
- **How do sectoral policies interact with an economy-wide policy?**
- **How might technological improvements and technological availability influence the answers to the above questions?**

Policies

- **The policy scenarios of the EMF 24 exercise are based on combinations of three different types of national policy instruments:**
  - ***Economy-wide* cap-and-trade policy,**
  - ***Transportation Sector* policy represented by a Corporate Average Fuel Economy (CAFE) standard for light-duty vehicles,**
  - ***Electricity Sector* policy represented by either a renewable portfolio standard (RPS) or clean energy standard (CES) combined with a CCS requirement for new coal.**

- **These policy scenarios do not reflect any specific legislative or administration policy proposals, but instead are intended to represent more generic versions of economy wide and sector specific policies.**

Net Present Value of Cumulative Cost vs. Cumulative Abatement



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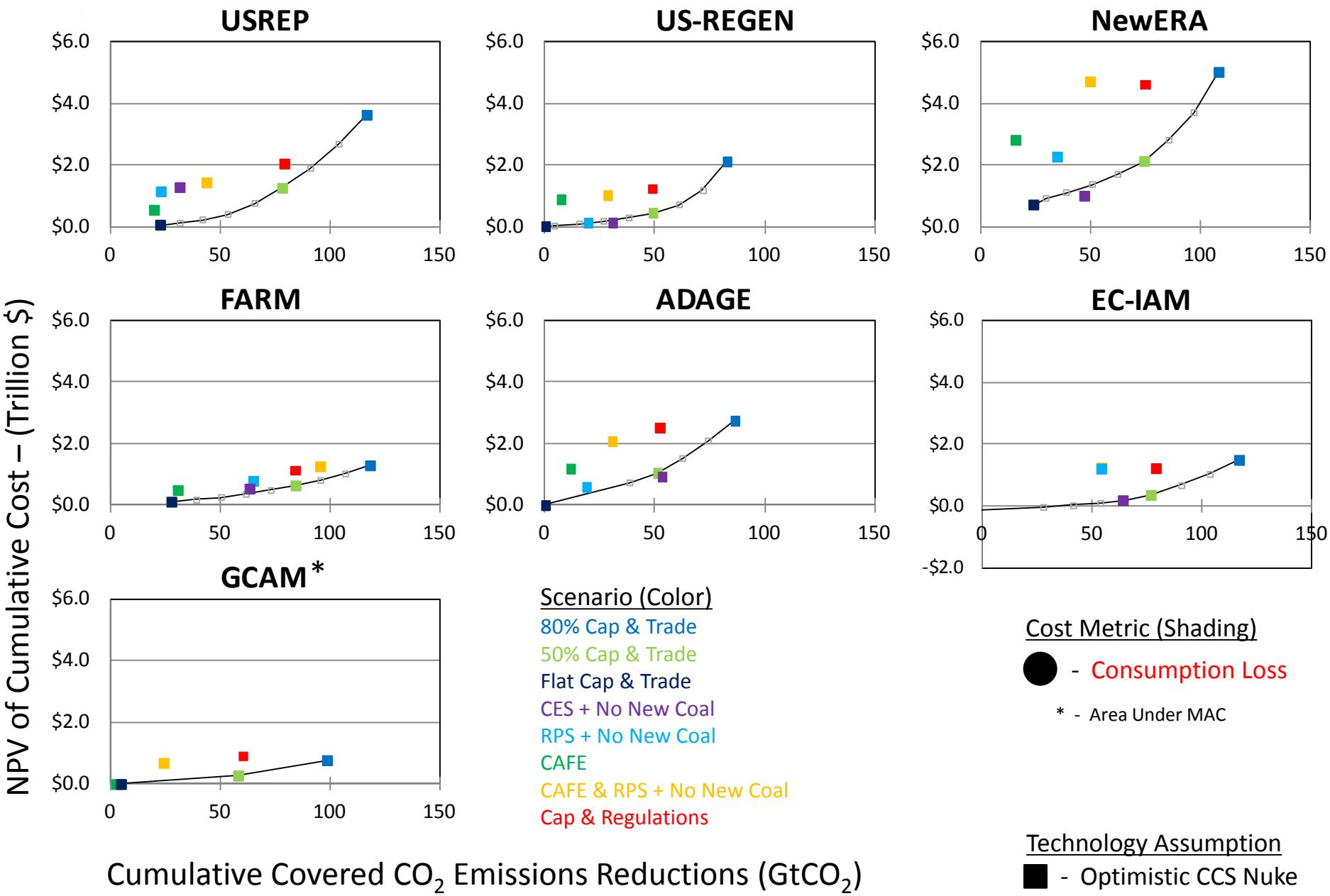

Conclusions

- **When comparing results from different models:**
  - **Baseline differences can drive large differences in costs and/or emissions outcomes.**
  - **Choice of cost metric matters.**
  - **Technology assumptions are important, but other underlying differences in model structure, parameters, and assumptions can matter more.**

- **Sectoral policies are generally less cost effective than economy-wide policies.**
  - **However, if the economy-wide policy does not use revenues to reduce other distortionary taxes, then some models find that an electricity sector policy can potentially achieve emissions reductions more cost effectively.**

- **Combining sectoral policies with an economy-wide emissions cap increases costs without increasing abatement.**
  - **Carbon price can be particularly misleading in these cases.**
  - **In contrast, when sectoral policies are combined with a carbon tax, the total amount of abatement increases.**

- **Models differ in the importance of technology assumptions, but when they do matter, they can have a greater impact on electricity sector policies than on economy-wide policies.**

THE END / QUESTIONS

Revenue Recycling Caveats

- **The cap-and-trade scenarios assume a per-capita based lump-sum recycling of the revenue.**
- **It is well-known from the literature that using the carbon revenue to lower pre-existing distortionary taxes may yield substantial efficiency gains.**
- **Due to model differences in the representation of the fiscal system, this study is not able to explore this dimension further, but it is important to bear in mind that the estimated cost for the cap-and-trade policies presented here should be interpreted as an upper bound, i.e. cost may be smaller if the carbon revenue would be recycled by lowering marginal tax rates.**

Concluding Thoughts

- **The models provide estimates of carbon prices, but there is wide variation in these estimates.**
- **Technology has a large effect on the challenge of mitigation, but it is not clear that any single technology is more important than others.**
- **Decarbonization of electricity by 2050 is robust across all models.**
- **Clarification needed regarding the potential for end use reductions and the associated welfare implications.**

Cost Effectiveness of Electricity Sector Policies

- For some models (US-REGEN, NewERA, ADAGE) the CES+New coal CCS requirements have smaller welfare impacts (in terms of EV) than an economy-wide cap with a comparable level of overall abatement.
- In a first-best world without pre-existing distortionary taxes, sectoral policies always lead to larger costs of carbon abatement than a carbon tax or permits as the former fail to equalize the marginal cost of abatement across sources and users.
- The welfare ranking of these policy instruments in a second-best setting, however, is ambiguous.
- By driving up the price of carbon-intensive goods relative to leisure, a carbon pricing policy tends to compound the factor-market distortions created by pre-existing taxes, thereby creating a negative welfare impact termed the tax-interaction effect.
- An electricity sector policy that yields a smaller increase in the consumer price of electricity as compared to a carbon-pricing policy may actually be a more efficient way to achieve a comparable level of abatement
- In models with relatively steep abatement costs in the non-electric sectors and a relatively flat curve in the electric sector, the efficiency gain from the economy-wide coverage in terms of lowering total abatement cost is not very large, and as a result the CES is very close to efficient abatement allocation.

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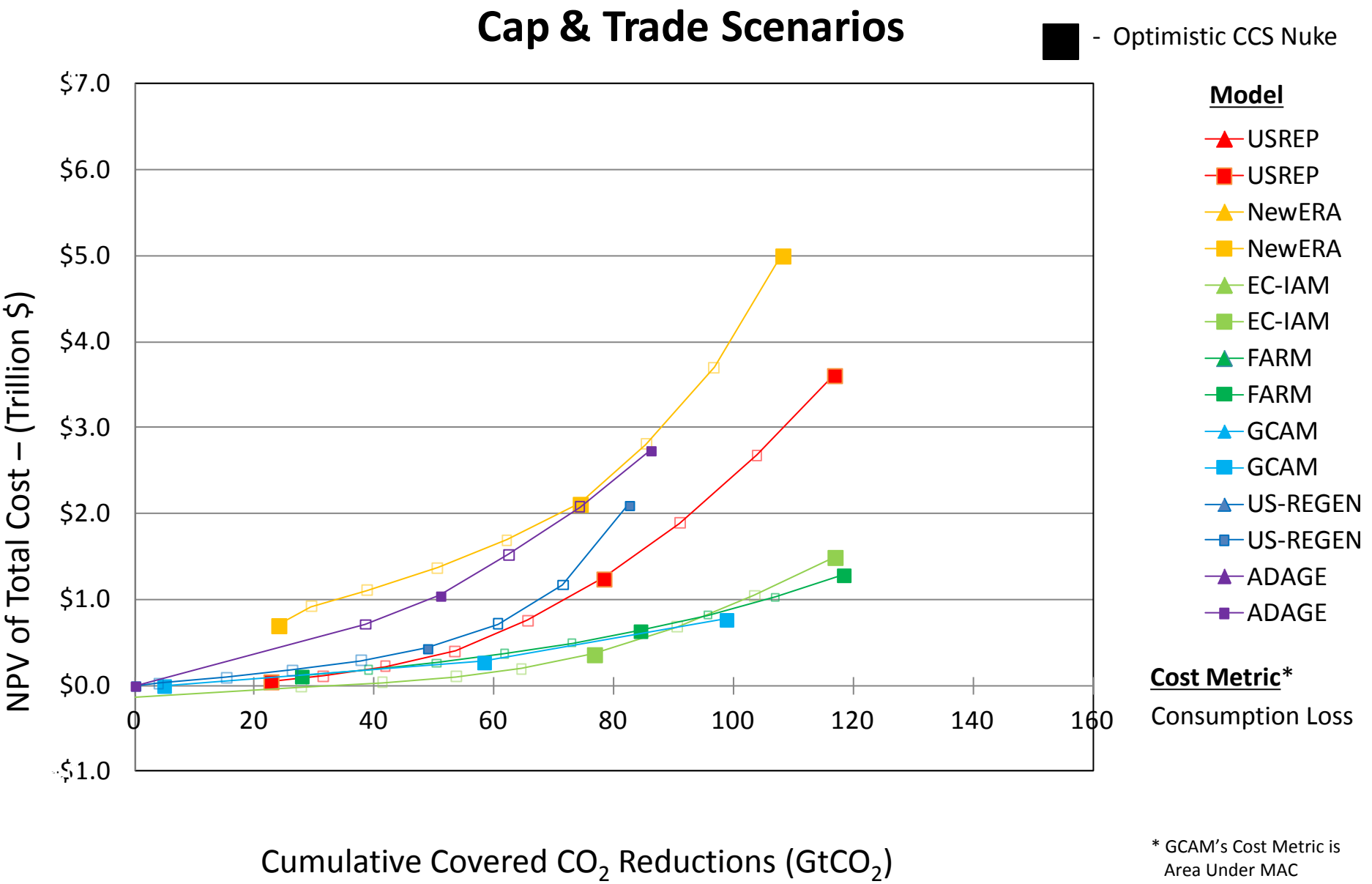

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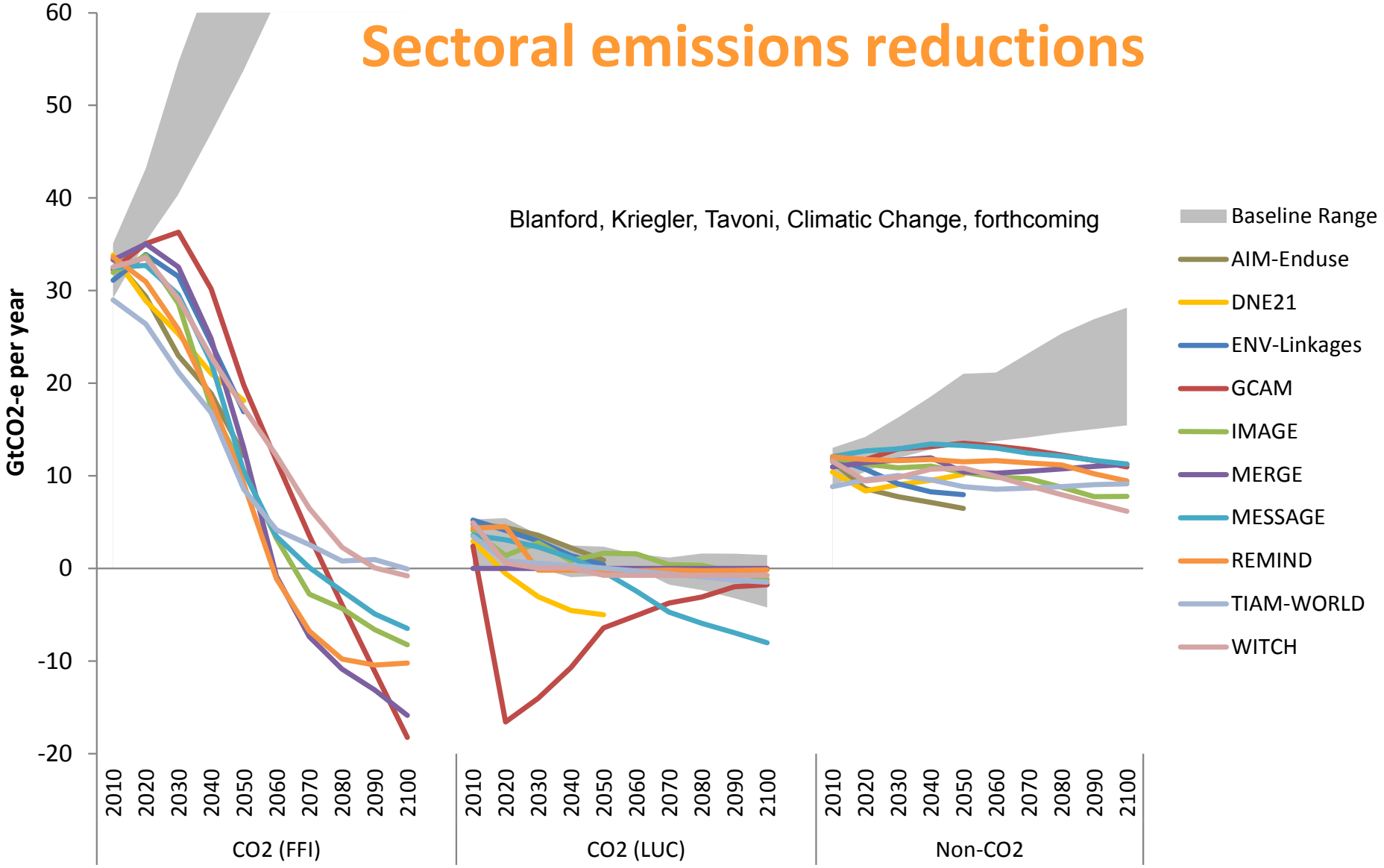
Sectoral emissions reductions



Energy system transformation

Kriegler, Weyant et al,
Climatic Change, forthcoming

Krey, Luderer et al,
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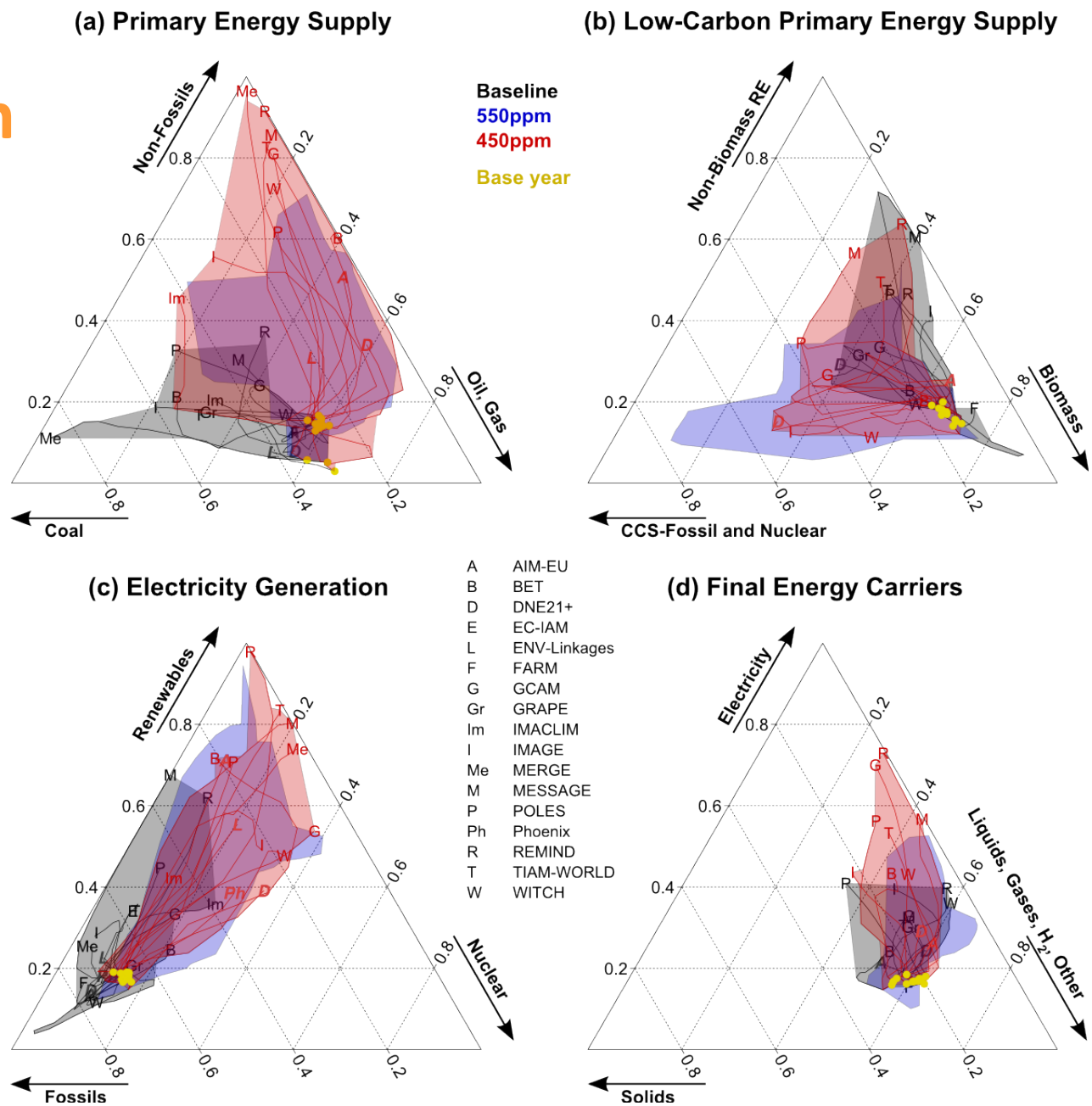

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Electricity (CES)								
Sectoral Policies (RPS & CAFE)								
Sectoral Policies + 50% Cap & Trade								

LEGEND

- Baseline Scenarios
- Cap & Trade Scenarios
- Regulatory Scenarios
- Combined Scenarios

“Efficient Frontier”
Cost Metric Comparison

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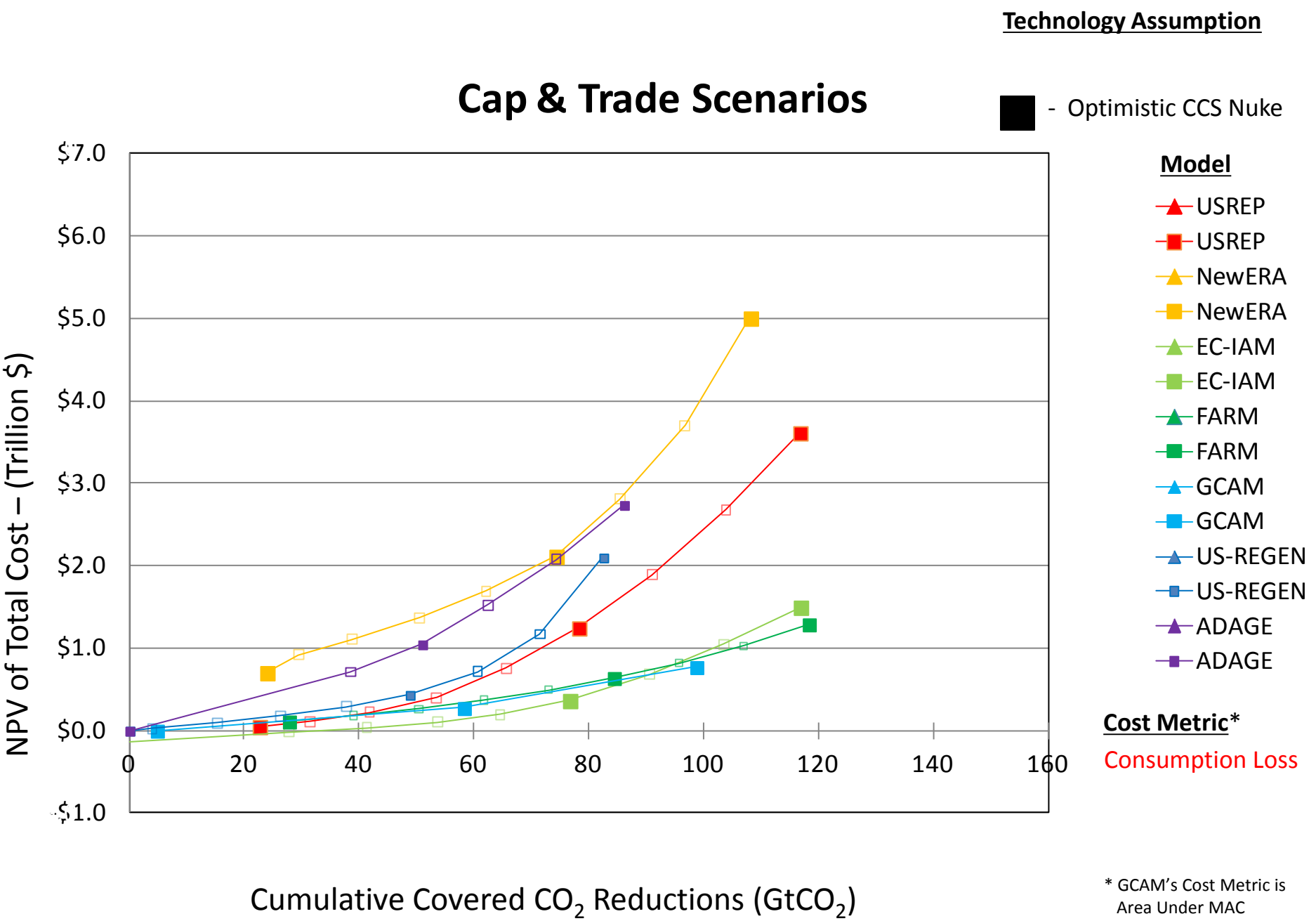

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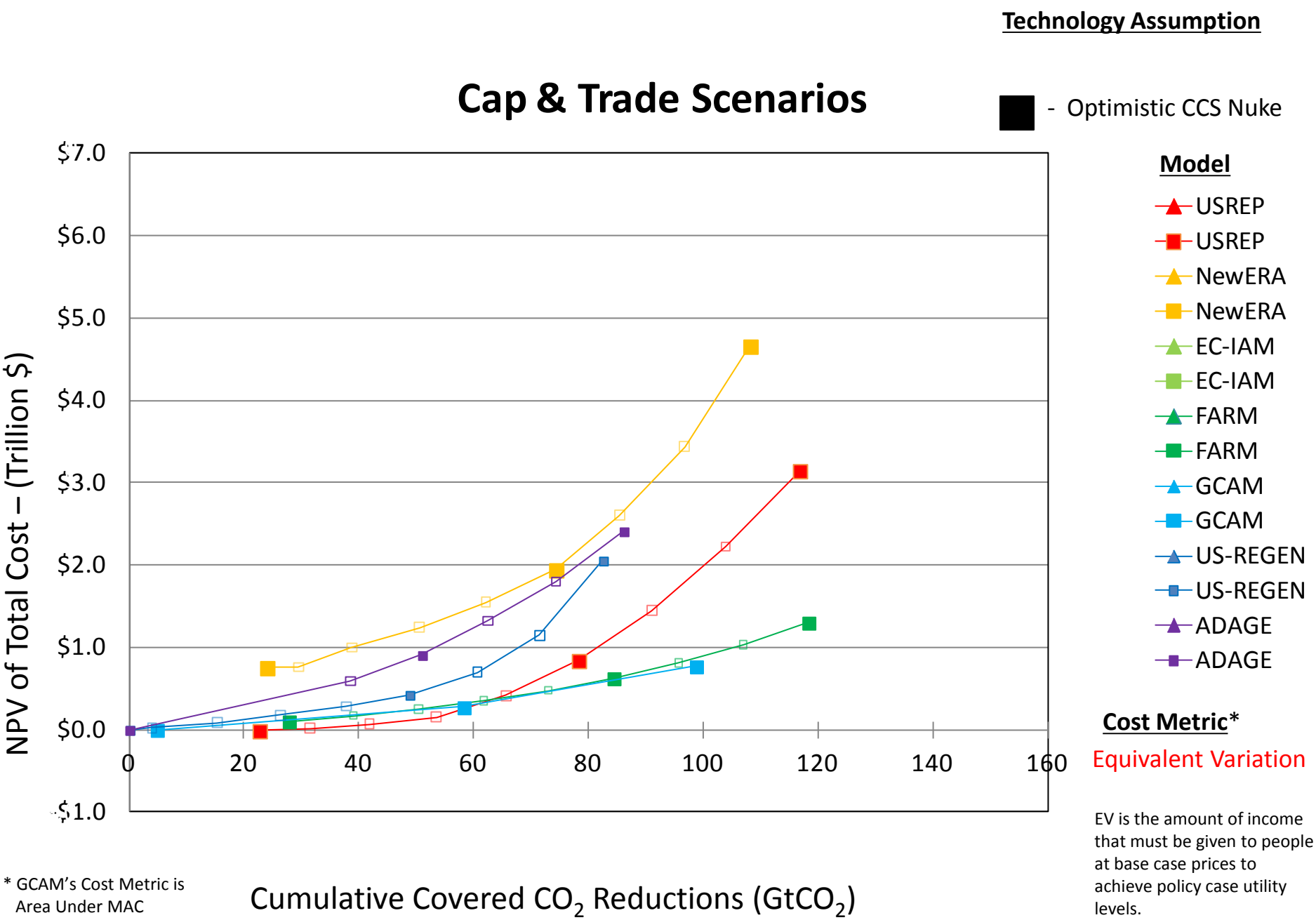

