# A Few EMF Perspectives on Climate and Energy Modeling

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EIA-WEPS
Climate Modeling Workshop
On-Line
June 29th, 2022

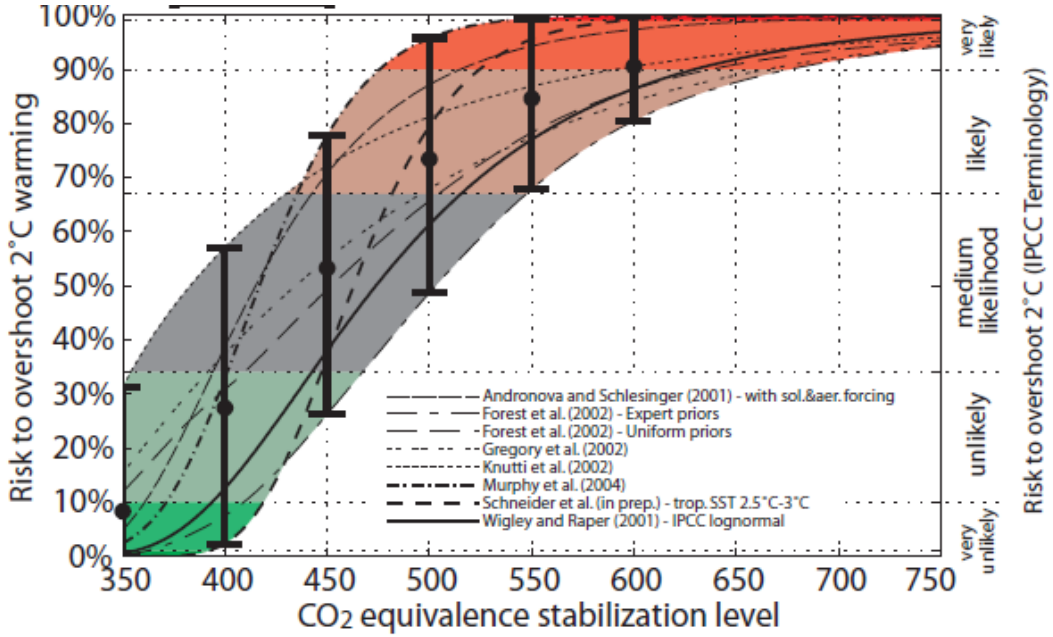
# Outline

- Climate Change Definitions and Nomenclature
- The Importance of Understanding Uncertainty
- EMF 36 on Trade and Coalition Formation
- EMF 33 on Global Bio-Energy, Includning Trade
- Some other Relevant EMF Studies
  - EMF 28 on European Climate Policy Options
  - EMF 30 on Short Lived Climate Forcers

# Some Useful Energy and Climate Accounting Nomenclature

- Anthropogenic $CO_2$ emissions come from fossil fuel & energy use, and land use.
- GHGs (carbon dioxide, methane, nitrous oxide and the industrial gases) lead to positive changes in radiative forcing (RF), and Short-Lived Climate Forcers (Black and Organic Carbon and Sulfate Aerosols) SLCFs currently lead to net negative changes in RF.
- Changes in RF lead to changes in temperature with lags (decades to centuries).
- The relationships between emissions and concentrations, concentrations and RF, RF and realized temperature change, and realized temperature change and equilibrium temperature change are all uncertain.
- The current $CO_2$ concentration is about 420 ppm, GHG concentration about 490 ppm $CO_2e$, the RF from GHGs and SLCFs is about 2.0 watts/$m^2$, realized temperature change is about 1.1 degree C and the equilibrium temperature change is about 1.5 degrees C with respect to pre-industrial levels.
- Solar Radiation Management (SRM) can reduce RF directly and Direct Air Capture (DAC) can Reduce $CO_2$ Concentrations in the atmosphere directly

# Example of the Implications of Uncertainty
# The Risk of Overshooting a Target Like 2°C




Source: Hare and Meinshausen (2004). PIK Rpt. #93.

# EMF 36: Climate Policies after Paris: Pledge, Trade and Recycle

***Objectives***

- Economic impact assessment of Nationally Determined Contributions (NDCs) by 2030
- Cost savings from coordinated $CO_2$ emissions pricing (emissions trading)
- Household-level incidence of $CO_2$ pricing and revenue recycling in individual countries

Christoph Böhringer, Sonja Peterson, Thomas F. Rutherford, Jan Schneider, Malte Winkler (2021). "Climate policies after Paris: Pledge, Trade and Recycle: Insights from the 36th Energy Modeling Forum Study (EMF 36)," From Special Issue of *Energy Economics*, Vol. 103, pp 1-16, November.

# EMF 36 Scenario Dimensions

- **Ambition** of emission reduction pledge (NDC)
- Degree of international **cooperation** (cross-country emissions trading)

**Table 5**
EMF36 core scenarios.

| Acronyms | Description |
|---|---|
| *Ambition* | |
| *NDC* | Translation of unconditional nationally determined contributions |
| *NDC+* | Translation of conditional nationally determined contributions |
| *NDC-2C* | Scaling of *NDC+* emission levels to reach 2°C temperature goal |
| *Cooperation* | |
| *ref* | Reference case where each region reaches its reduction target without further international emissions trading |
| *global* | Emissions trading across all regions and sectors |
| *partial* | Emissions trading across all regions in EITE and power sectors |
| *eur-chn* | Emissions trading between Europe and China in EITE and power sectors |
| *asia* | Emissions trading between China, Japan and South Korea in EITE and power sectors |

- Policy appraisal: Impacts in % change from business-as-usual in 2030 (**BaU**)
  - IEO: 2030 GDP and CO2 based on the International Energy Outlook (EIA)
  - WEO: 2030 GDP and $CO_2$ based on the World Energy Outlook (IEA)

# EMF 36: Global Welfare