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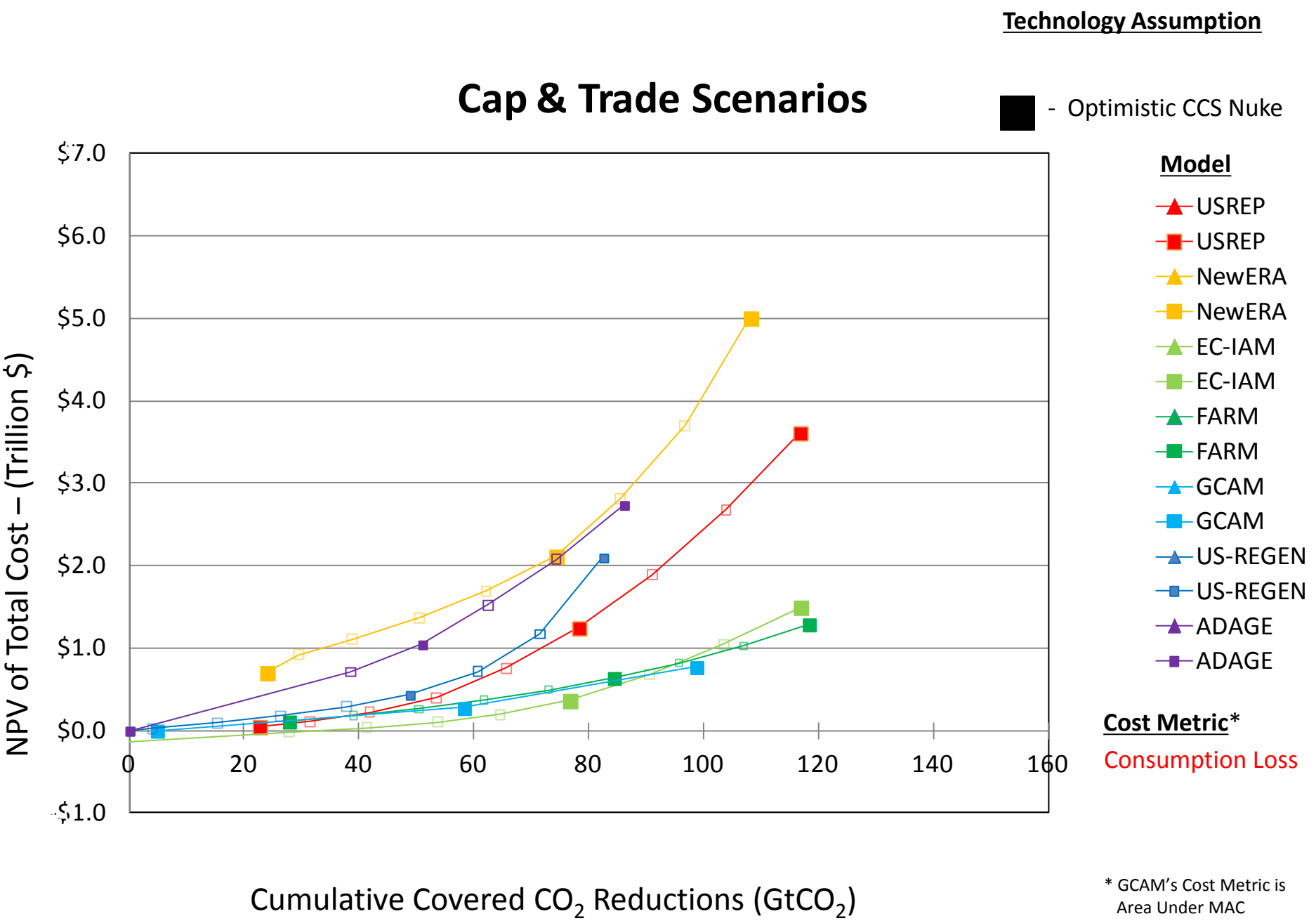

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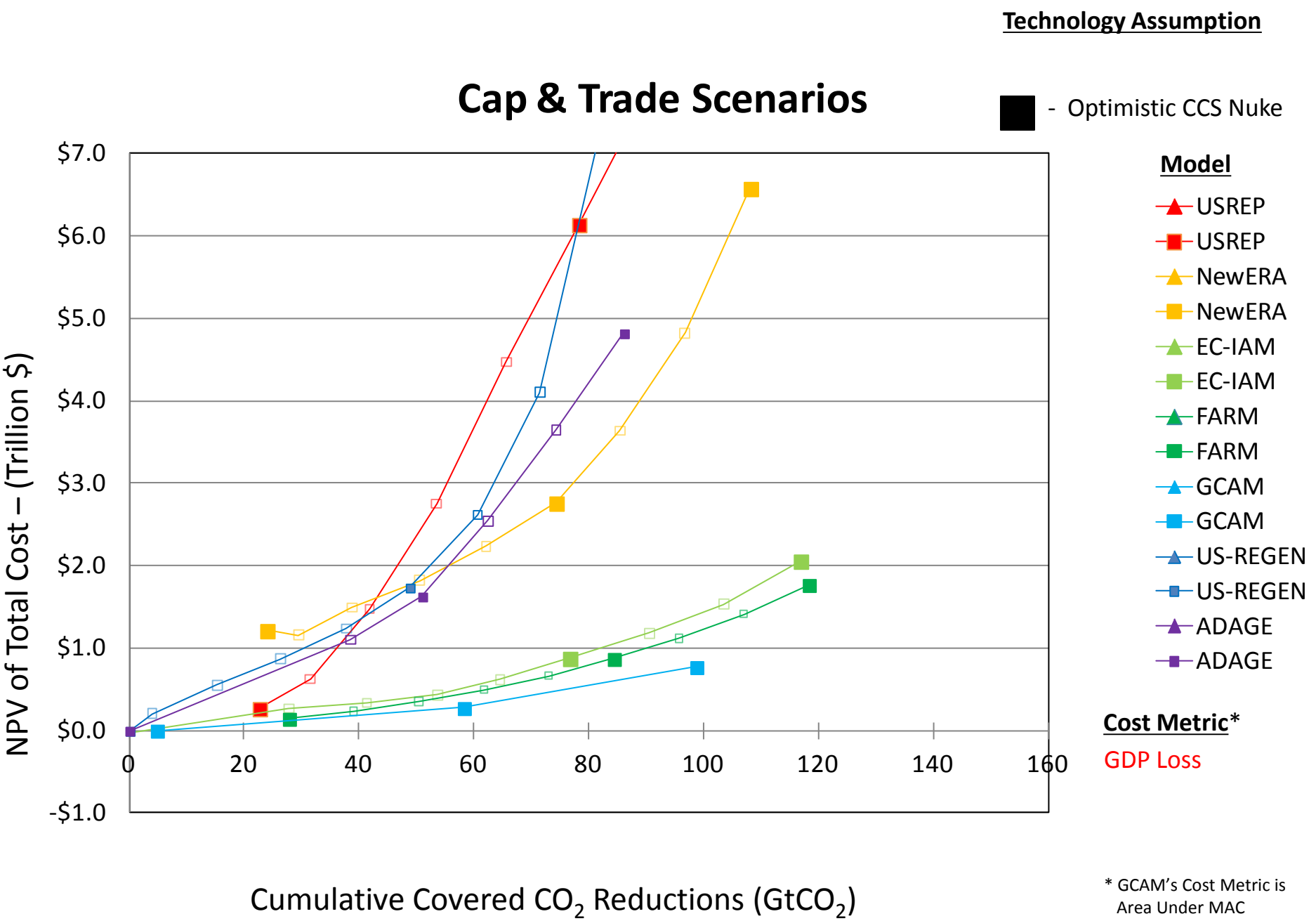

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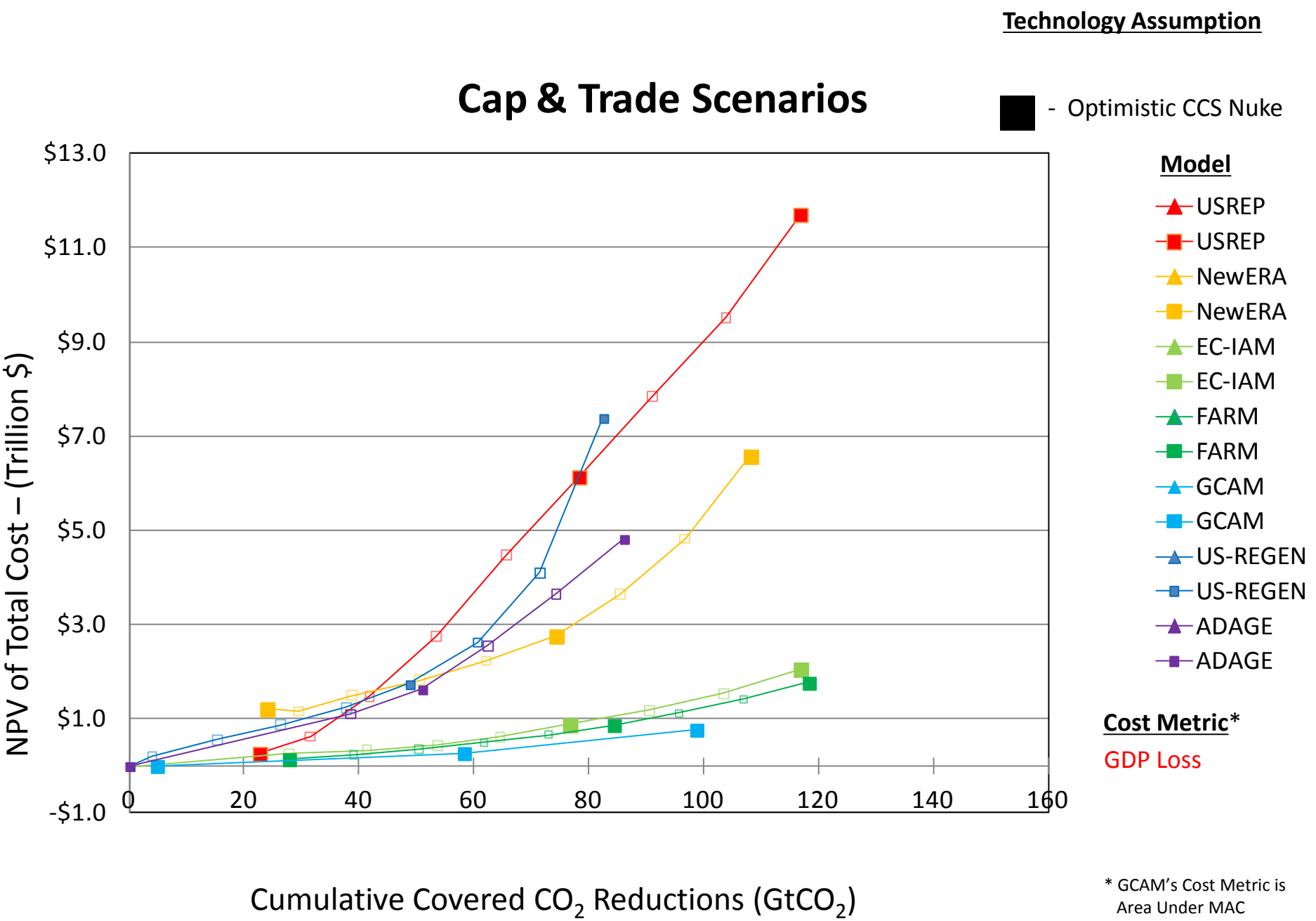

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AN OVERVIEW OF THE REFERENCE SCENARIOS

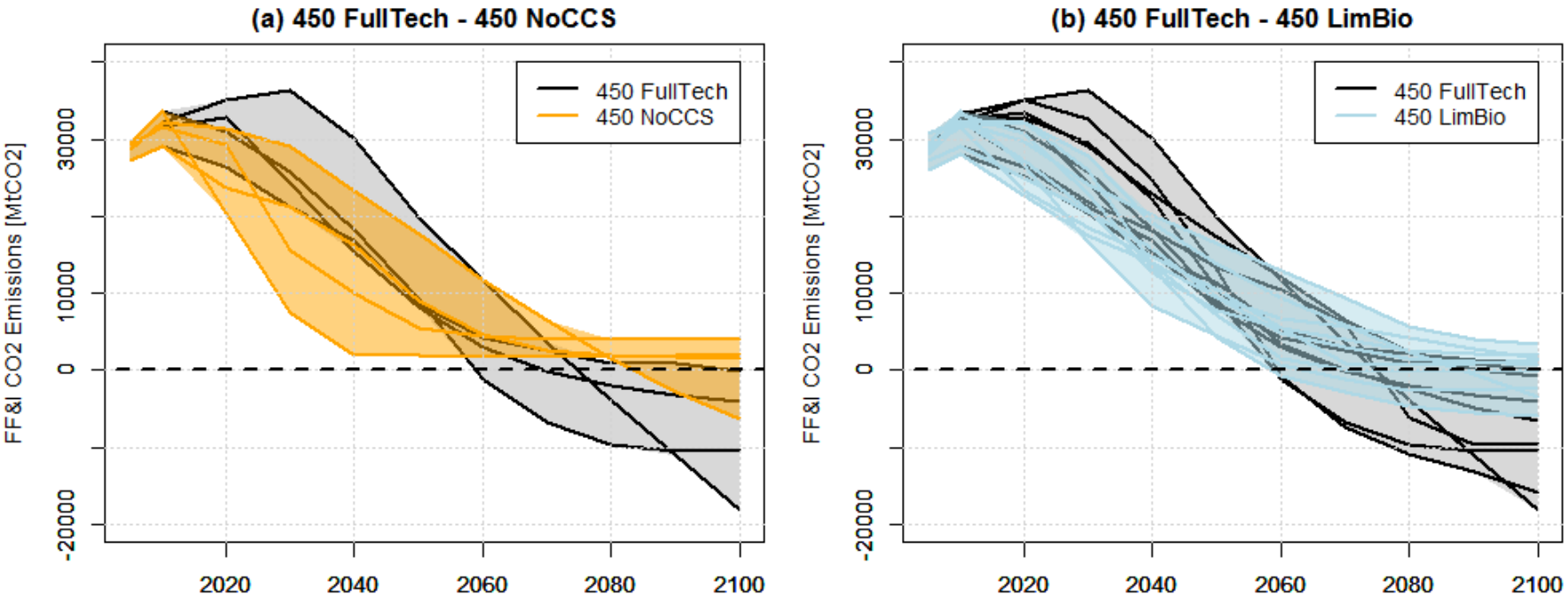
Regional groups

- **Group I: USA, Japan, Canada, Australia, New Zealand, and "Greater Europe", consisting of EU-27, Norway, Switzerland, and Iceland, and the Non-EU Eastern European countries including Belarus, Ukraine, Moldova.**

- **Group II: All developing countries with the exception of several identified non-participants (the third group). Technically, all countries not included in Group I or III. Included are China, India, Brazil, South Africa, OECD members Korea, Mexico, and Turkey, and most other countries in Asia, Latin America, and Africa.**

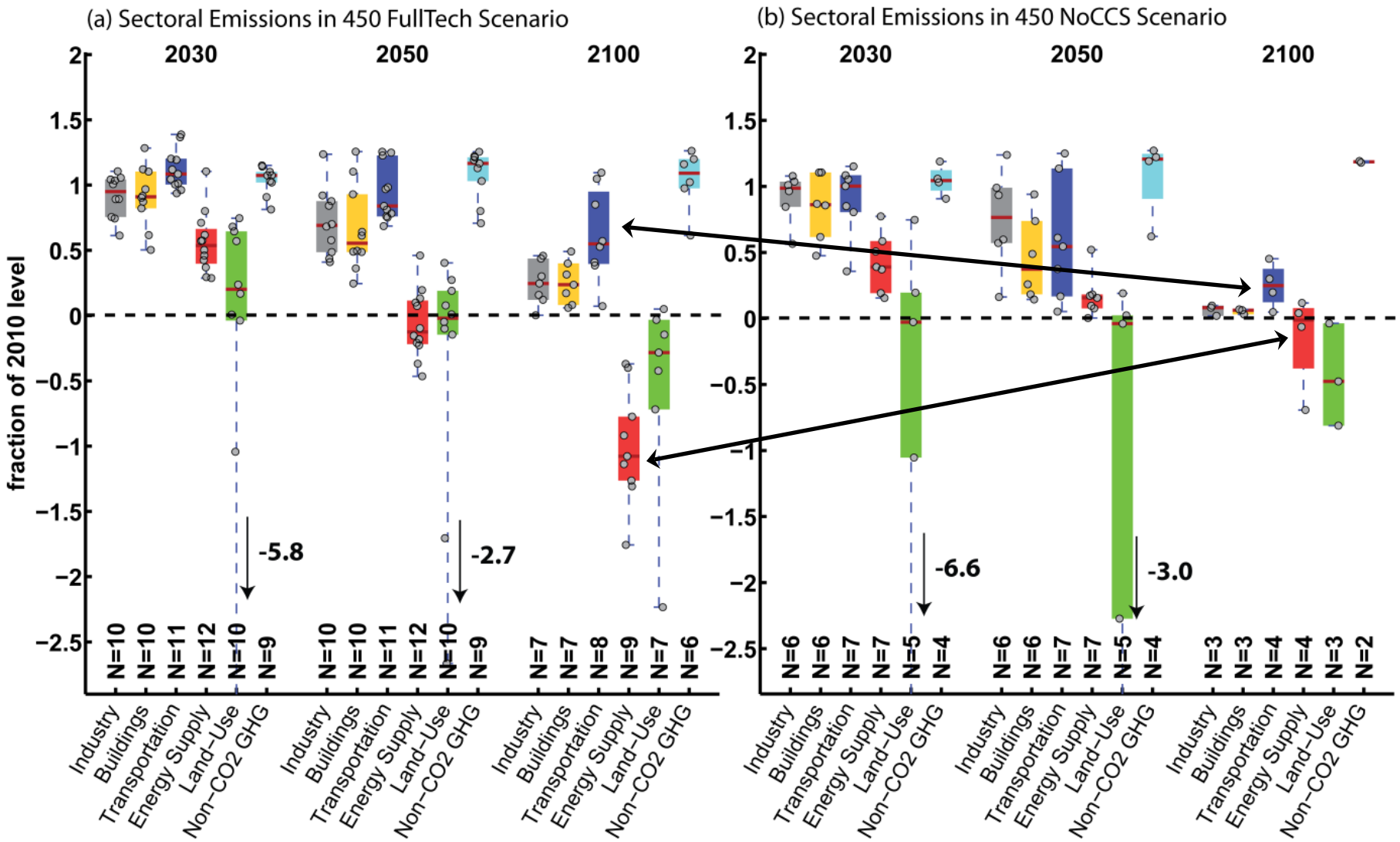
- **Group III: Includes fossil energy resource owners that may have little or no incentive to participate in a global climate policy regime. Included are Russia, the (Central) Asian Former Soviet Union countries (Armenia, Azerbaijan, Georgia, Uzbekistan, Turkmenistan, Kyrgyzstan, Tajikistan and Kazakhstan), as well as Middle East OPEC countries Saudi Arabia, Iran, Iraq, Algeria, Libya, Kuwait, Qatar, and UAE.**

Impact of technology on emissions profile



Krey, Luderer et al, Climatic Change, forthcoming

Sectoral emissions response



Krey, Luderer et al, Climatic Change, forthcoming

ROSE study on the role of population, economic growth, fossil fuel availability and delayed action for achieving concentration targets

Special issue in Climate Change

Delayed action (Luderer et al.), Energy security (Cherp et al.), African development & emissions (Calvin et al.), Fossil fuel markets (Bauer et al.), Fossil fuel and biofuel interactions (Calvin et al.), Drivers of energy investment (DeCian et al.), China energy transformation (Chen et al.)

5 participating models (4 x global, 1 x China)

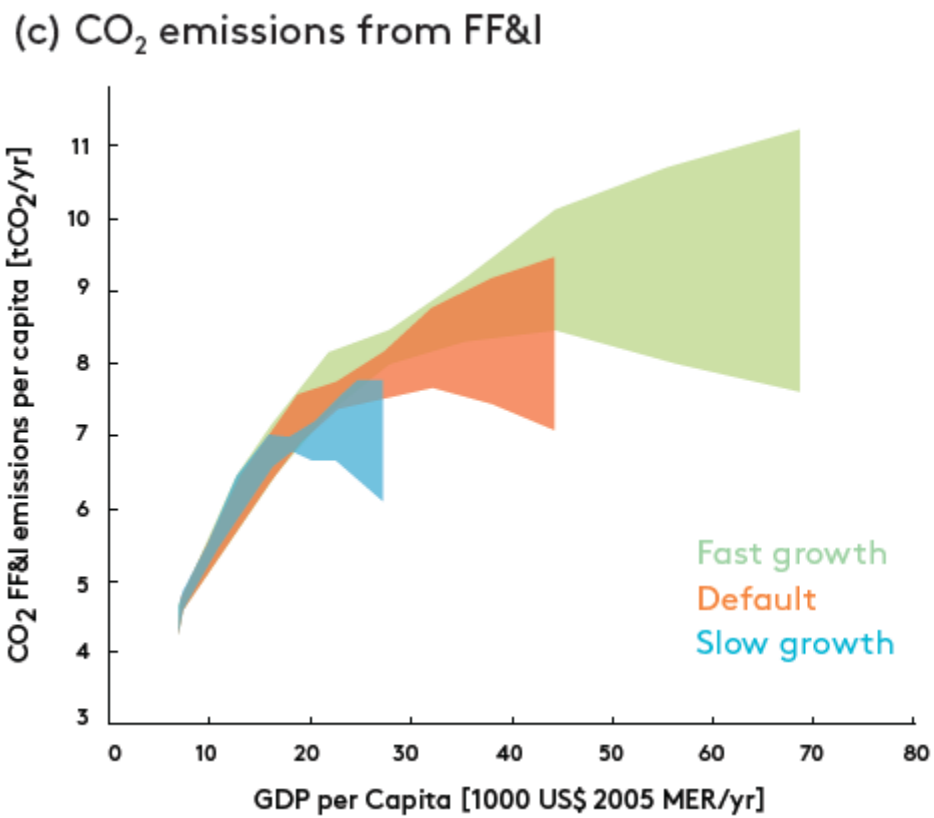
GCAM, IPAC, REMIND, WITCH, China-TIMES

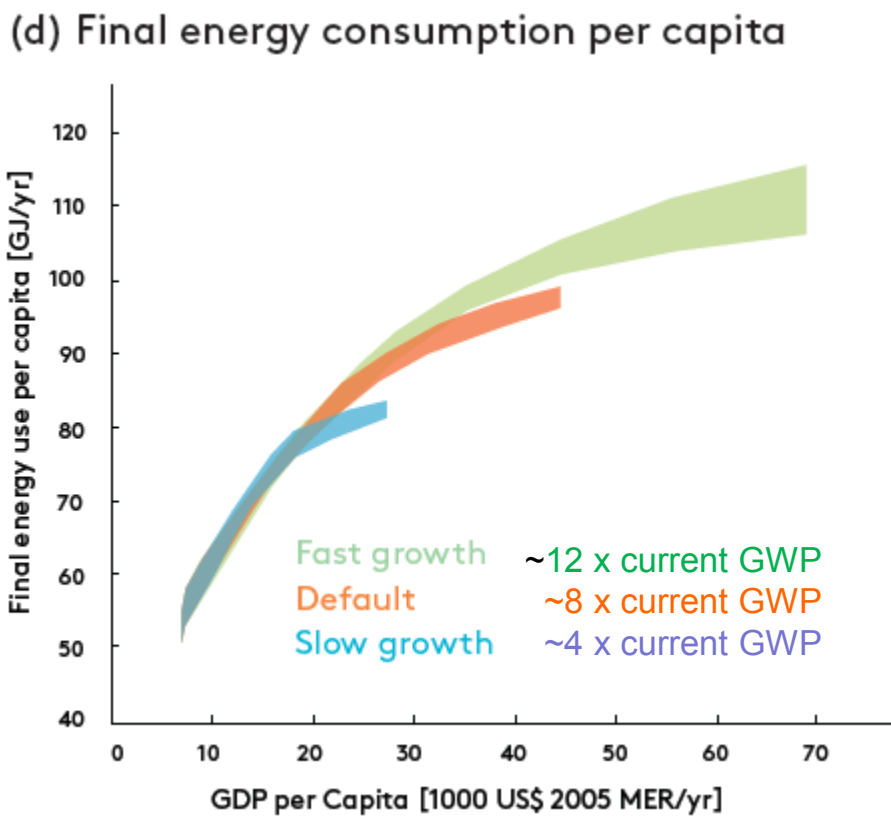
For more information on the RoSE study: www.rose-project.org

Funded by Stiftung Mercator

Climate stabilization requires strong climate policy

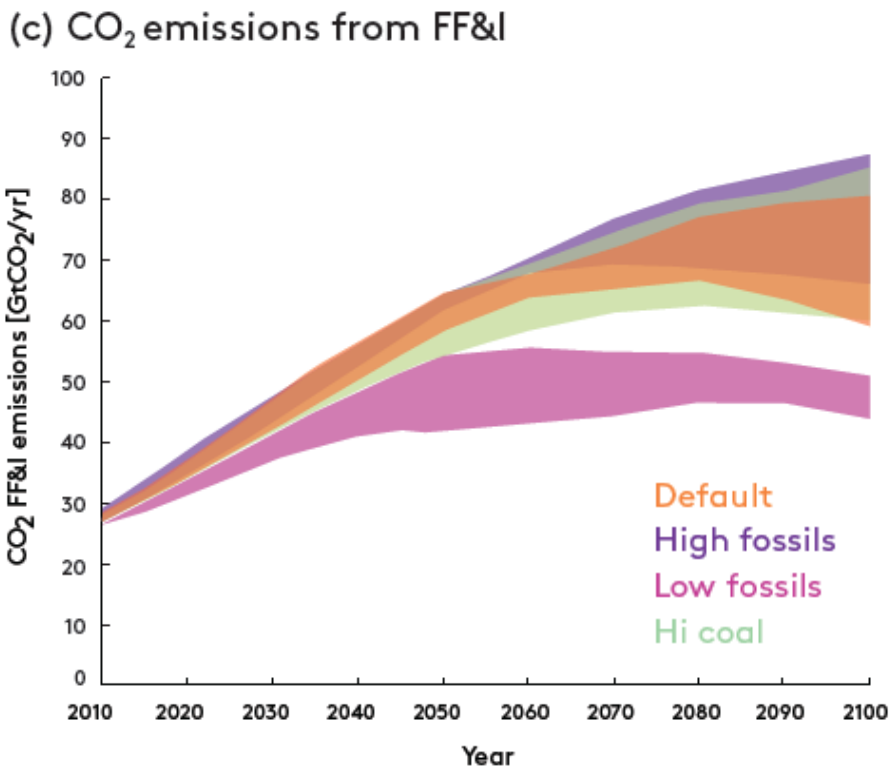
In the absence of climate policy and with current trends in energy intensity, energy demand and CO_2 emissions will increase with per capita income

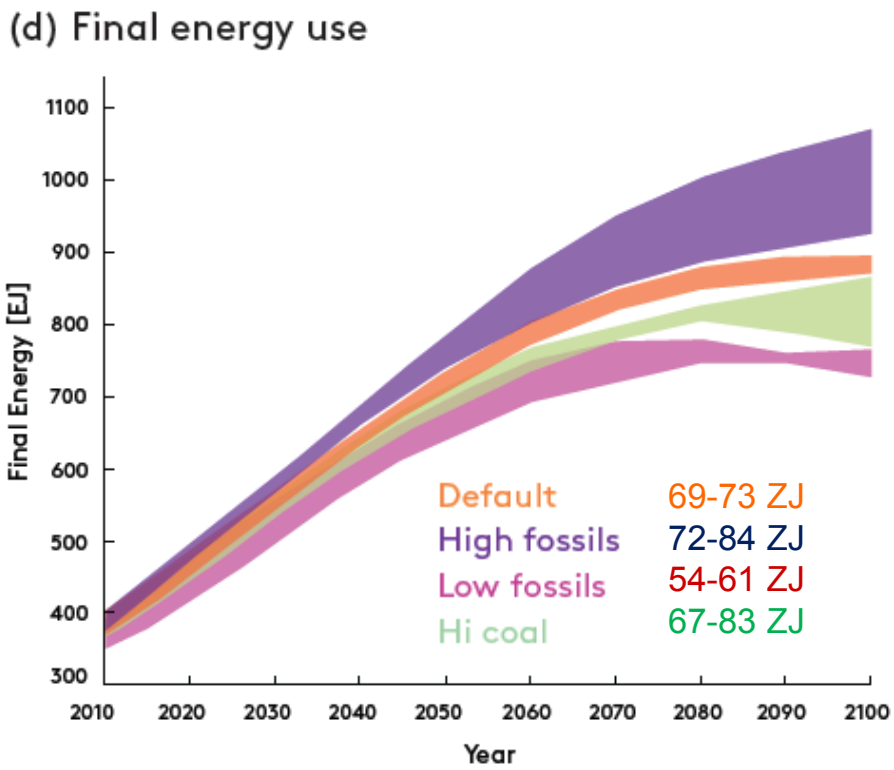




Climate stabilization requires strong climate policy

Fossil fuel scarcity alone is not sufficient to reduce CO_2 emissions





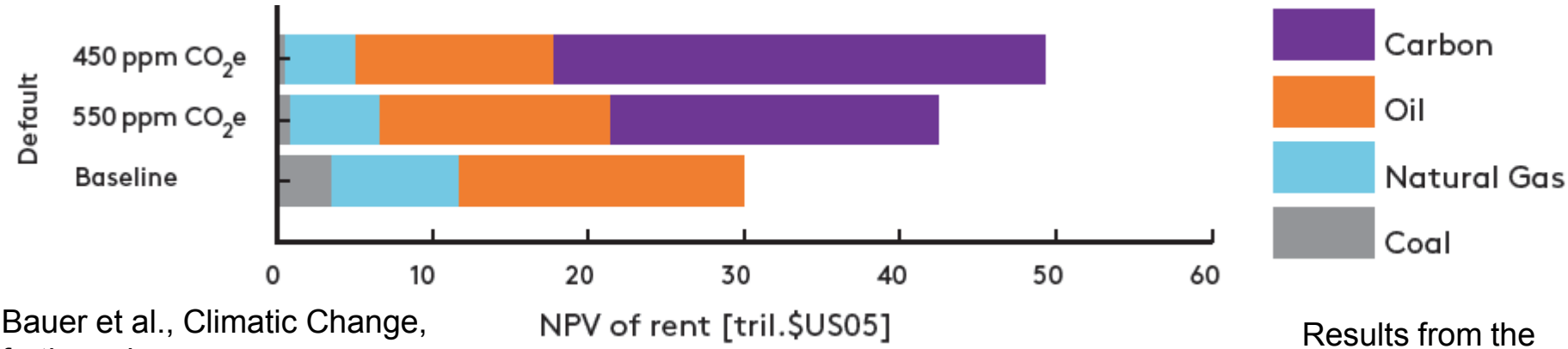
ca. 19 ZJ of fossil fuels burned until today
ca. 36 ZJ of proven reserves today

Mitigation strongly impacts fossil fuel markets

- Mitigation improves energy security by diversifying energy supply
  Cherp et al., Climatic Change, forthcoming

- Mitigation reduces fossil fuel rents.
- This is overcompensated by the emerging carbon rent.

Fossil fuel rent = (Price - Production costs) * Fuel; Carbon rent = CO_2 price * Emissions



Bauer et al., Climatic Change, forthcoming

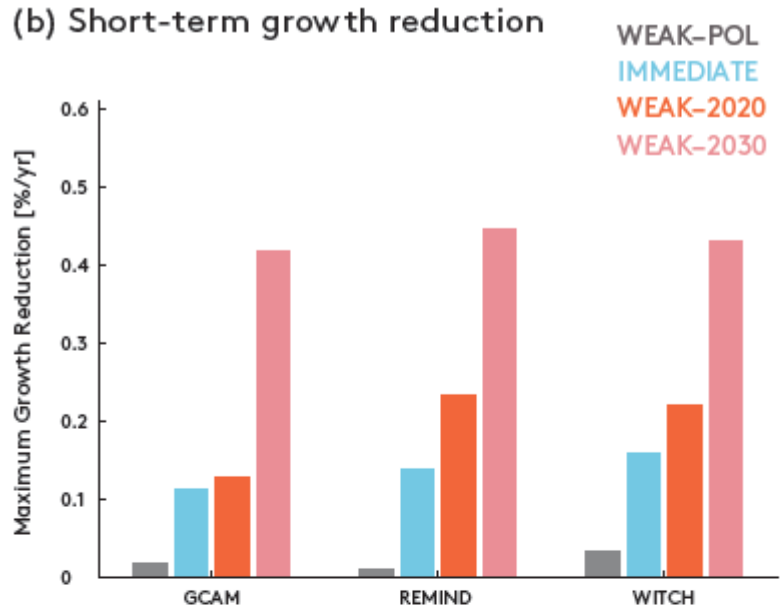
2010-2100, discounted at 5%

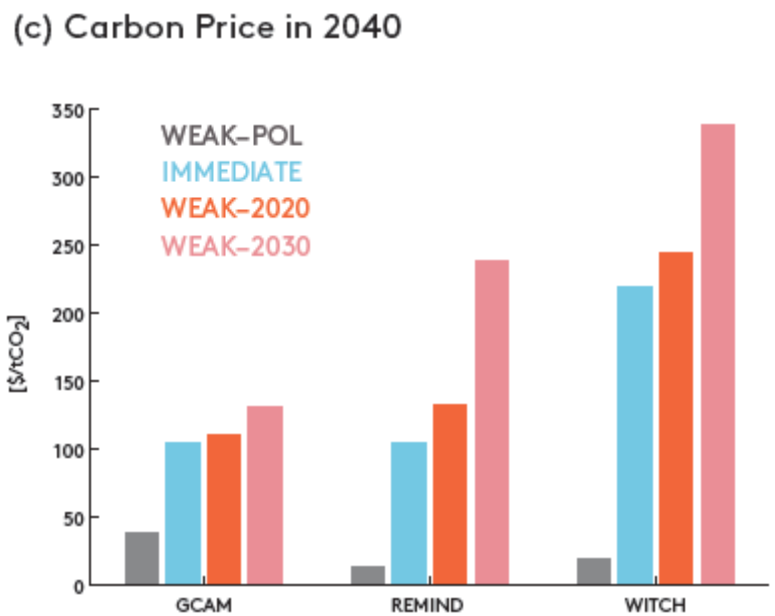
Results from the ReMIND model

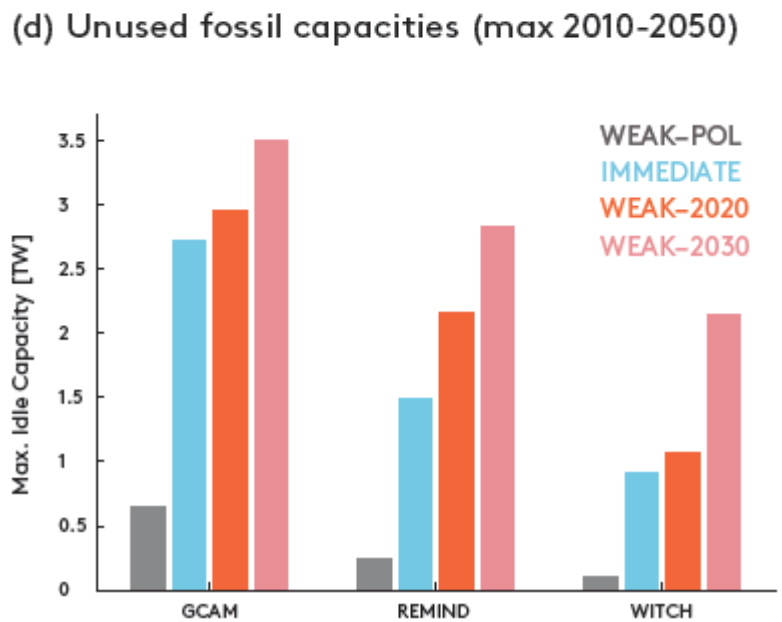
Economic impact of later action

- **Later action implies greater economic and institutional challenges for reaching 2°C**

Luderer et al., Climatic Change, online

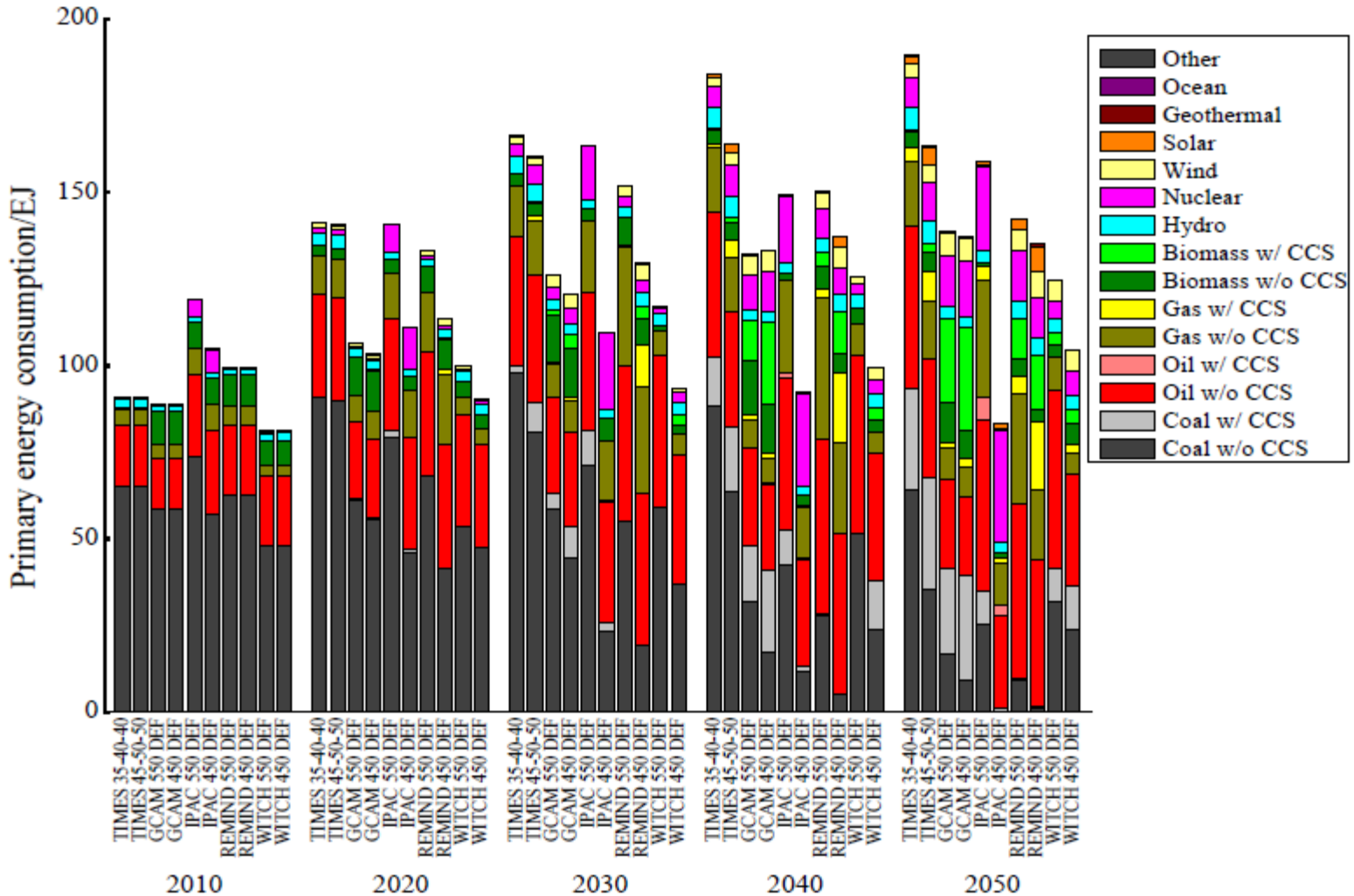






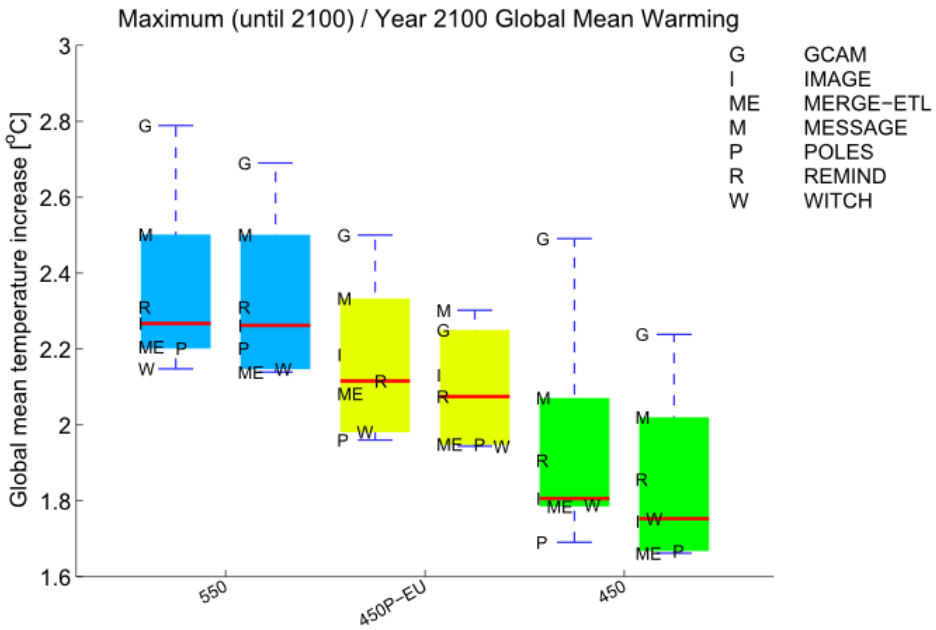
China energy transformation

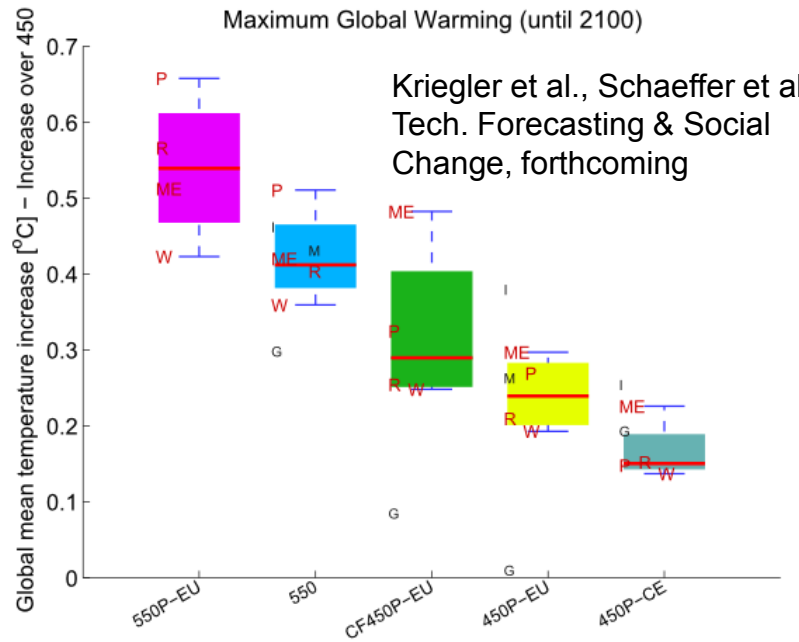
Comparison of global models with China-TIMES



Chen et al., Climatic Change, published

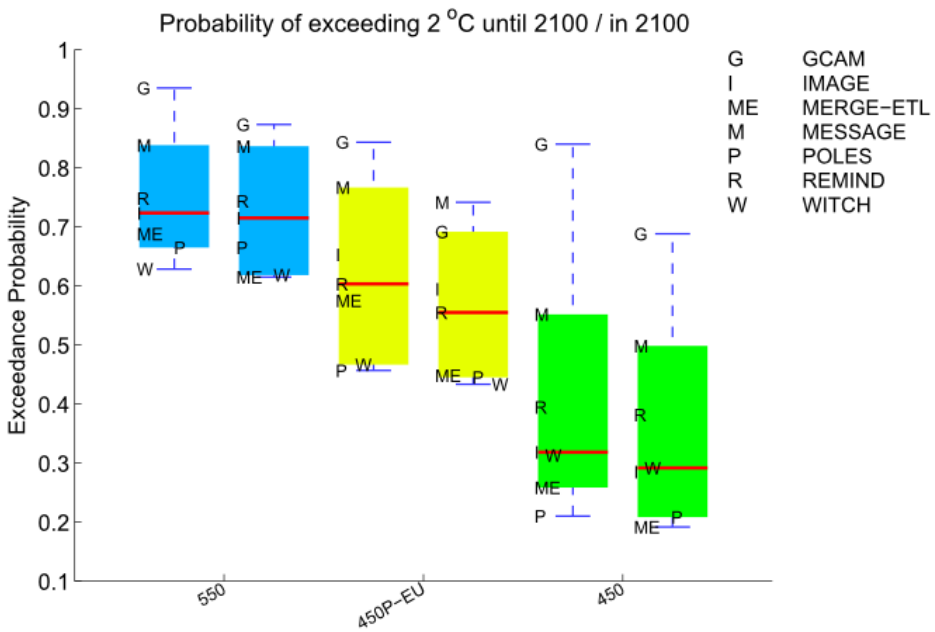
Global mean warming - over pre-industrial (a) and over 450 (b)

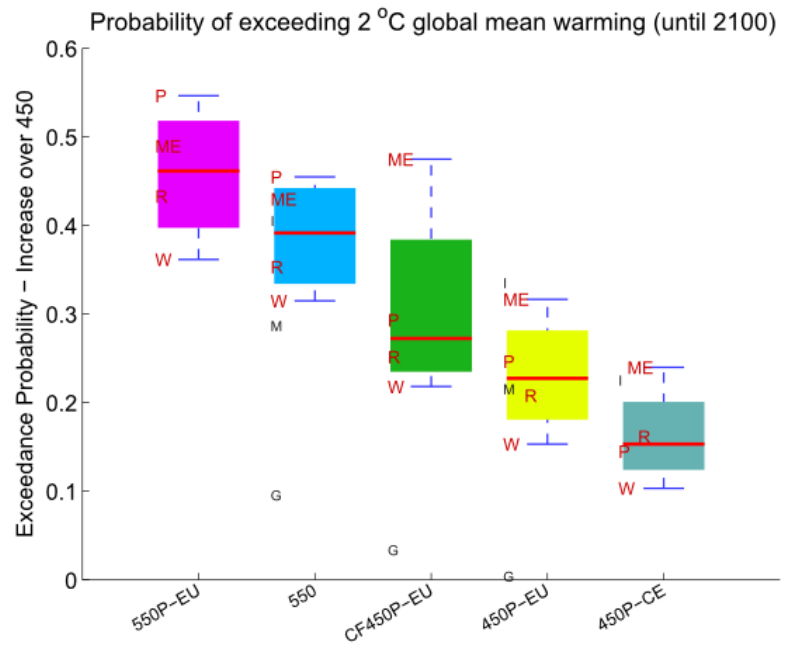




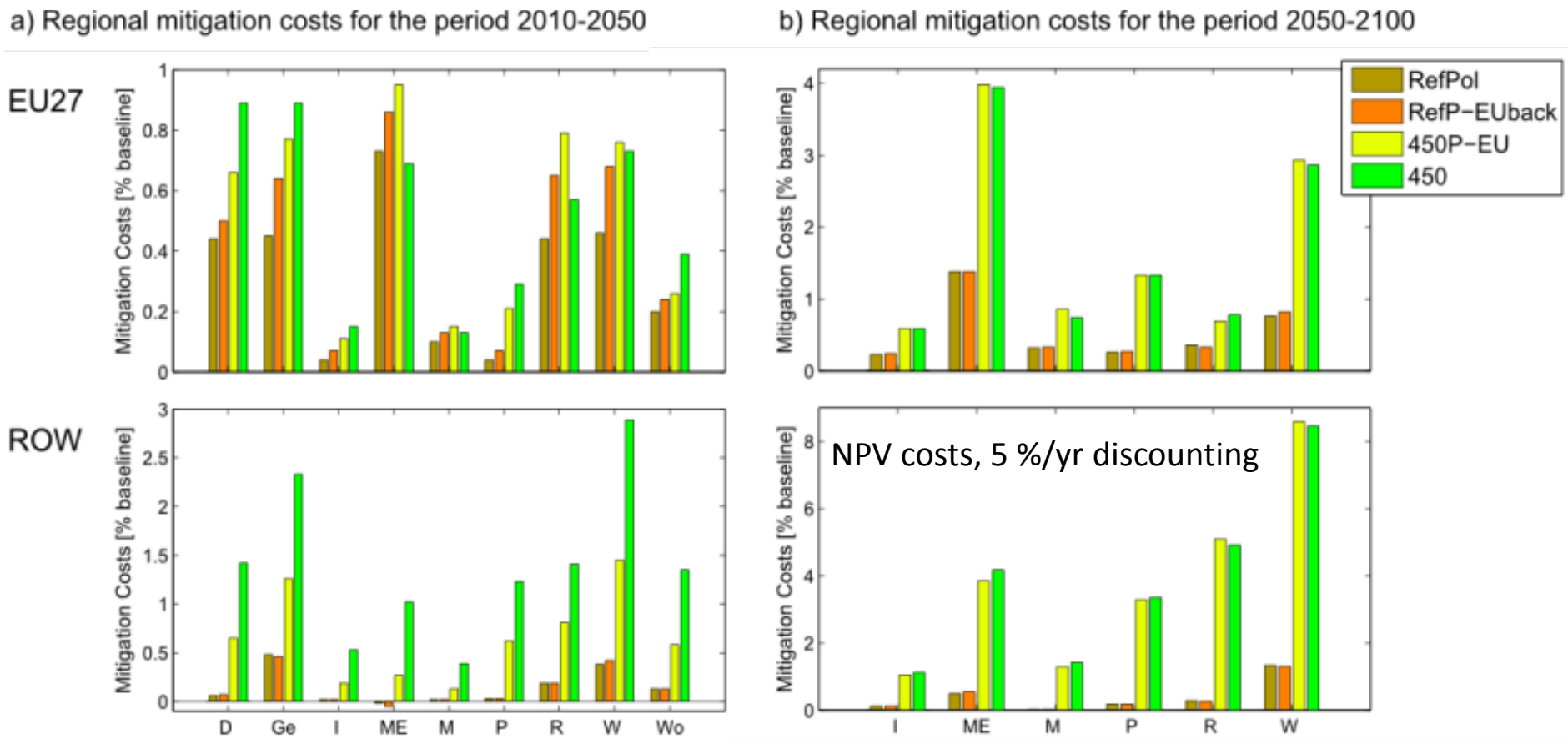
Kriegler et al., Schaeffer et al., Tech. Forecasting & Social Change, forthcoming

Probability of exceeding 2 degrees - total (c) and relative to 450 (d)





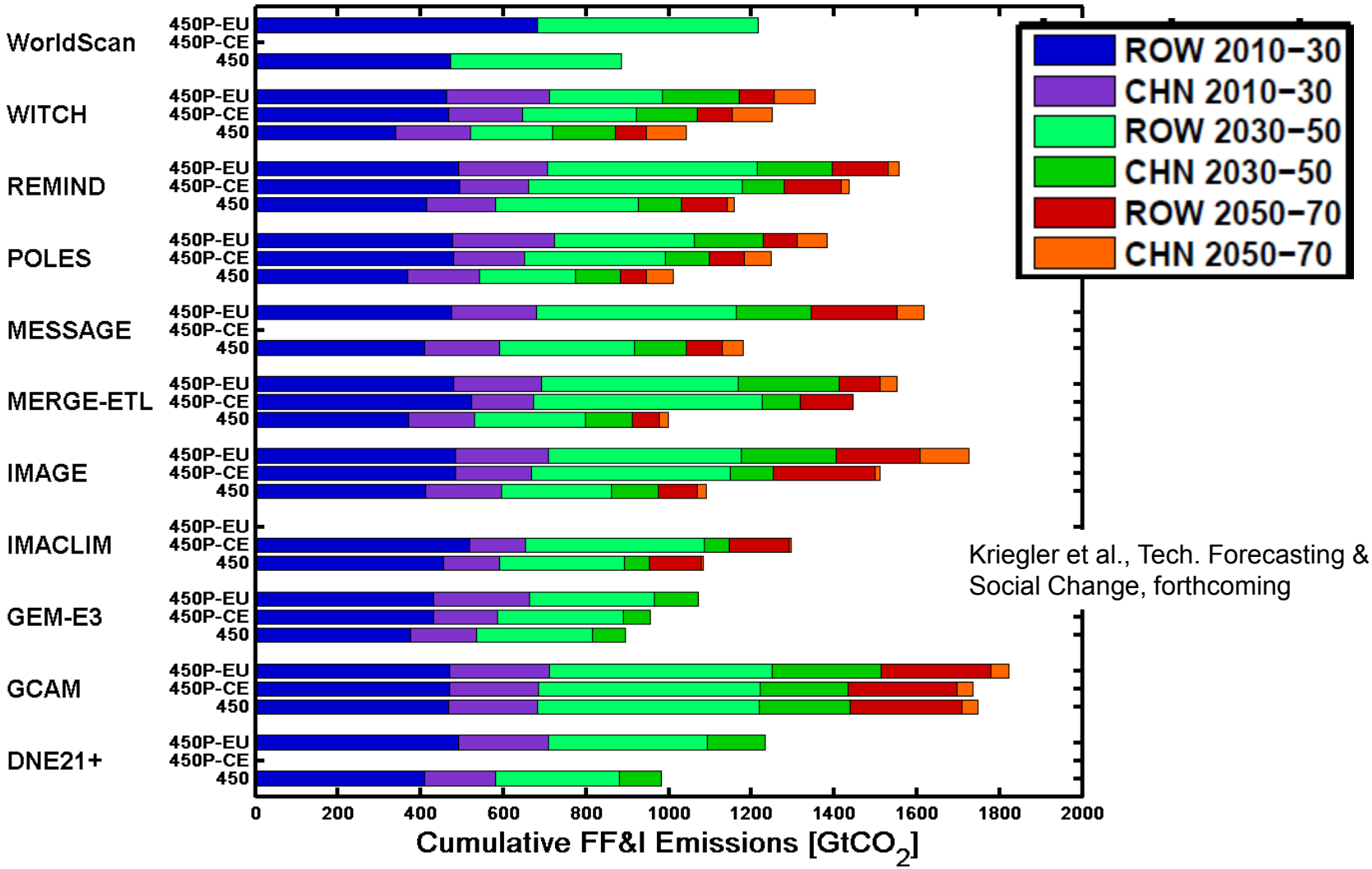
Mitigation costs for early movers & late adopters



Reference policy (20-30-40% reduction in 2020-30-50) costs for EU significant portion of 450 ppm policy costs

Kriegler et al., Tech. Forecasting & Social Change, forthcoming

Carbon lock-in for late adopters



Kriegler et al., Tech. Forecasting & Social Change, forthcoming

- Excess emissions after 2030 exceed those before 2030
- Lower short term costs, but higher transitional costs due to carbon lock-ins

Fossil fuel market impact of delay & fragmentation

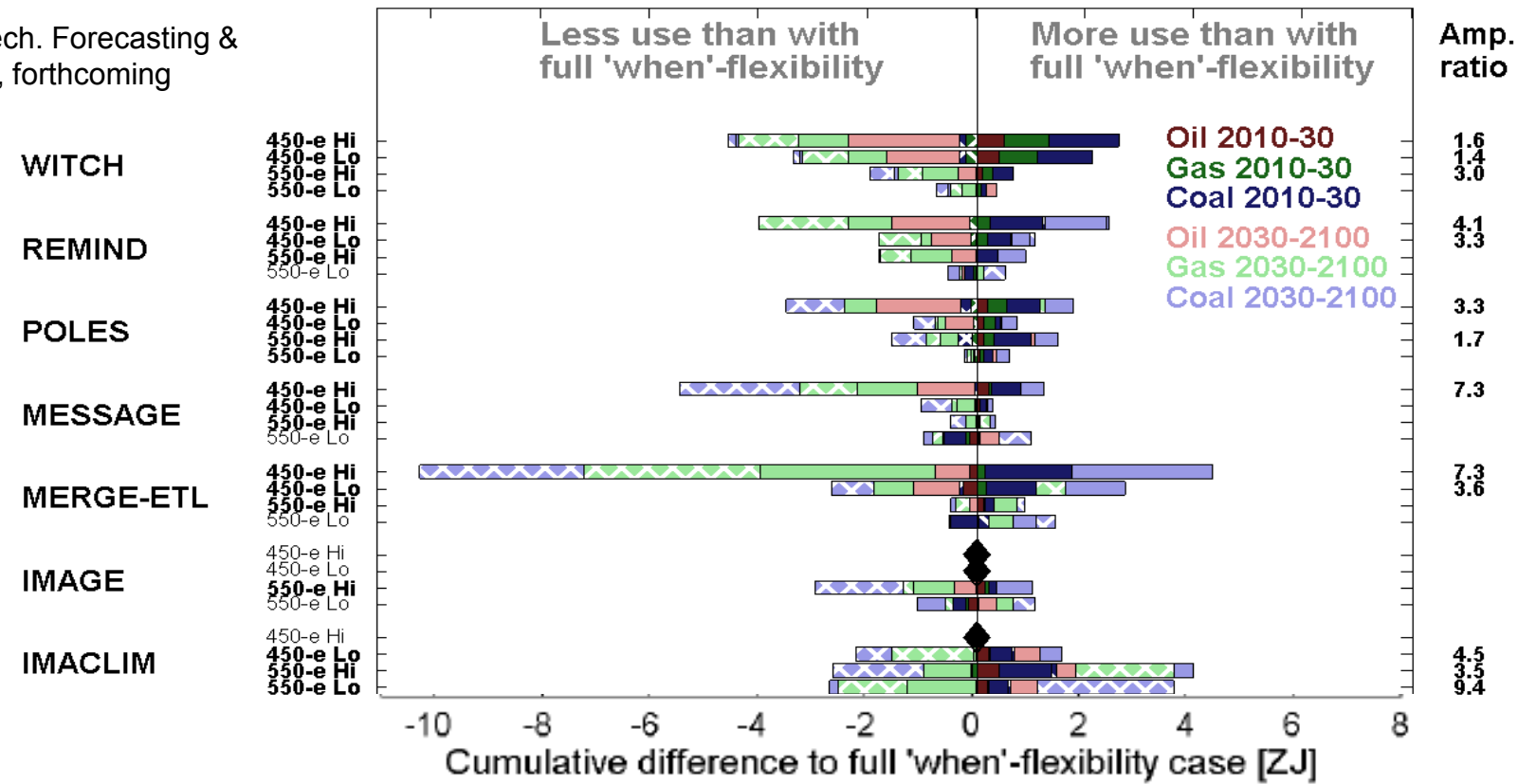
Fragmentation in staged accession scenarios (AMPERE WP3)

➔ Carbon leakage effects limited (leakage rate < 20% in most cases)

Delayed action in reaching long term targets (AMPERE WP2)

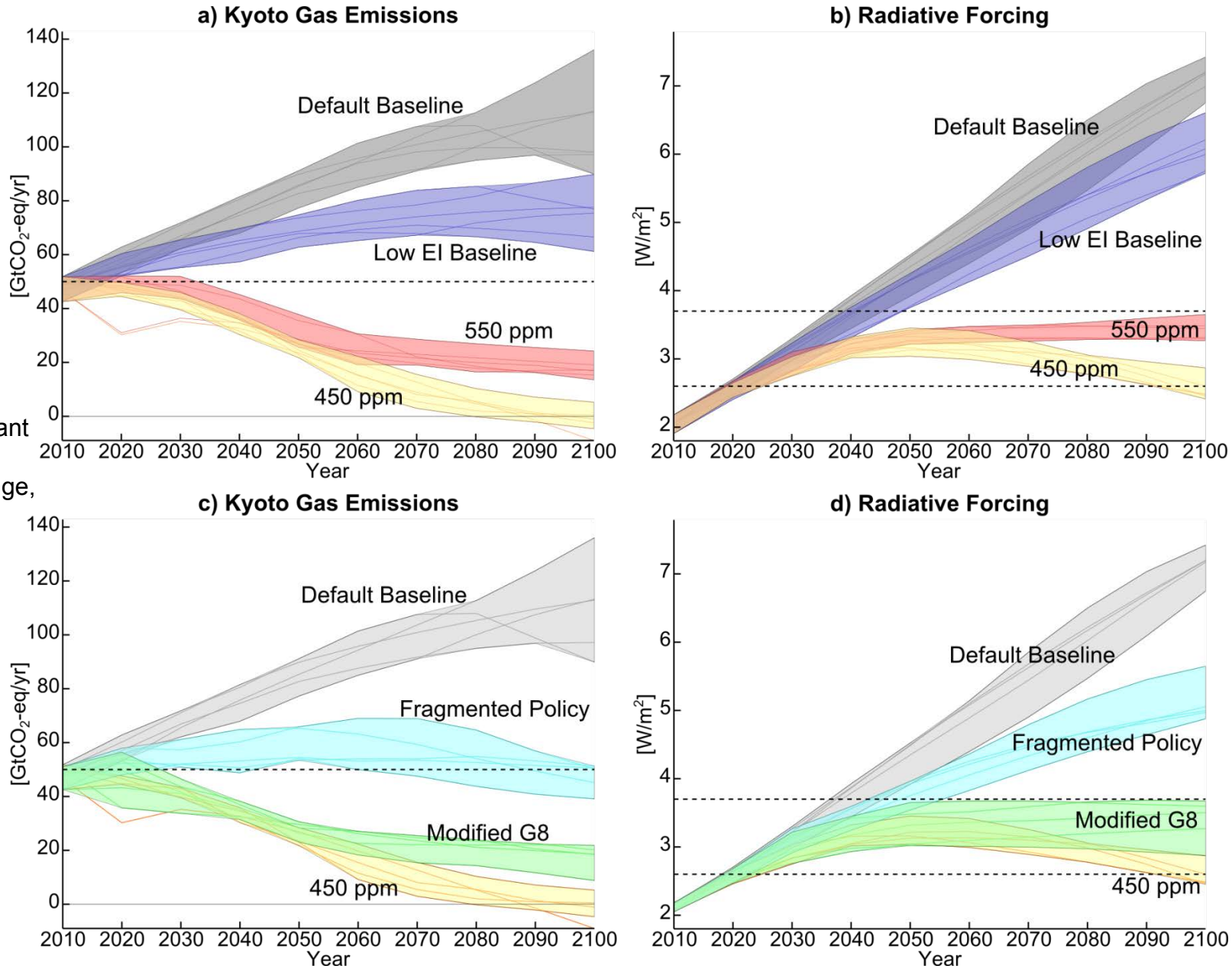
➔ Less cumulative fossil fuel use (2010-2100) in the case of delay

Bauer et al., Tech. Forecasting & Social Change, forthcoming

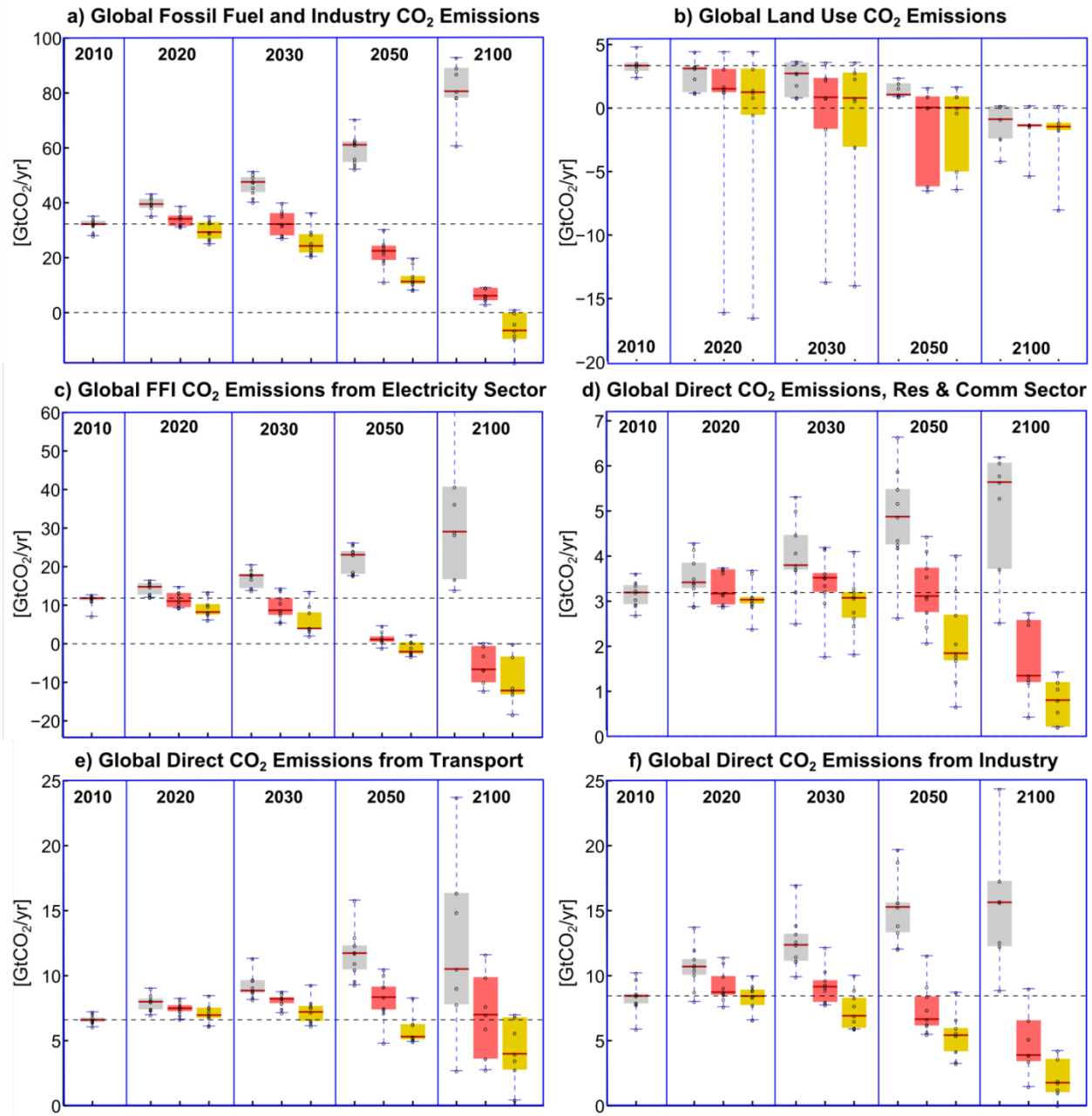


Backup slides

Kriegler, Weyant et al., Climatic Change, forthcoming



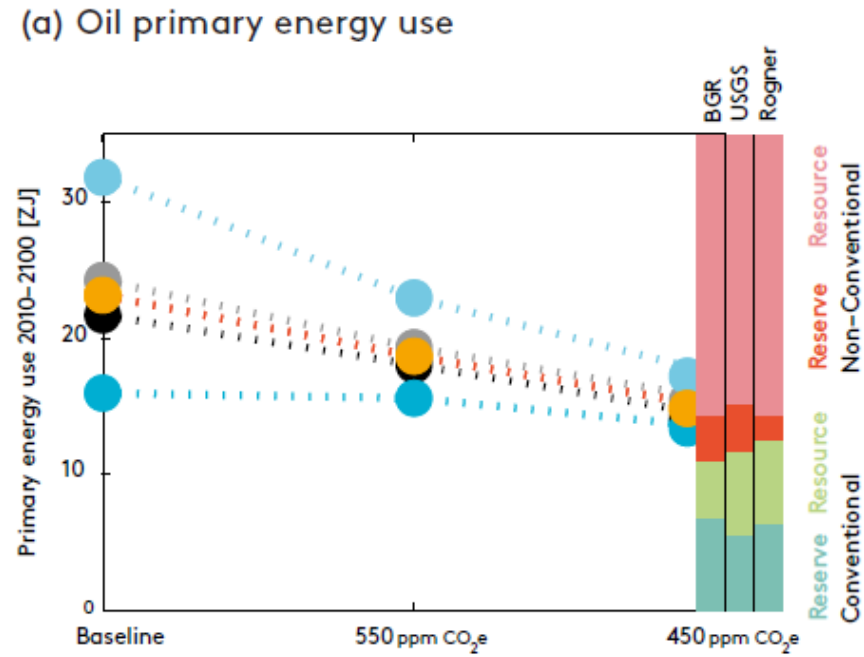
Kriegler, Weyant et al., Climatic Change, forthcoming

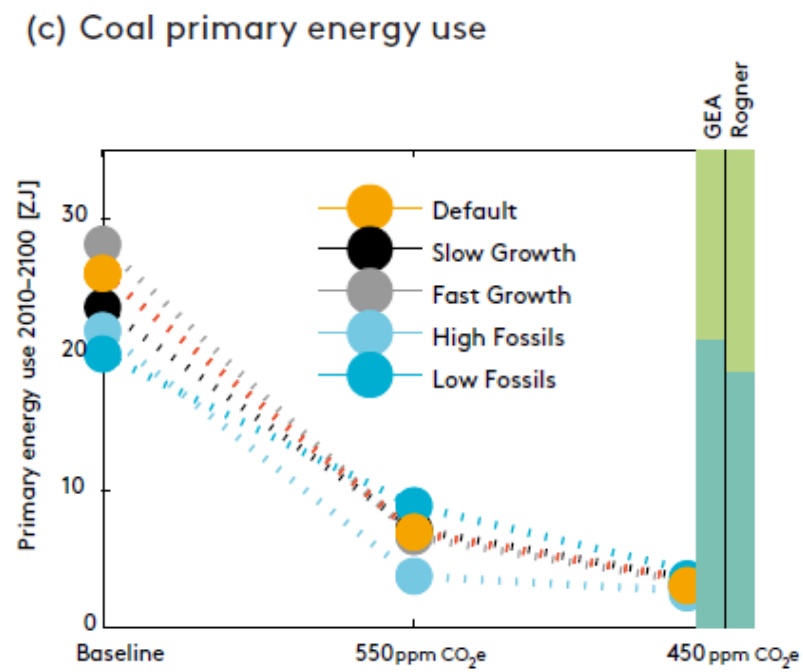


Mitigation strongly impacts fossil fuel markets

- **Strong reduction of coal use**
- **Only moderate reduction of oil use (conventional reserves & resources are still being used)**
- **Climate mitigation effectively limits uncertainty about future fossil fuel use**

Bauer et al., Climatic Change, forthcoming



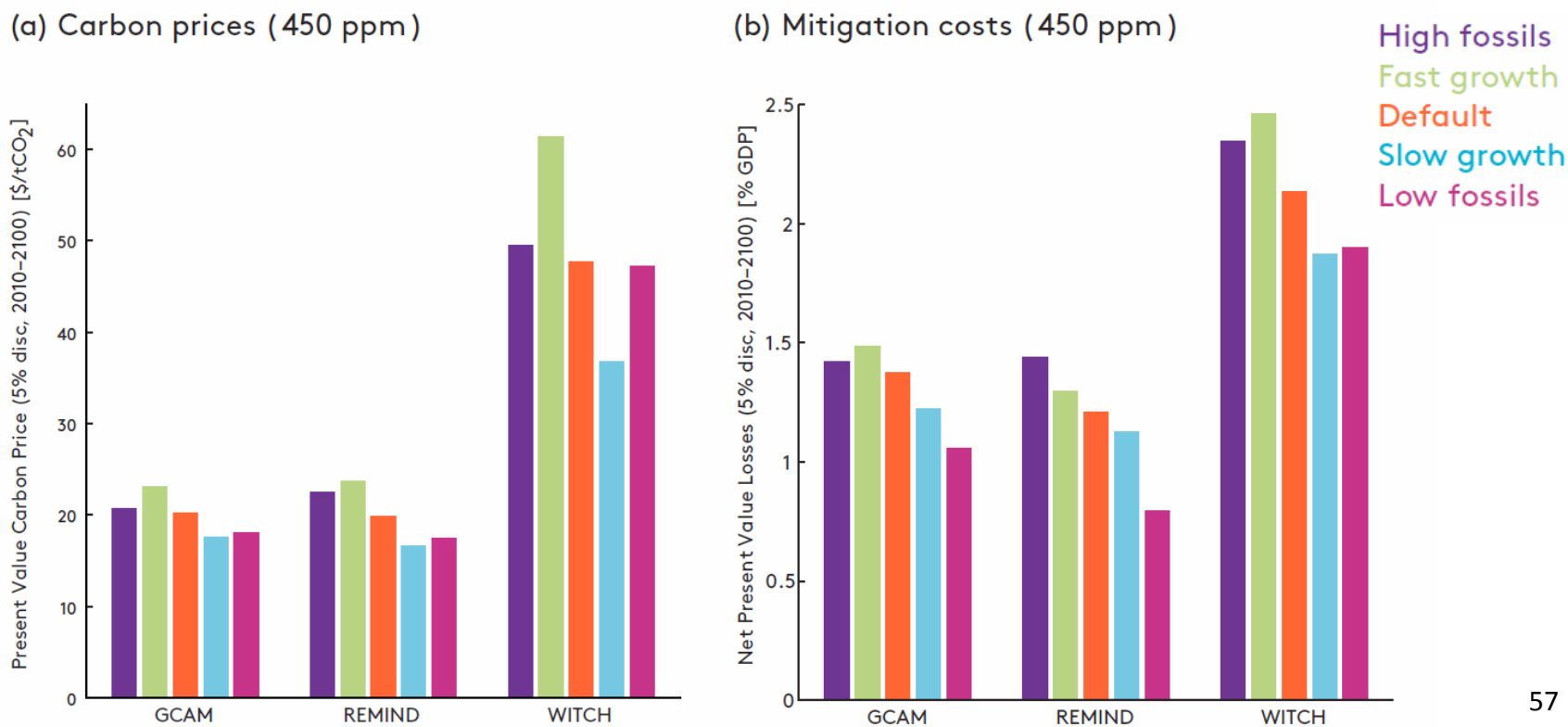


Carbon prices and mitigation costs 2010-2100

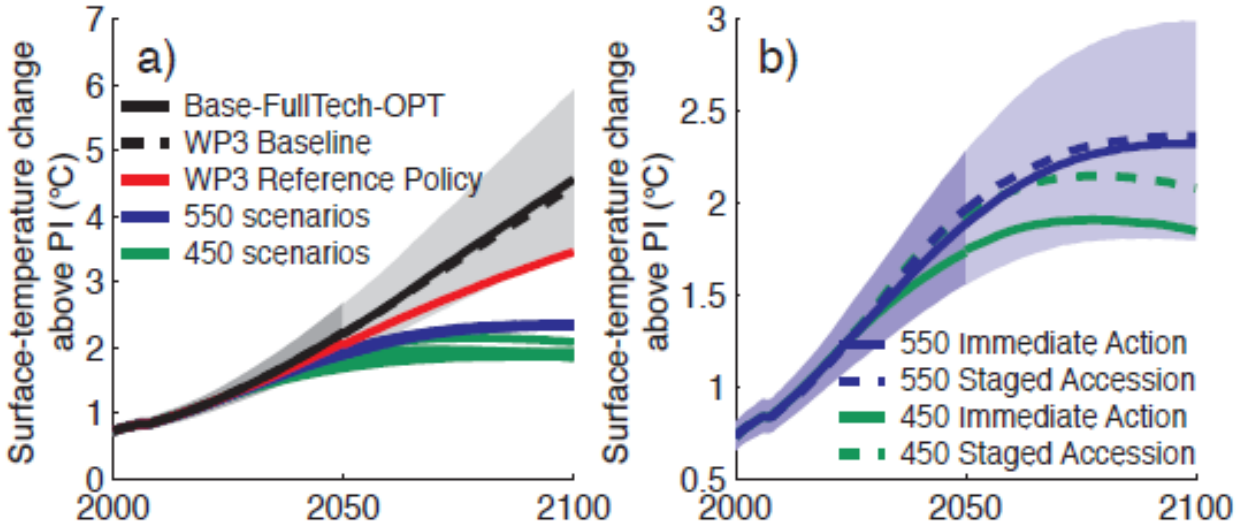
- **Estimates for „idealized immediate global action scenarios“!**
- **Only direct costs of climate mitigation. No benefits, co-benefits or adverse side-effects included**

➢ **Costs vary by 25-80% with economic growth and fossil fuel assumptions**

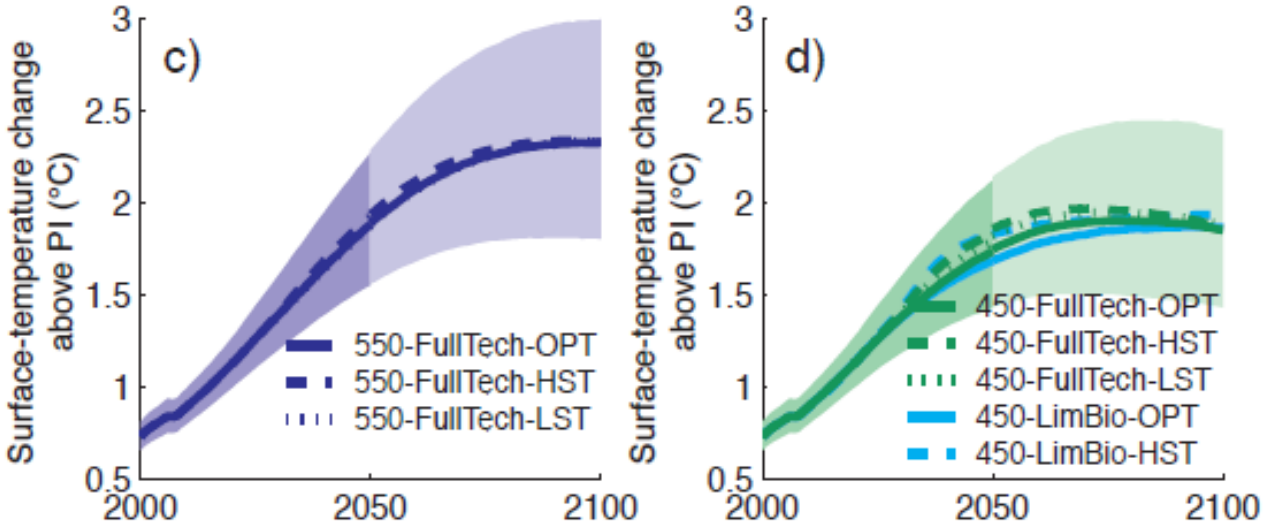
➢



Temperature outcomes of AMPERE scenarios

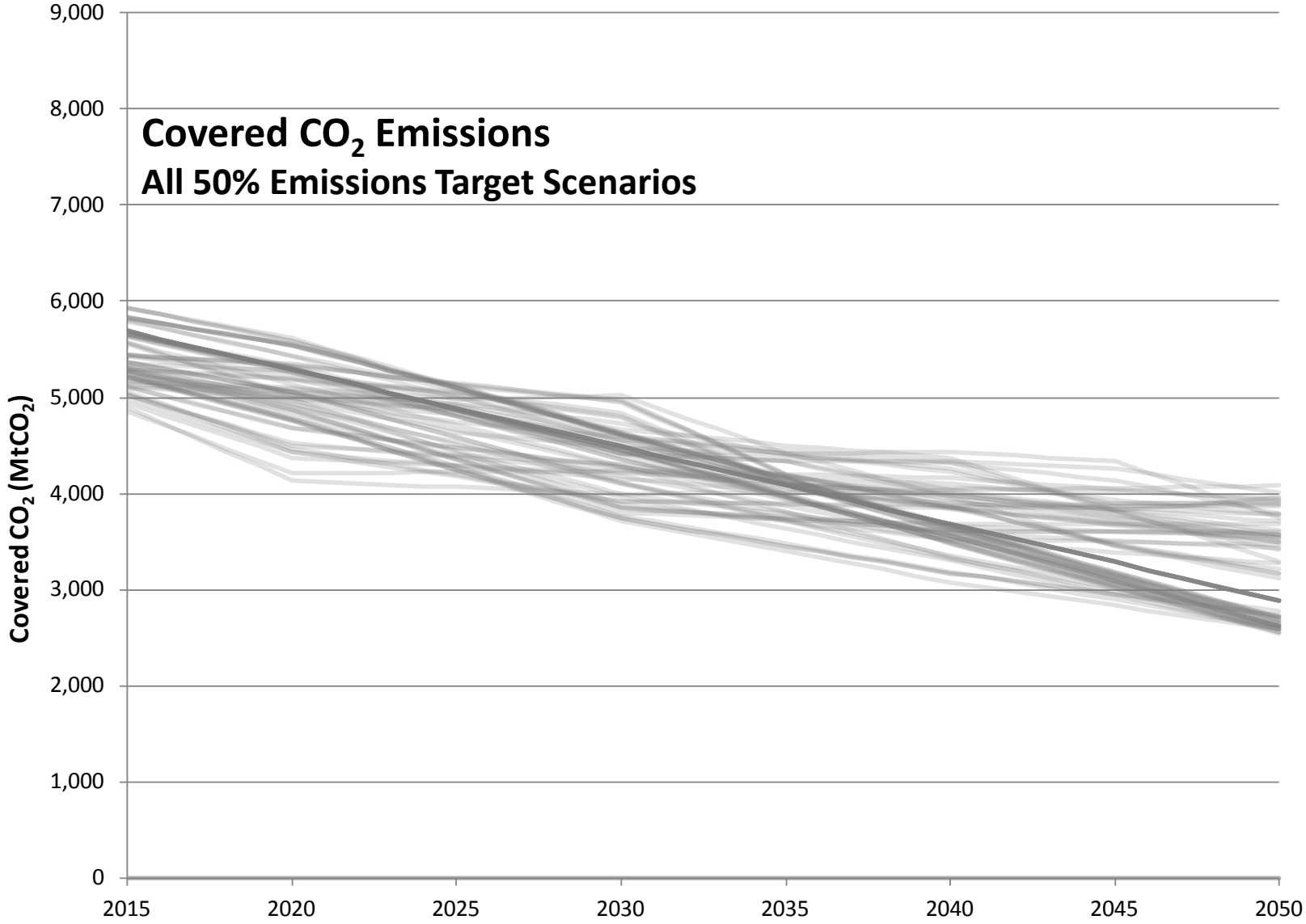


Schaeffer et al., Technological Forecasting & Social Change, forthcoming

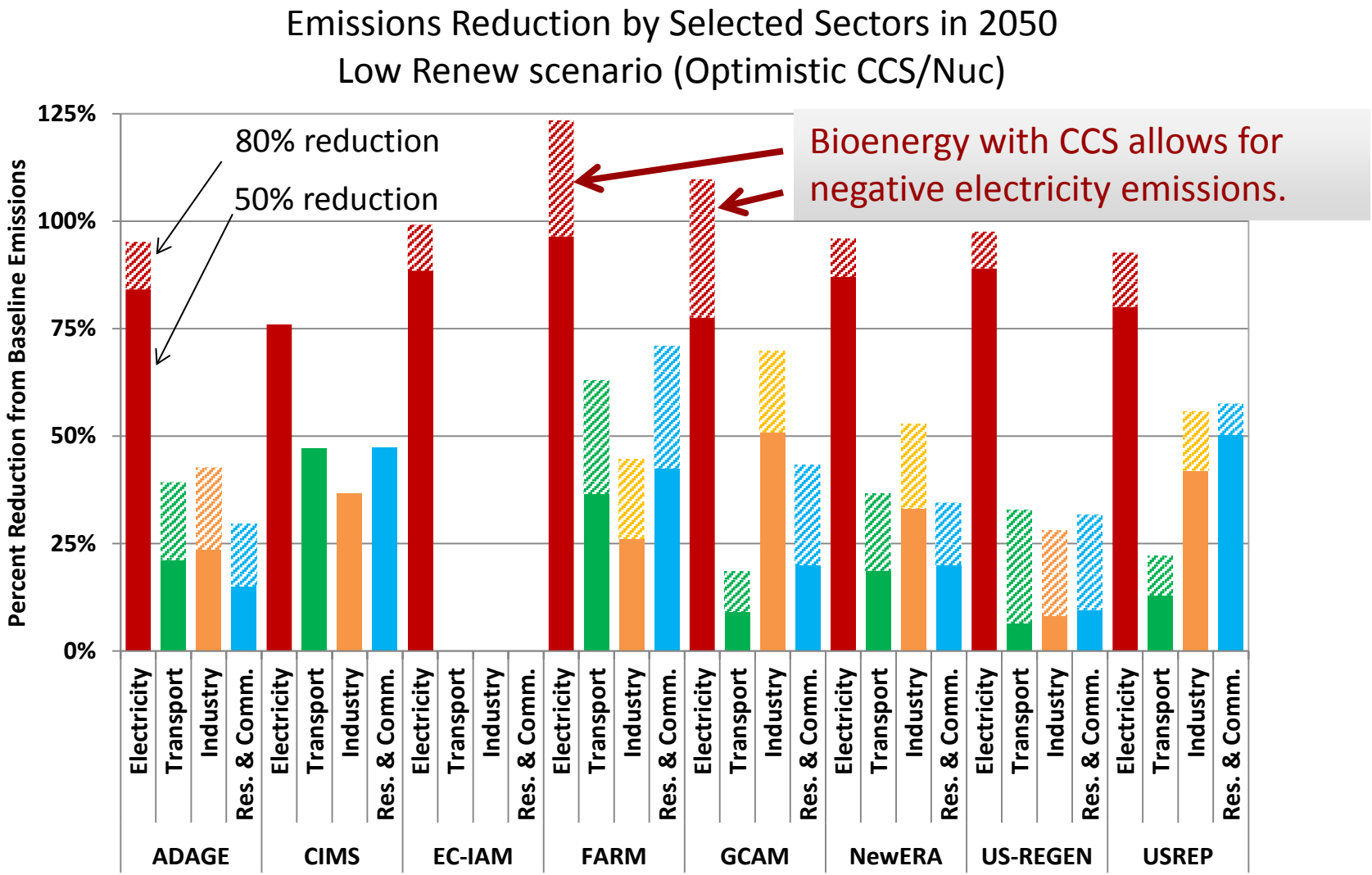


KEY RESULTS FROM THE MITIGATION SCENARIOS: TECHNOLOGY DIMENSION

By construction, the scenarios include banking, but not borrowing



The Nature of Sectoral Emissions Reductions



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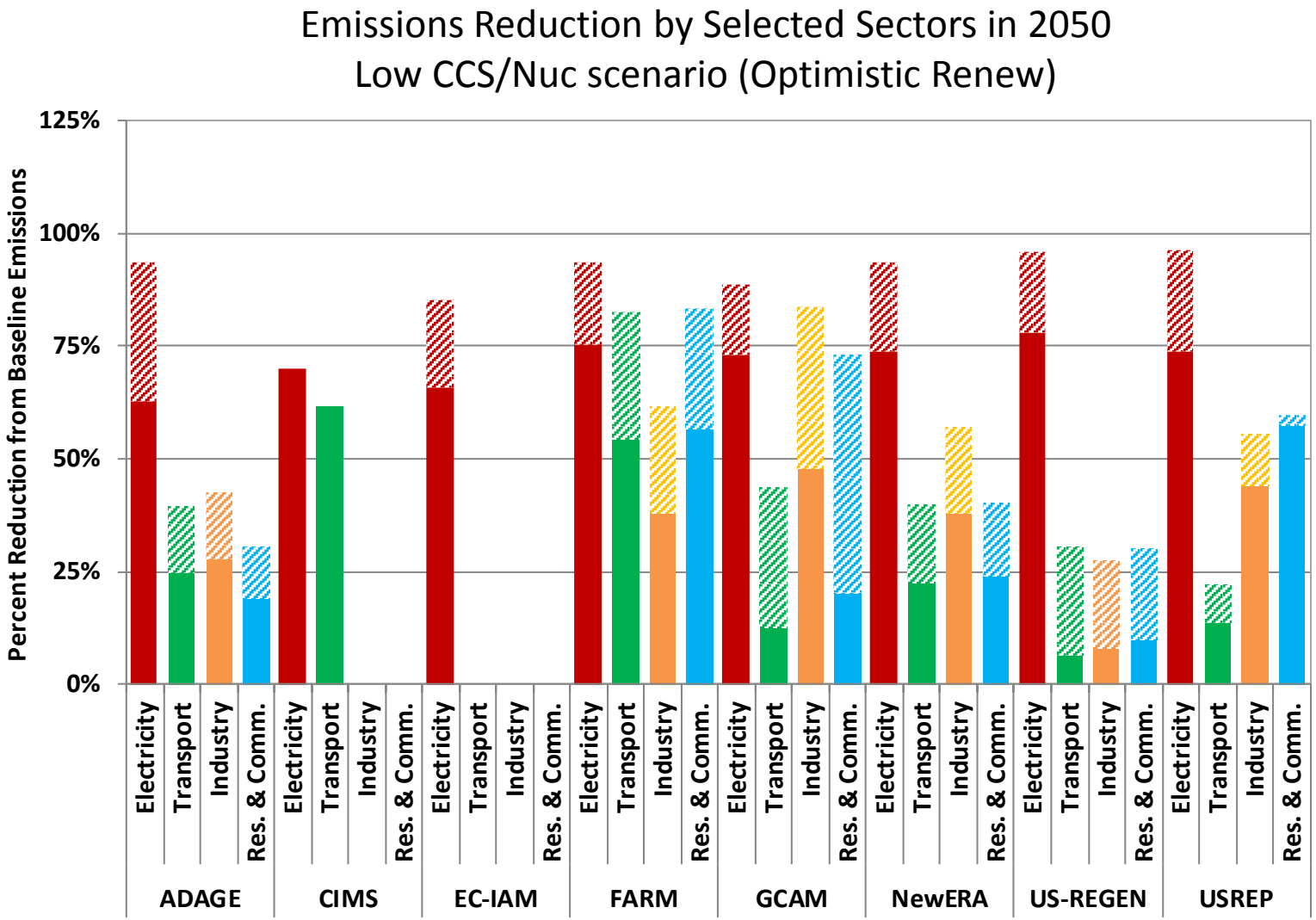
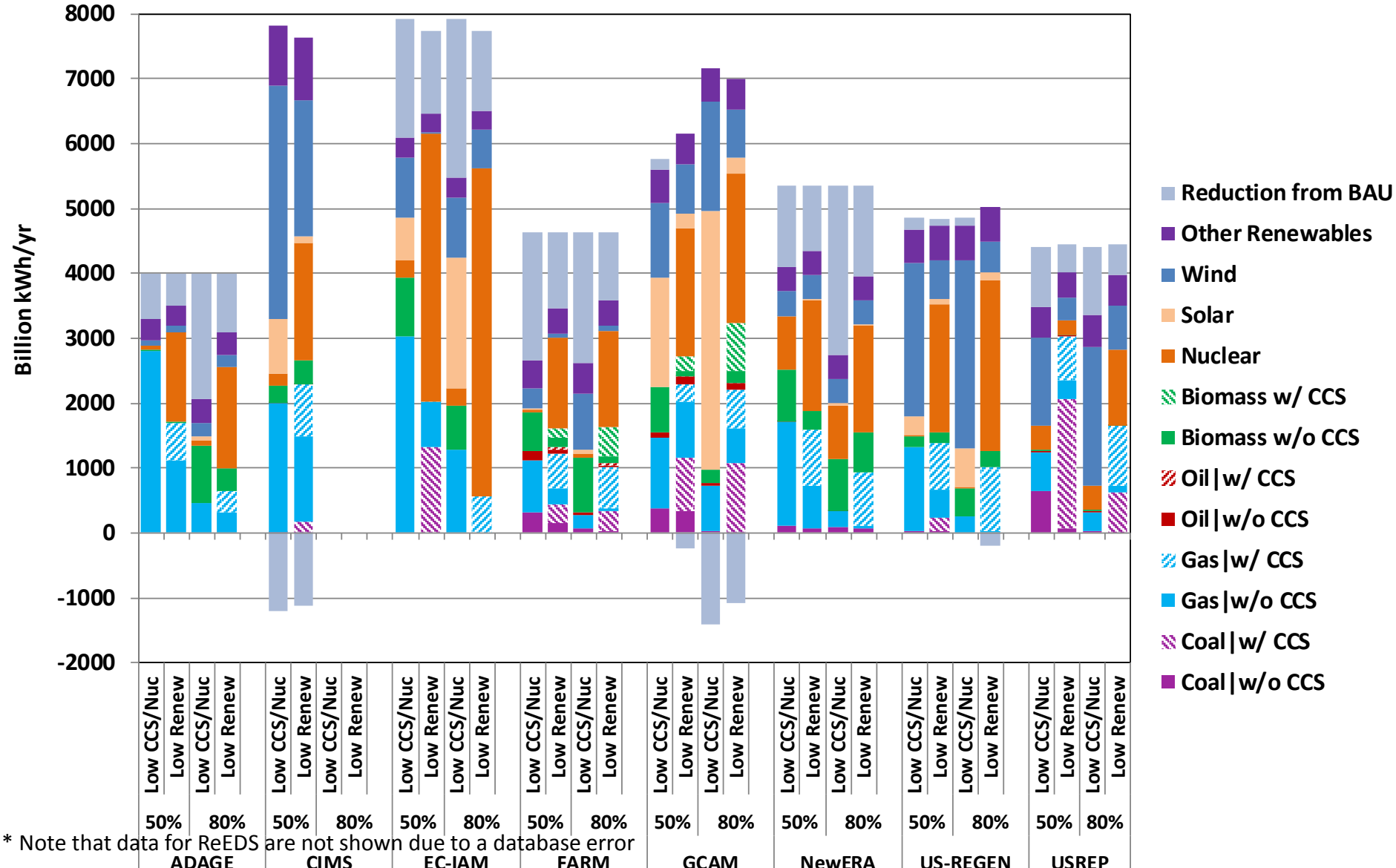
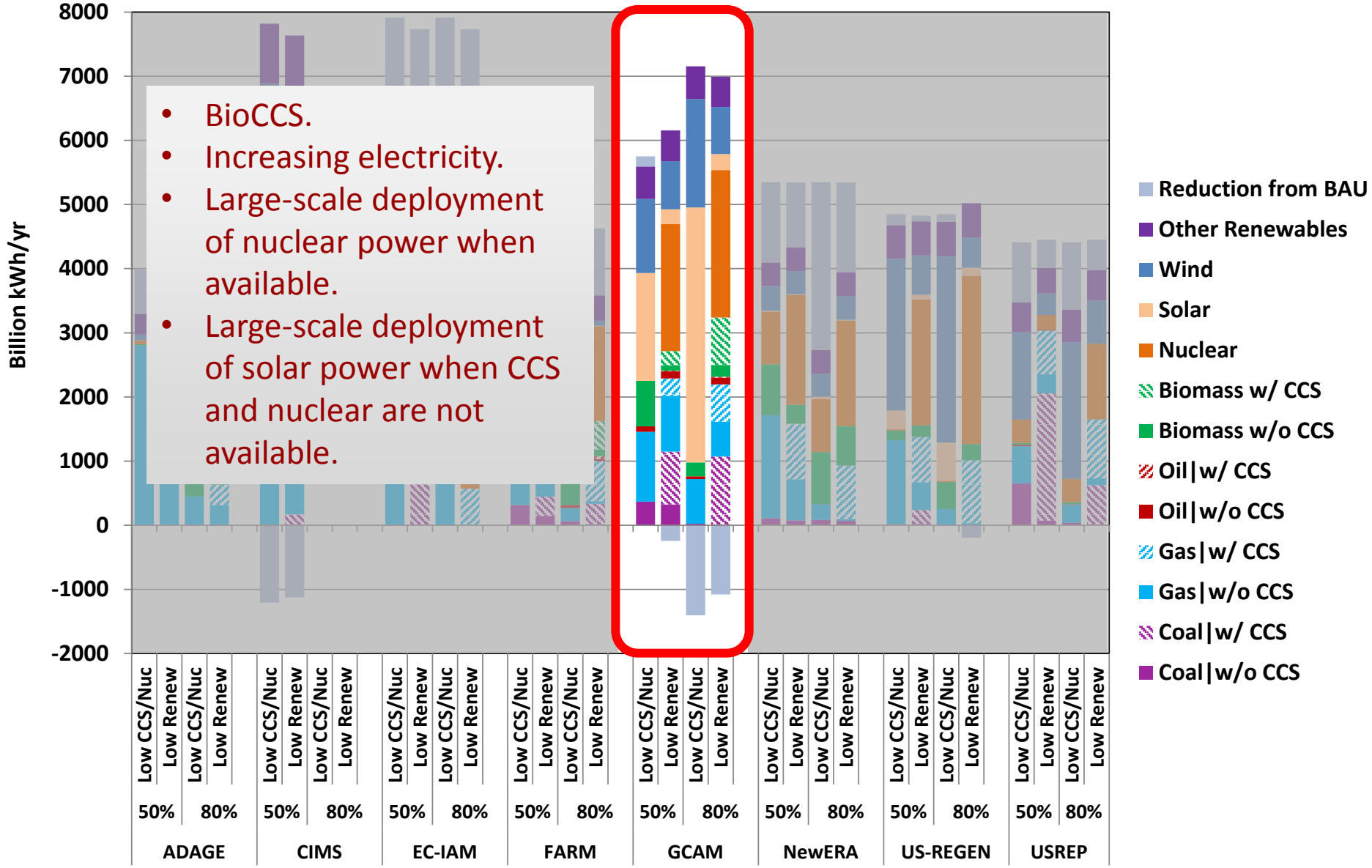


Electricity System Transitions*



* Note that data for ReEDS are not shown due to a database error

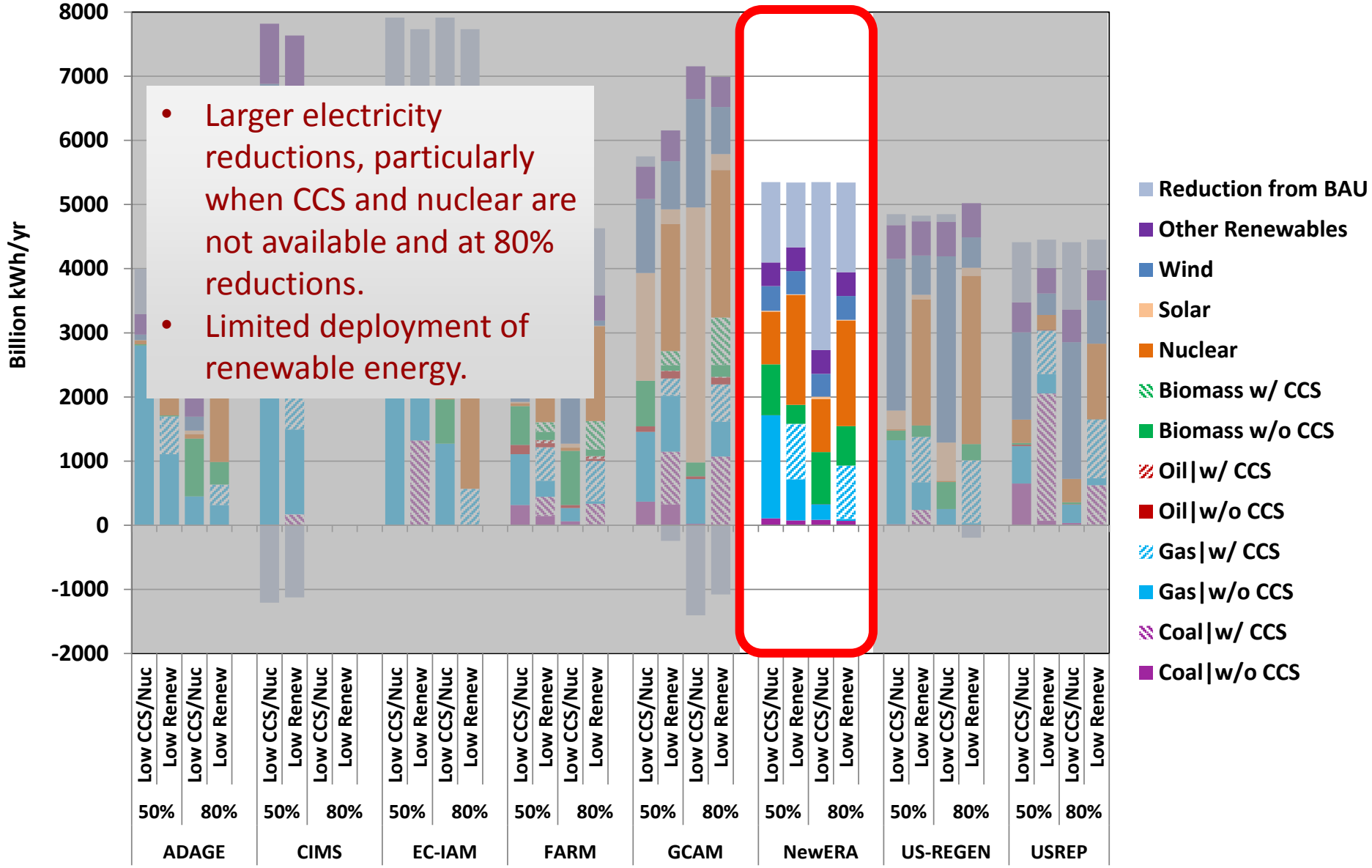
Electricity System Transitions*



- BioCCS.
- Increasing electricity.
- Large-scale deployment of nuclear power when available.
- Large-scale deployment of solar power when CCS and nuclear are not available.

* Note that data for ReEDS are not shown due to a database error

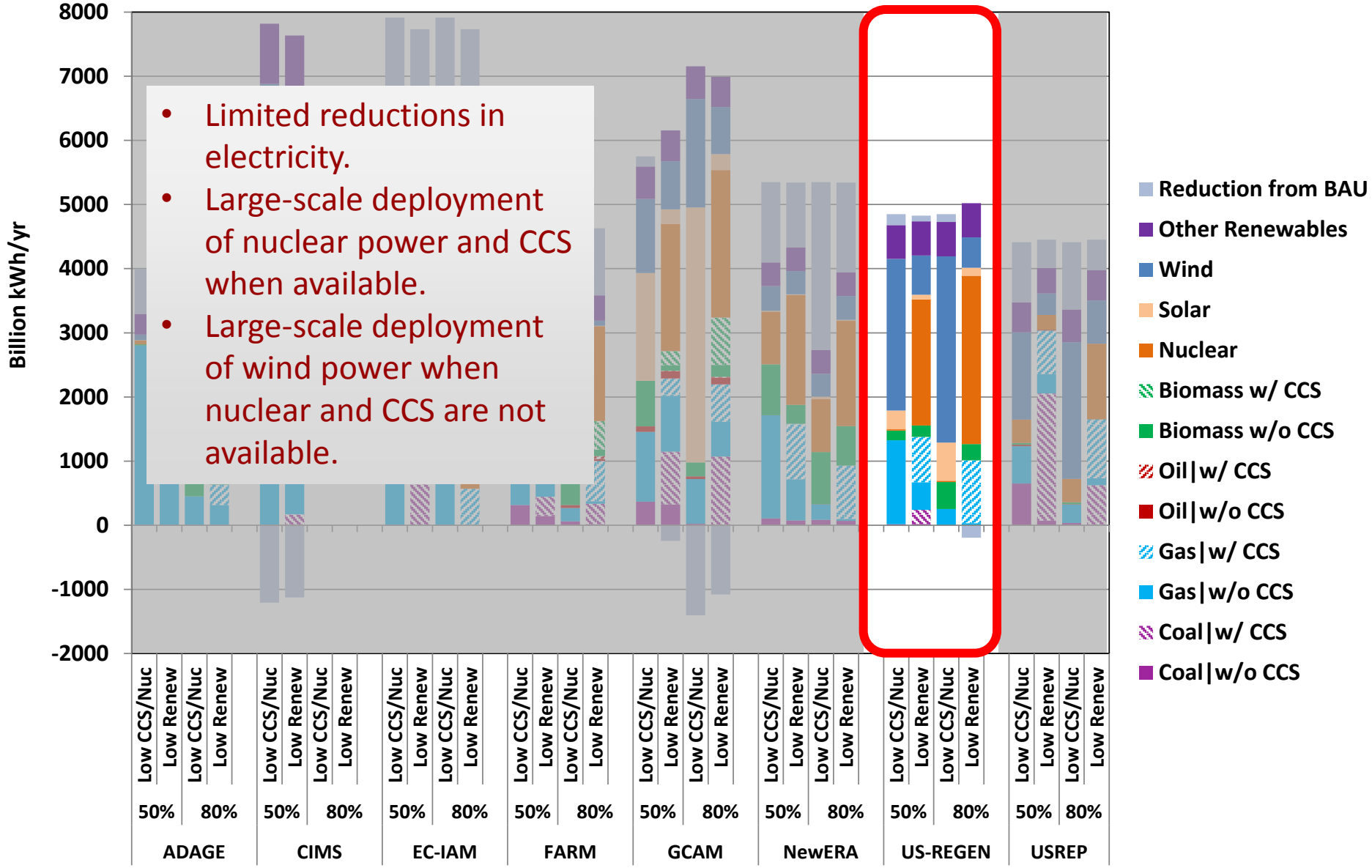
Electricity System Transitions*



- Larger electricity reductions, particularly when CCS and nuclear are not available and at 80% reductions.
- Limited deployment of renewable energy.

* Note that data for ReEDS are not shown due to a database error

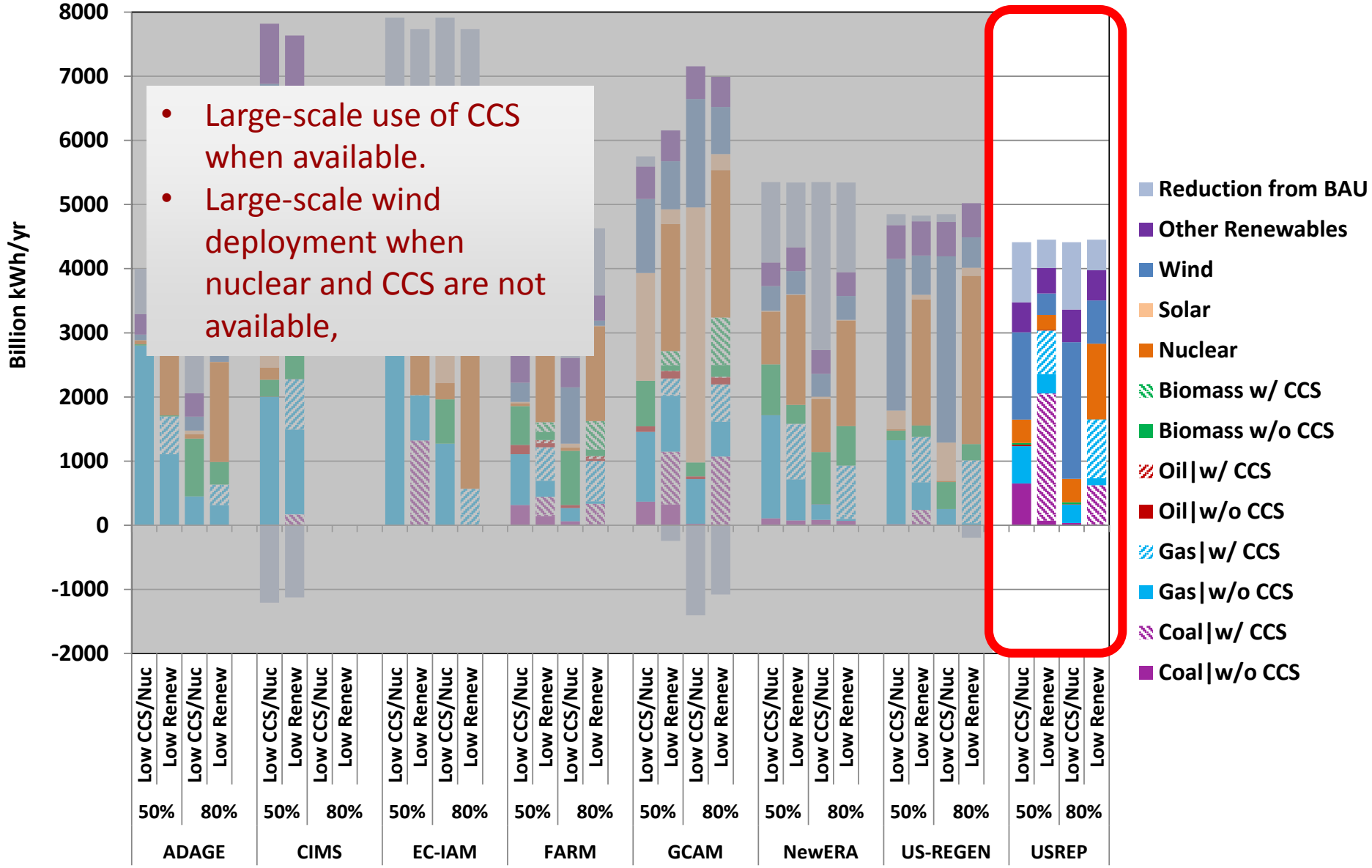
Electricity System Transitions*



- Limited reductions in electricity.
- Large-scale deployment of nuclear power and CCS when available.
- Large-scale deployment of wind power when nuclear and CCS are not available.

* Note that data for ReEDS are not shown due to a database error

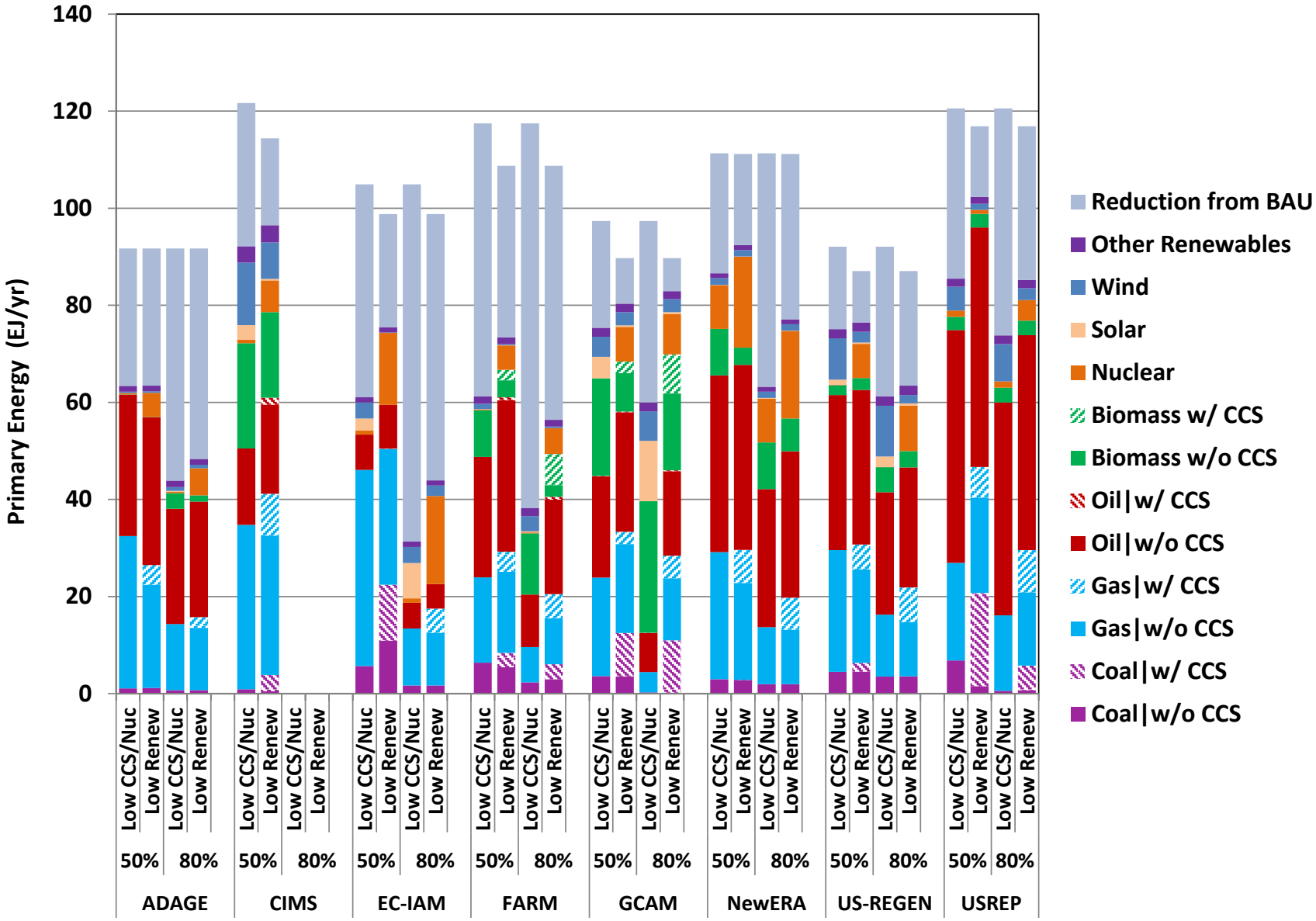
Electricity System Transitions*



- Large-scale use of CCS when available.
- Large-scale wind deployment when nuclear and CCS are not available,

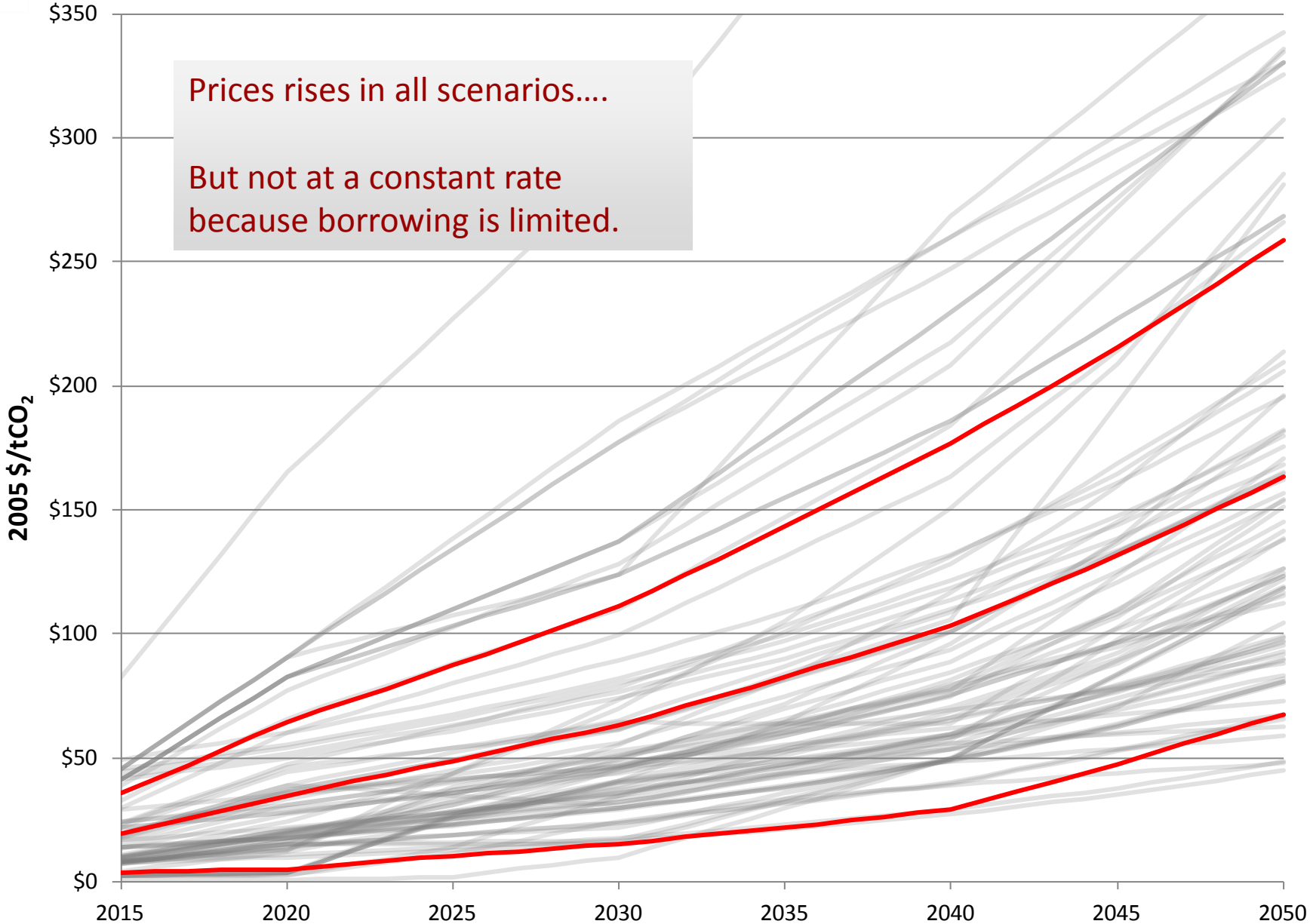
* Note that data for ReEDS are not shown due to a database error

Primary Energy Transitions

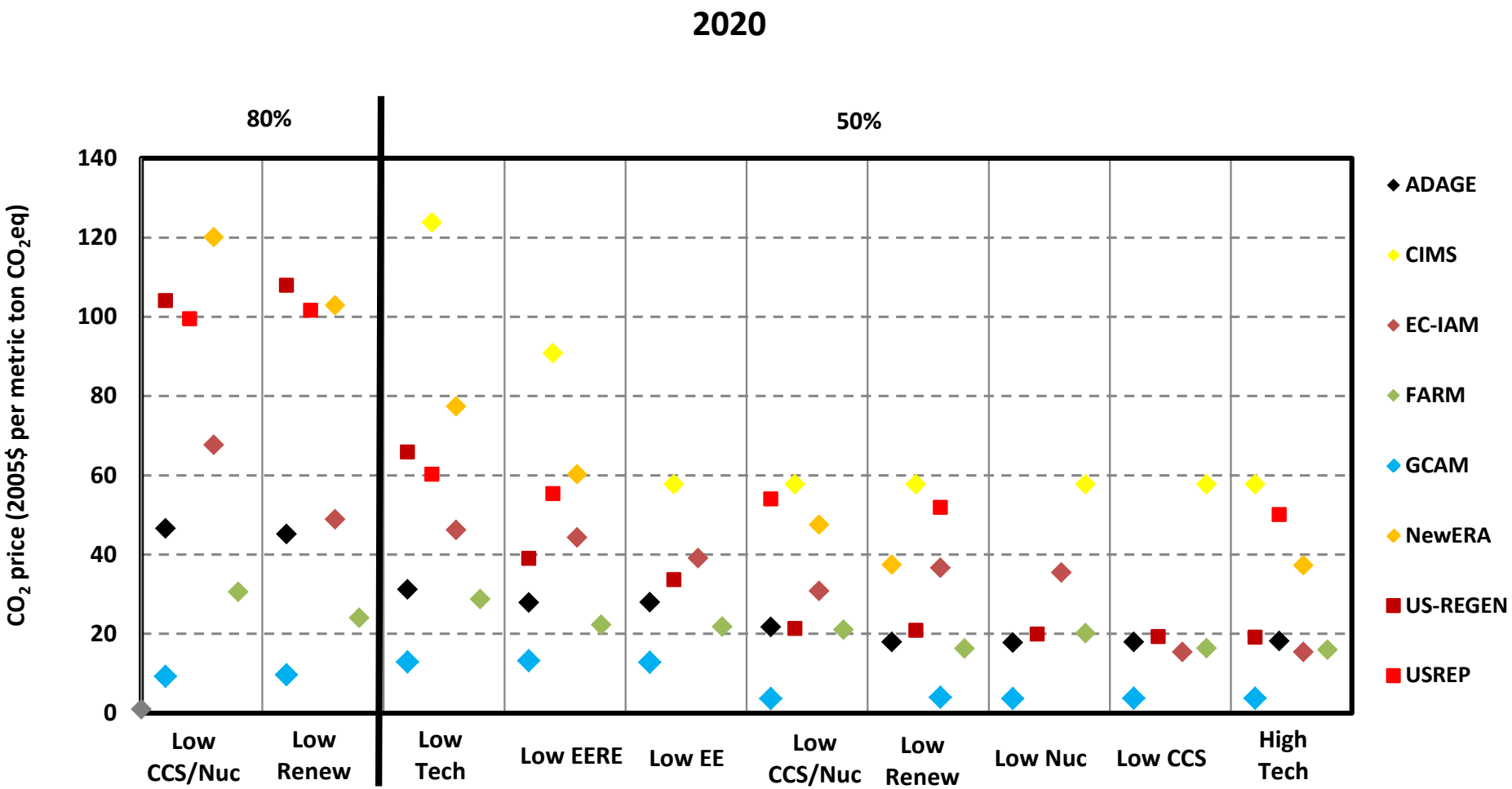


Carbon Price

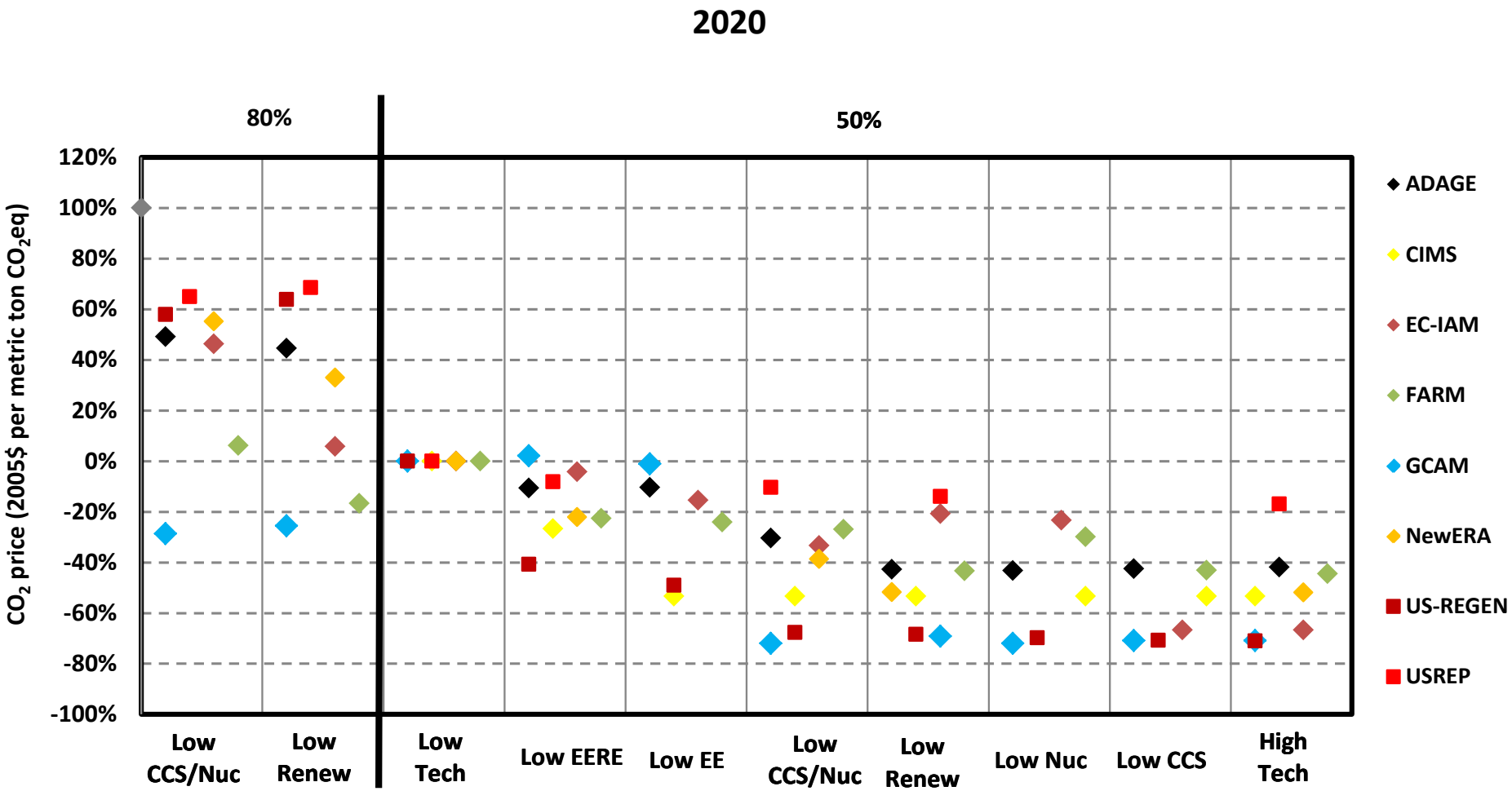
50% Emissions Target



Carbon Prices



Carbon Prices



Why Might Prices and Costs Vary?

- **Differences in model structure**

Overview of the Models

Model	Covered Sectors	Number of US Regions	Covered Gases	Model Base Year	Model of Technology Choice	Model Time Step (years)	Last Model Year without Climate Policy	Intertemporal Solution Approach	Bio w/CCS	Citation for Paper in this Volume
ADAGE	Energy, Rest of Economy (Limited Land Use)	6	CO2, CH4, N2O, HFC, PFC, SF6	2010	CES production function	5	2010	Intertemporal Optimization	No	Ross et al. (2013)
CIMS	Energy	1	C02, CH4, N20	2005	Probabilistic choice model	5	2010	Recursive Dynamic	No	Jaccard and Goldberg (2013)
EC-IAM	Energy, Rest of Economy (no Land Use)	1	CO2,CH4, N2O, Short lived F-gases, long lived F-gases	2000	Linear/Non-Linear programming (Electric supply Sector, Non-Electric Energy Supply Sector); CES production function (Rest of Economy),	10	2010	Intertemporal Optimization	No	Zhu and Ghosh (2013)
FARM	Energy, Rest of Economy (no Land Use)	1	CO2	2004	CES production function	5	2009	Recursive Dynamic	Yes	Sands et al. (2013)
GCAM	Energy, Land use	1	CO2, CH4, N2O, HFC, PFC, SF6	2005	Logit choice model	5 (but 2012 is included as an additional year)	2012	Recursive Dynamic	Yes	Wise et al. (2013)
NewERA	Energy, Rest of Economy (no Land Use)	1*	CO2	2008	Linear/Non-Linear Programming (Electric Supply Sector); CES Production Function (all Other Sectors)	5	2010	Intertemporal Optimization	No	Tuladhar et al. (2013)
ReEDS	Electric Supply	134	CO2	2010	Linear/Non-Linear Programming	2	2012	Sequential Myopic	No	Sullivan et al. (2013)
USREP	Energy, Rest of Economy (no Land Use)	12	CO2, CH4, N2O, HFC, PFC, SF6	2004	CES production function	5	2010	Recursive Dynamic	No	Rausch et al. (2010)
US-REGEN	Energy, Rest of Economy (no Land Use)	15	CO2	2010	Linear/Non-Linear Programming (Electric Supply Sector); CES Production Function (all Other Sectors)	5	2010	Intertemporal Optimization	No	Blanford et al. (2013)

* At the time the EMF 24 were completed, NewERA with only one U.S. region. The default is now 12 U.S. regions

Why Might Prices Vary

- **Differences in model structure**
- **Differences in implementation of optimistic and pessimistic assumptions regarding end use, wind and solar, and bioenergy**
- **Differences in what other technologies might be available (e.g., the combination of bioenergy with CCS)**

Overview of the Models

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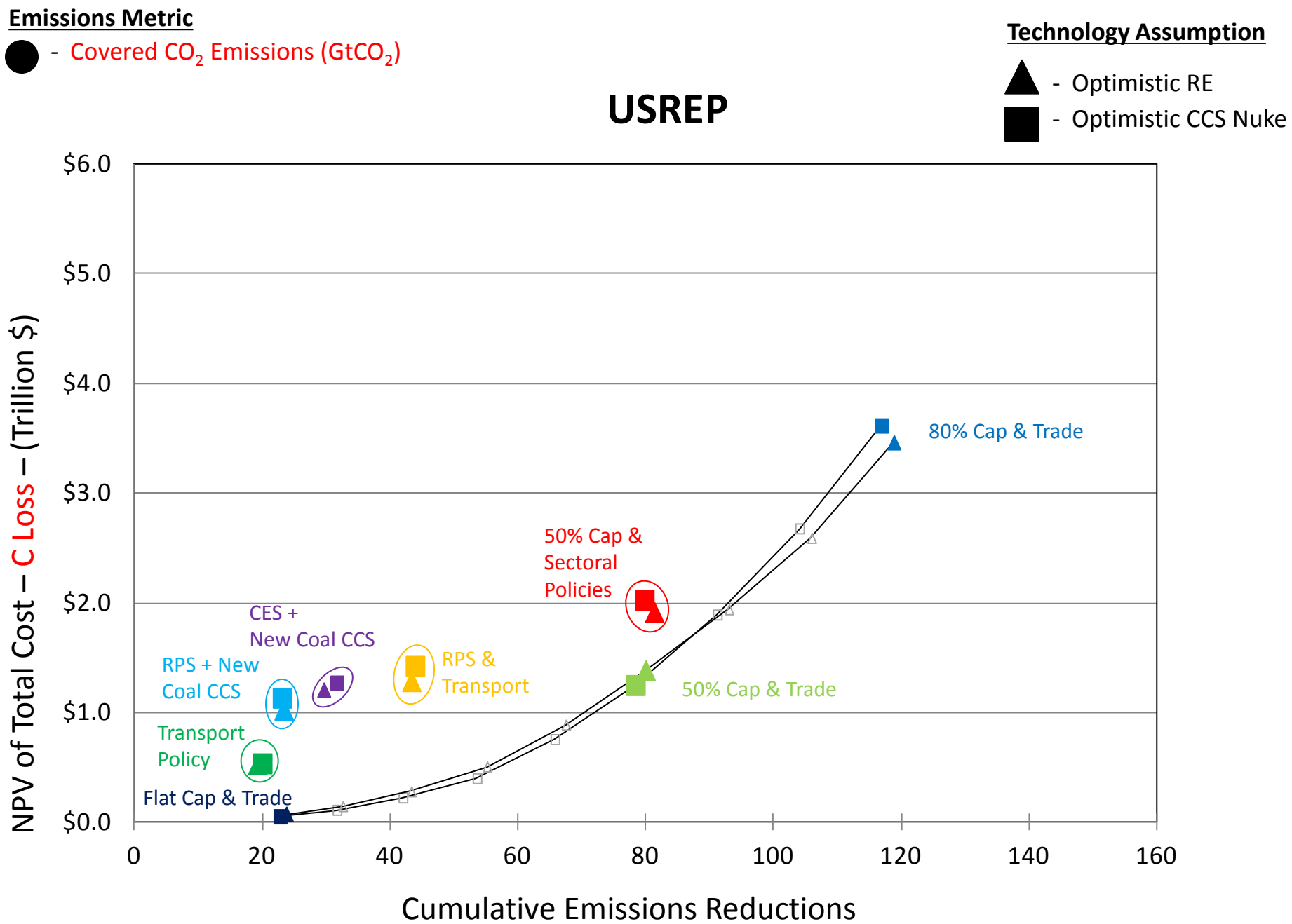
Why Might Prices Vary

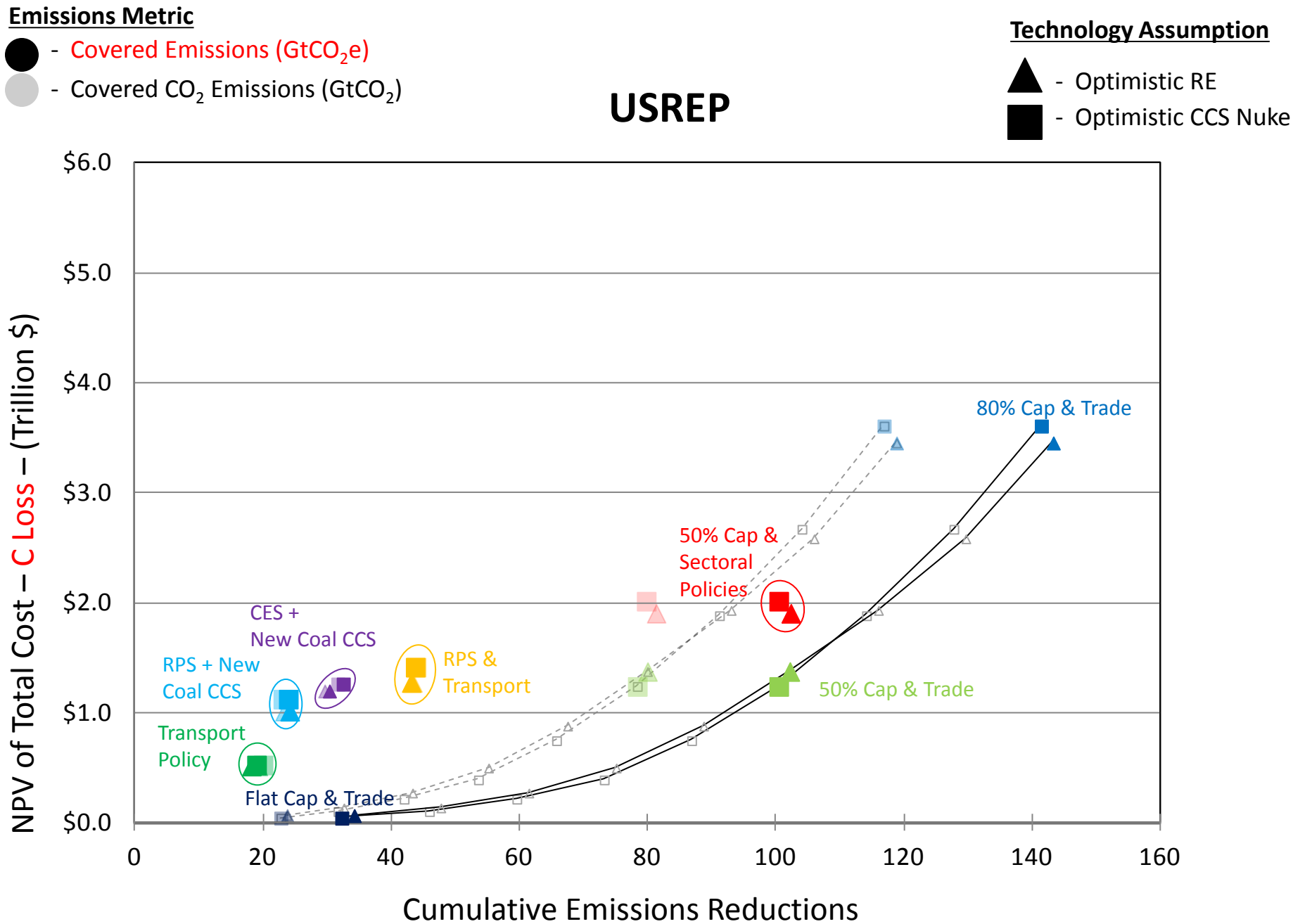
- **Differences in model structure**
- **Differences in implementation of optimistic and pessimistic assumptions regarding end use, wind and solar, and bioenergy**
- **Differences in what other technologies might be available (e.g., the combination of bioenergy with CCS)**
- **Different assumptions about driving forces, such as population, GDP, and energy intensity.**
- **Differences in a wide range of additional assumptions about resources and costs.**
- **Associated differences in baseline emissions in any year.**

Individual Models

Net Present Value of Cumulative Cost vs. Cumulative Abatement



Net Present Value of Cumulative Cost vs. Cumulative Abatement



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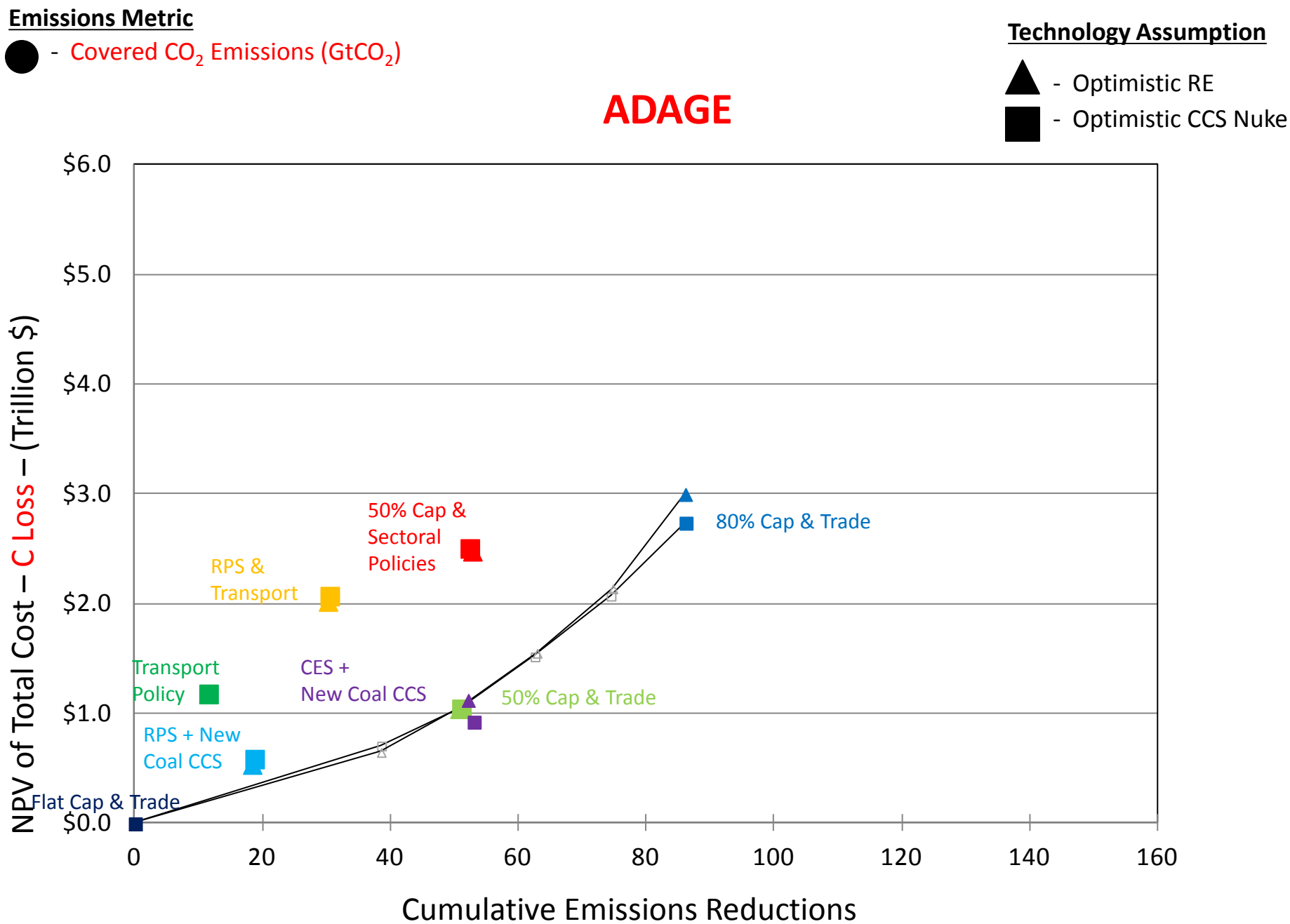
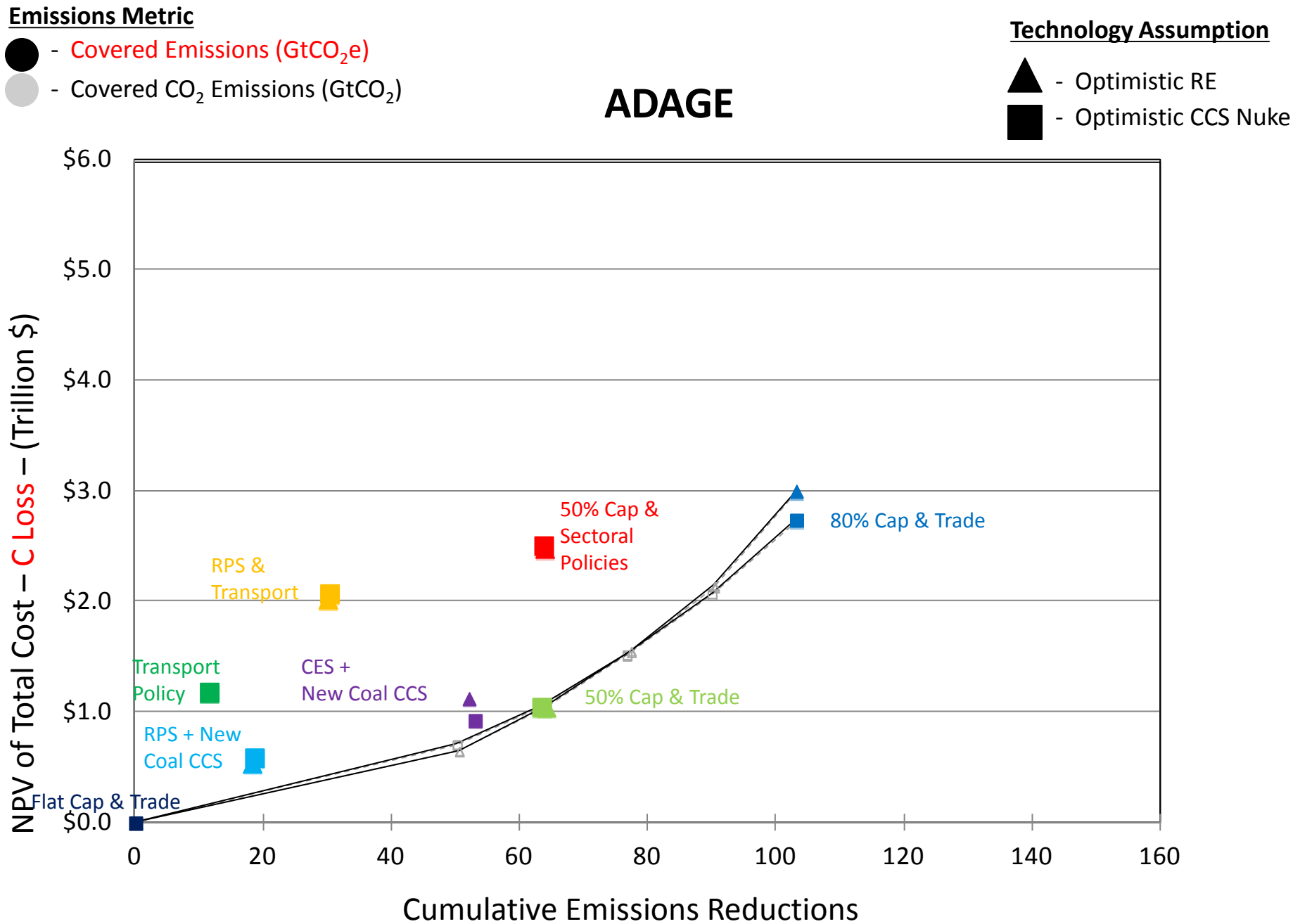


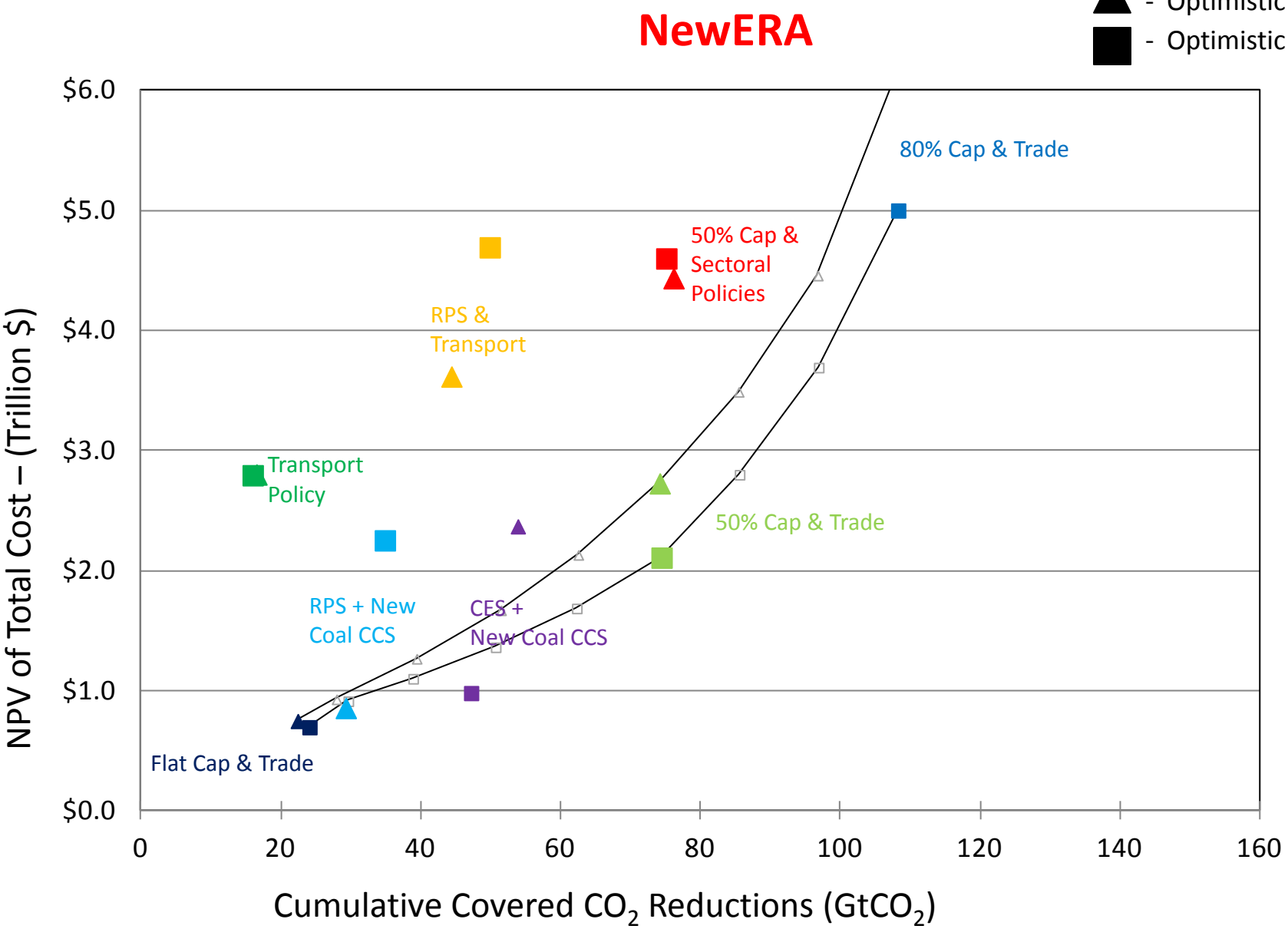
Net Present Value of Cumulative Cost vs. Cumulative Abatement



Net Present Value of Cumulative Cost vs. Cumulative Abatement

Cost Metric
Consumption Loss

Technology Assumption
- Optimistic RE
- Optimistic CCS Nuke



Net Present Value of Cumulative Cost vs. Cumulative Abatement

Cost Metric
Consumption Loss

Technology Assumption
▲ - Optimistic RE
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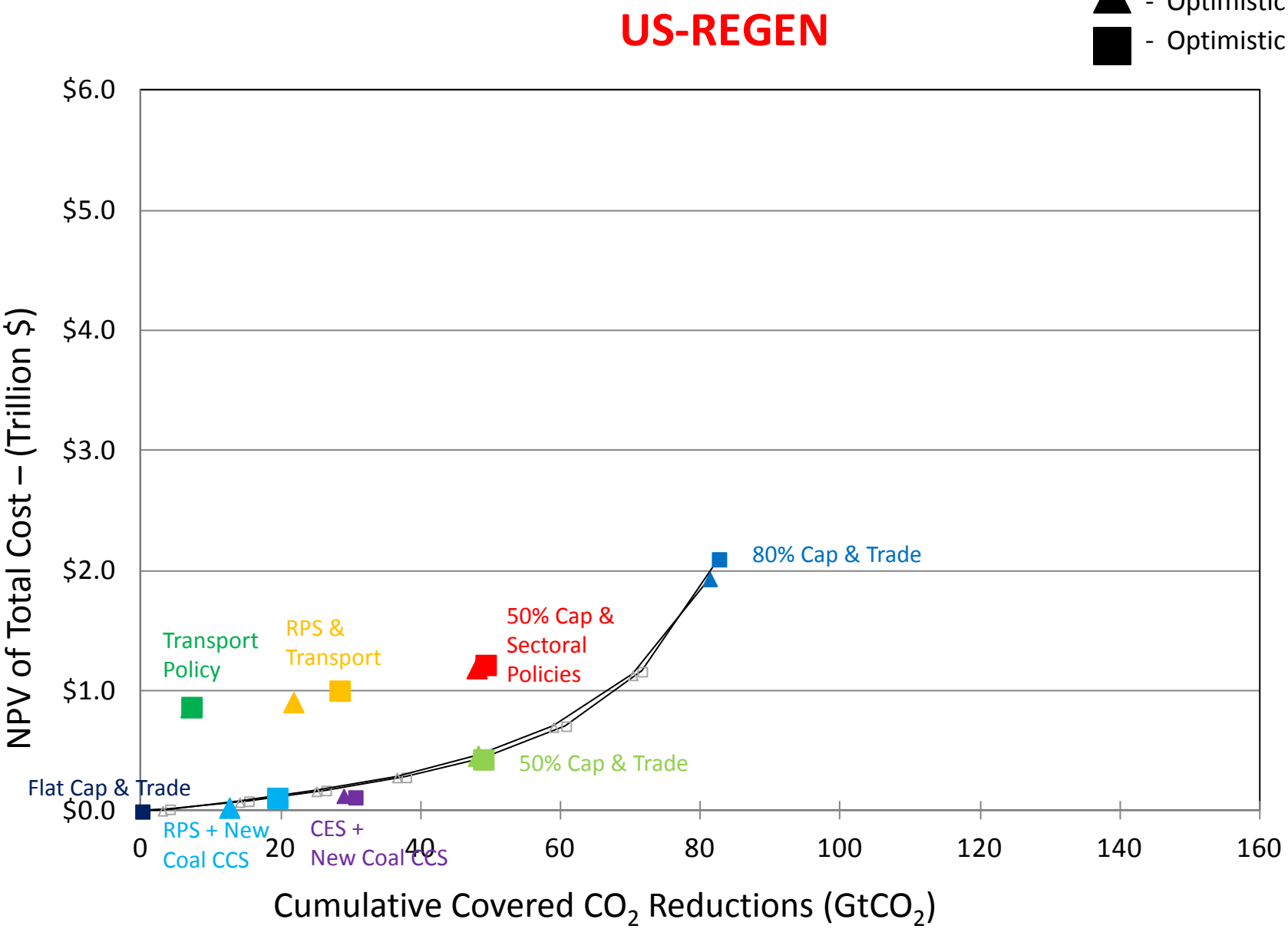

Net Present Value of Cumulative Cost vs. Cumulative Abatement

Cost Metric
Consumption Loss

Technology Assumption
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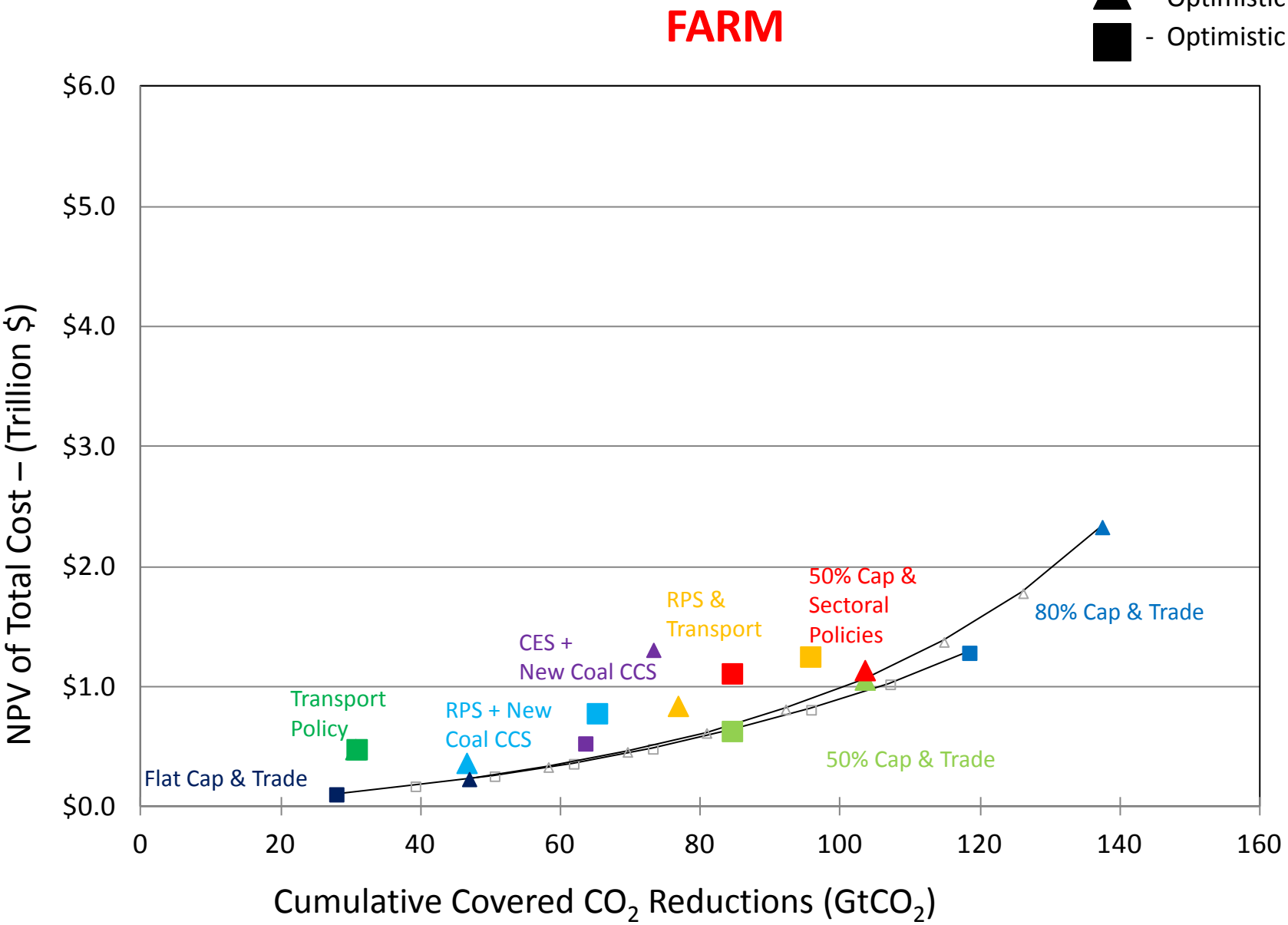
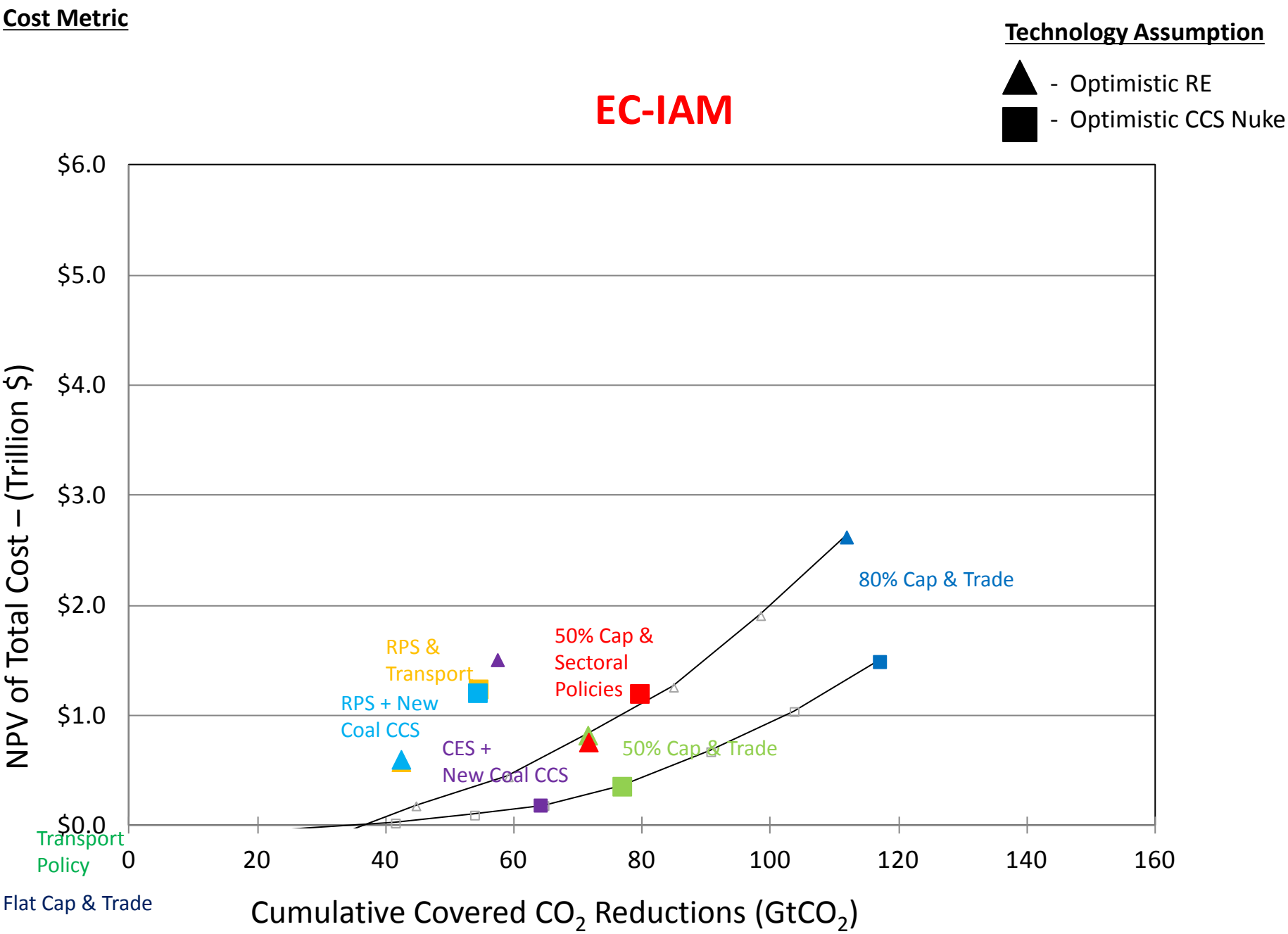


Net Present Value of Cumulative Cost vs. Cumulative Abatement



EMF27 Study on Global Technology and Climate Policy Strategies

Special issue in Climatic Change

- Synthesis (Kriegler, Weyant et al.), Policy Overview (Blanford et al.), Technology Overview (Krey et al.)
- X-cuts on Energy Efficiency (Sugiyama et al.), CCS (Koelbl et al.), Nuclear (Kim et al.), Non-Bio Renewables (Luderer et al.), Bioenergy (Rose et al.), Land use (Popp et al.), Resources (McCollum et al.), Non-Kyoto forcing (Rose et al.)
- 17 modeling team papers

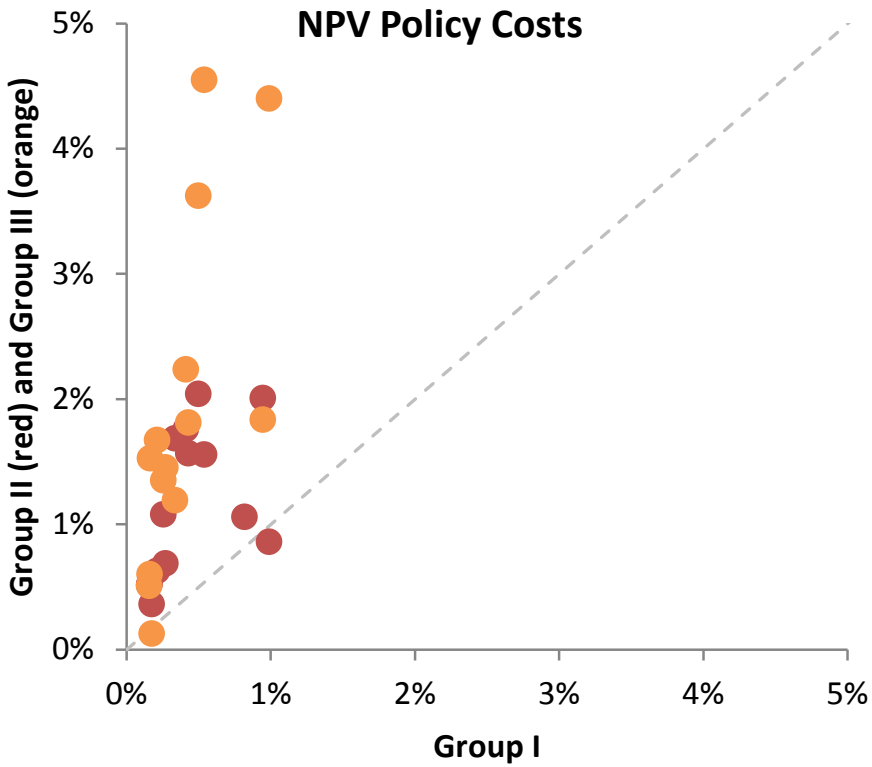
18 participating models (17 x global, 1 x India)

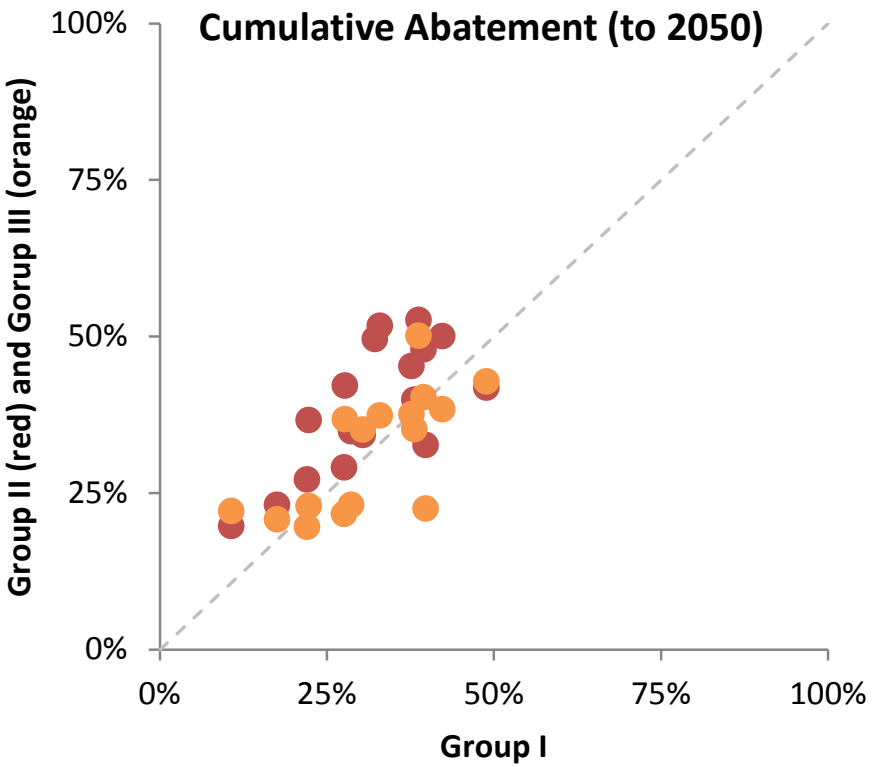
AIM-Enduse, BET, DNE21+, EC-IAM, ENV-Linkages, FARM, GCAM, GCAM-IIM, GRAPE, IMACLIM, IMAGE, MERGE, MESSAGE, Phoenix, POLES, REMIND-MAgPIE, TIAM-ECN, WITCH

	FullTech	LowEI	NoCCS	NucOff	LimSW	LimBio	Conv	EERE	LimTech
Baseline	13/13	13/13		11/11	11/11	13/13	13/13	13/13	11/11
550 ppm	13/13	13/13	12/12	11/11	11/11	13/13	13/13	12/12	6/9
450 ppm	10/11	9/10	4/11	9/10	9/10	9/11	8/11	6/11	0/10

Regional emissions reductions and policy costs

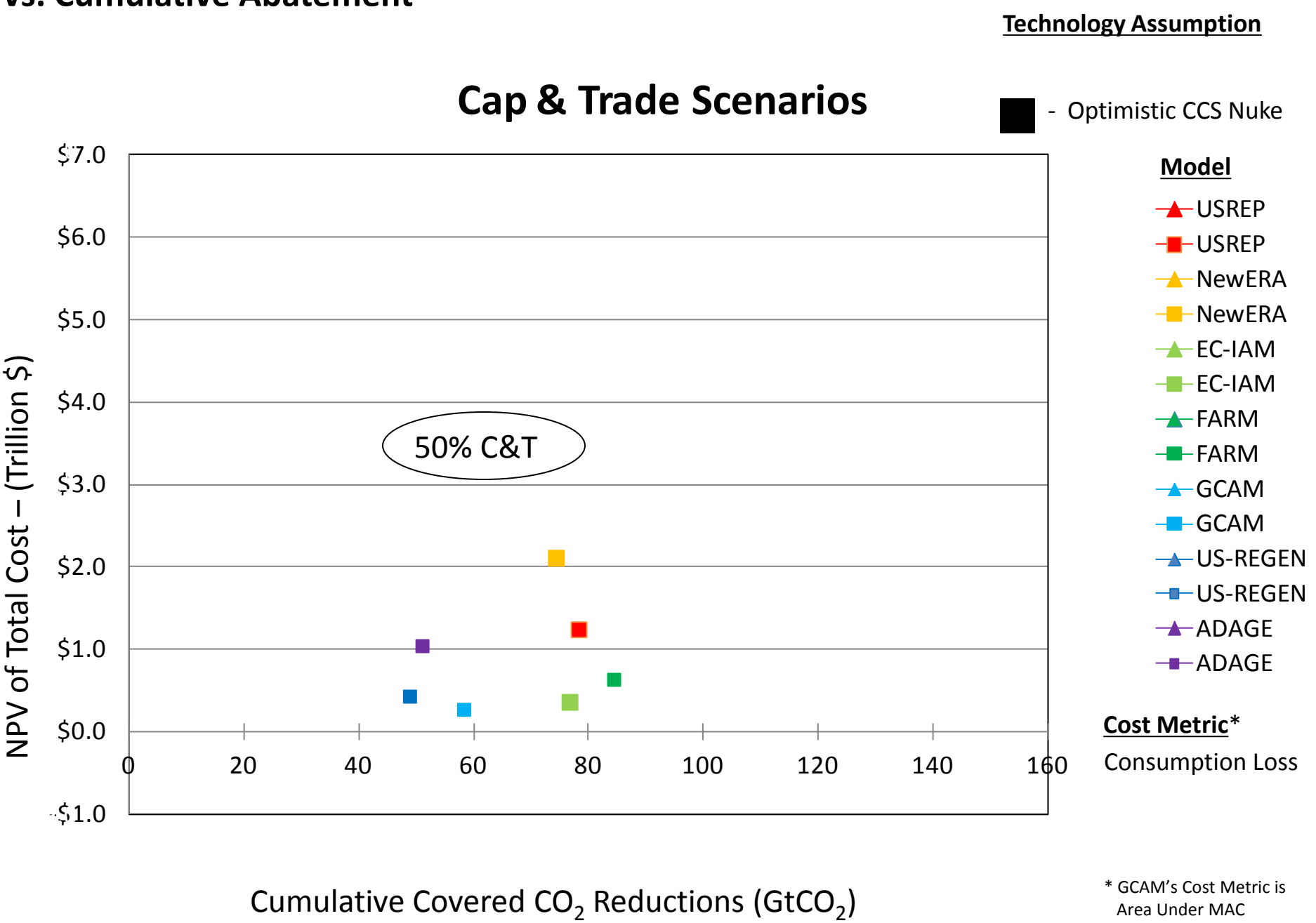
550 ppm CO2e scenario





Blanford, Kriegler, Tavoni, Climatic Change, forthcoming

Net Present Value of Cumulative Cost vs. Cumulative Abatement



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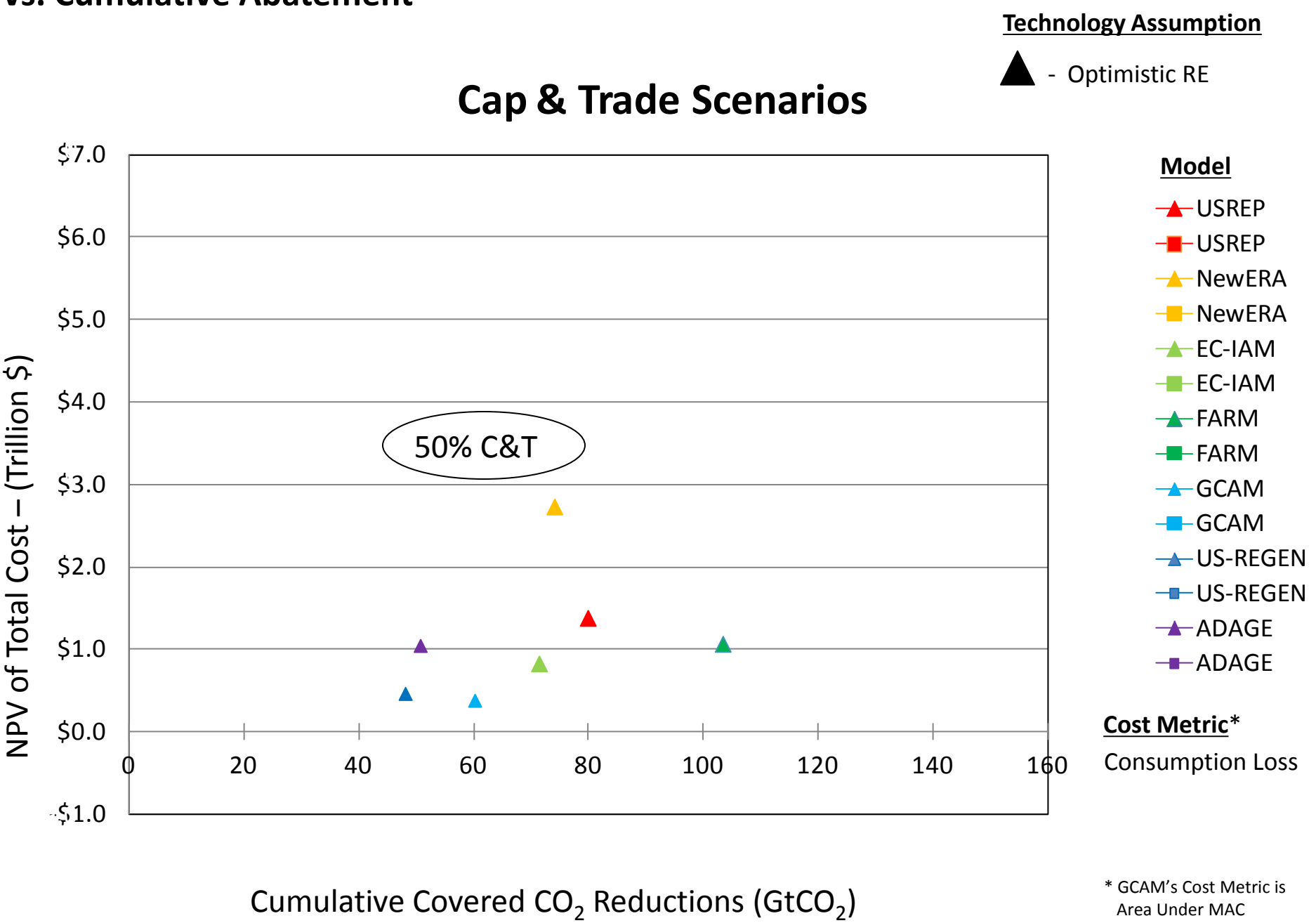

* GCAM's Cost Metric is Area Under MAC

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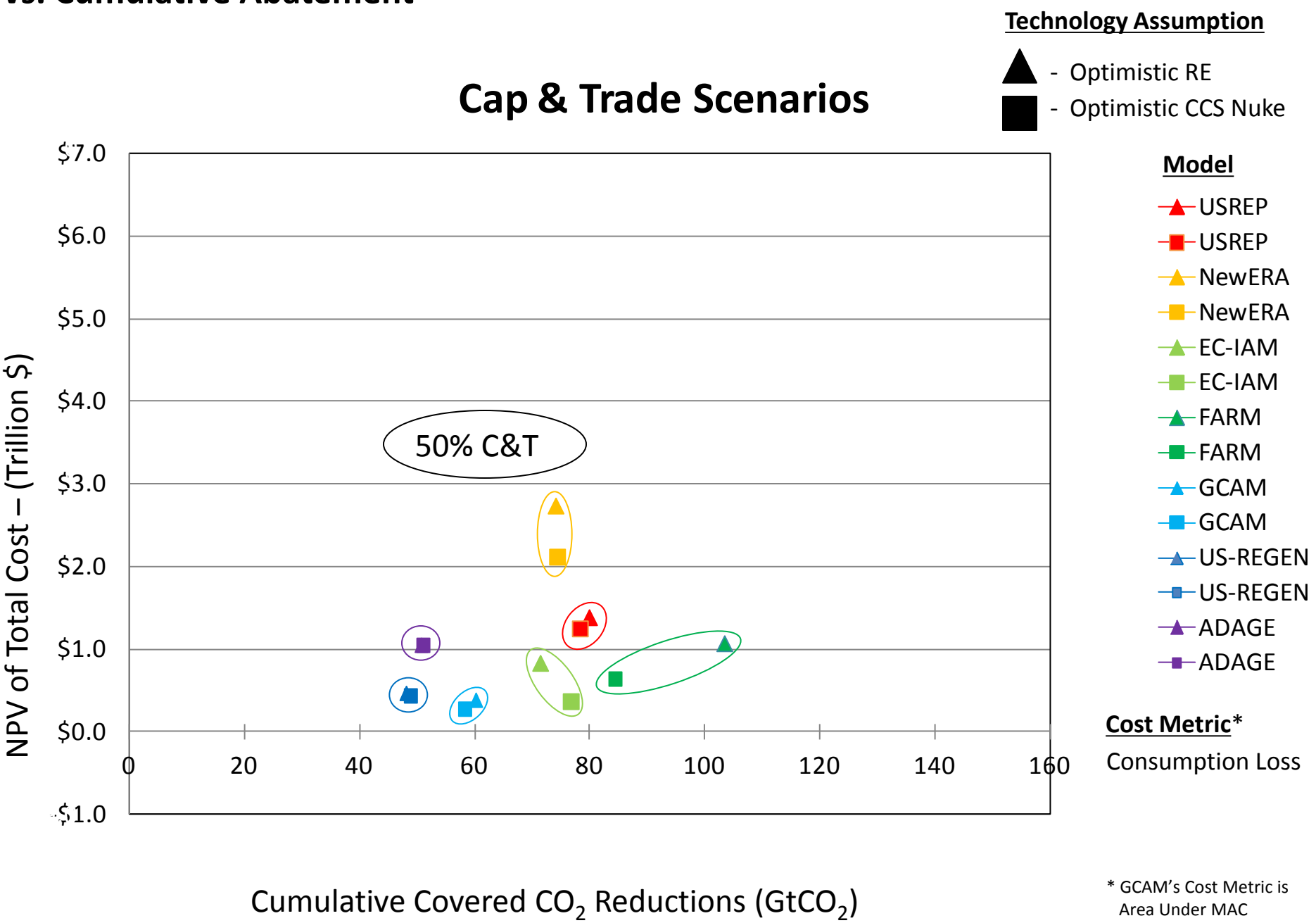

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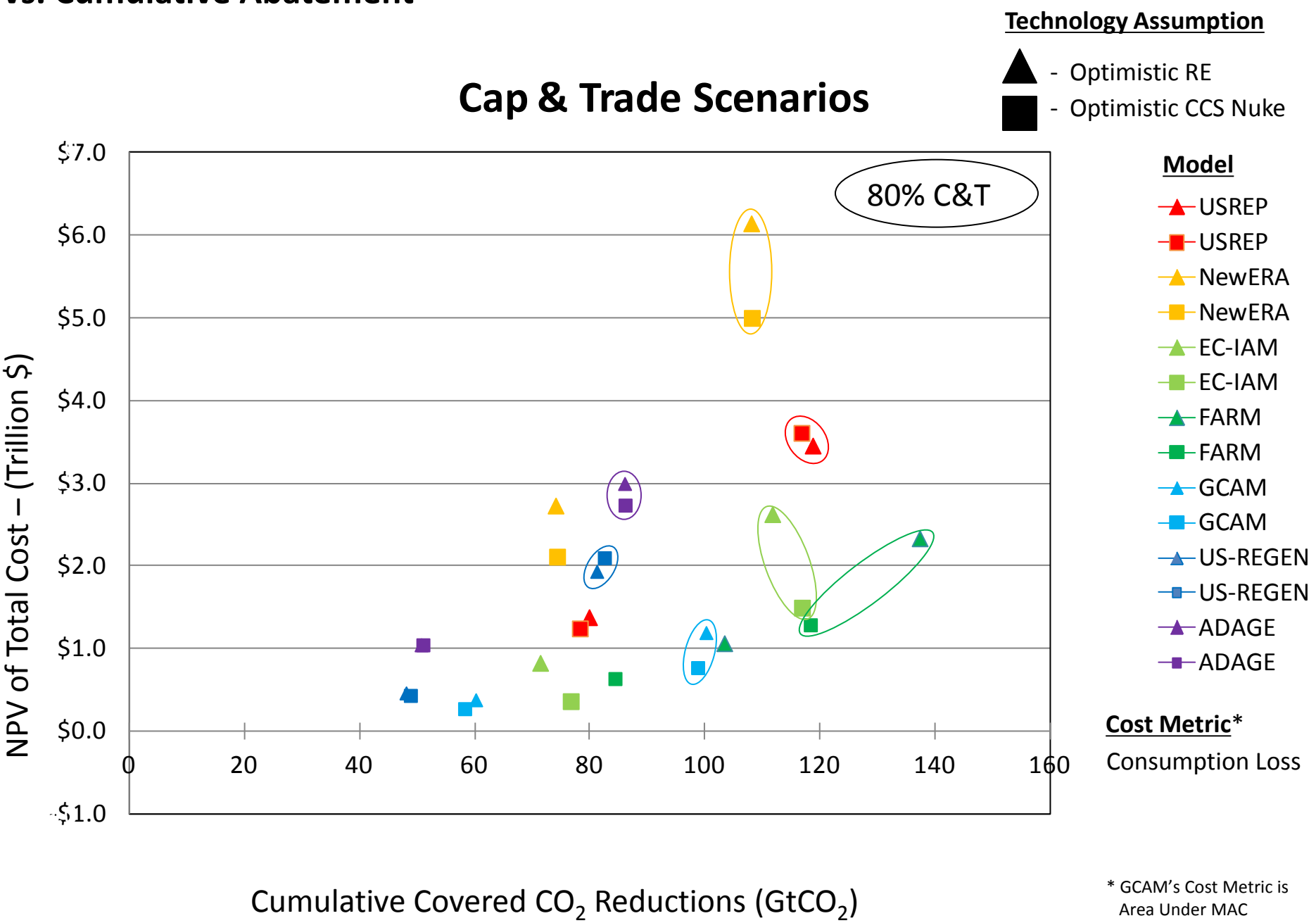

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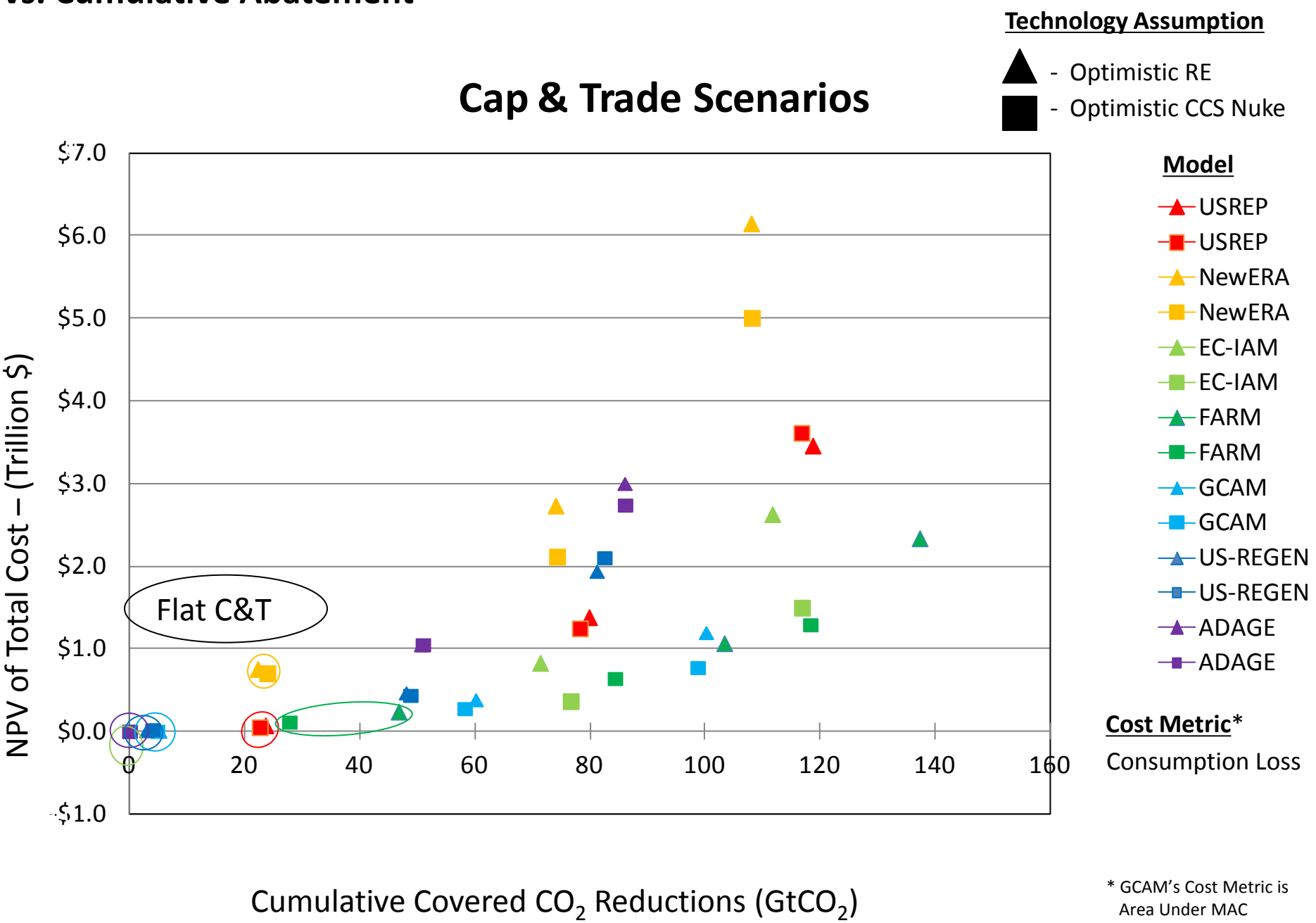

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Overview of Discussion

- **Part 1:**
  - **Study Design**
  - **Reference Scenarios**
  - **Overview of Results from the EMF 24 Technology Scenarios**
- **Part II: Overview of the EMF 24 Policy Scenarios**
- **Part III: Discussion of the Results from Individual Modeling Team Papers**

AN OVERVIEW OF THE EMF 24 STUDY DESIGN

TOTAL COST & EMISSIONS REDUCTIONS ACROSS SCENARIOS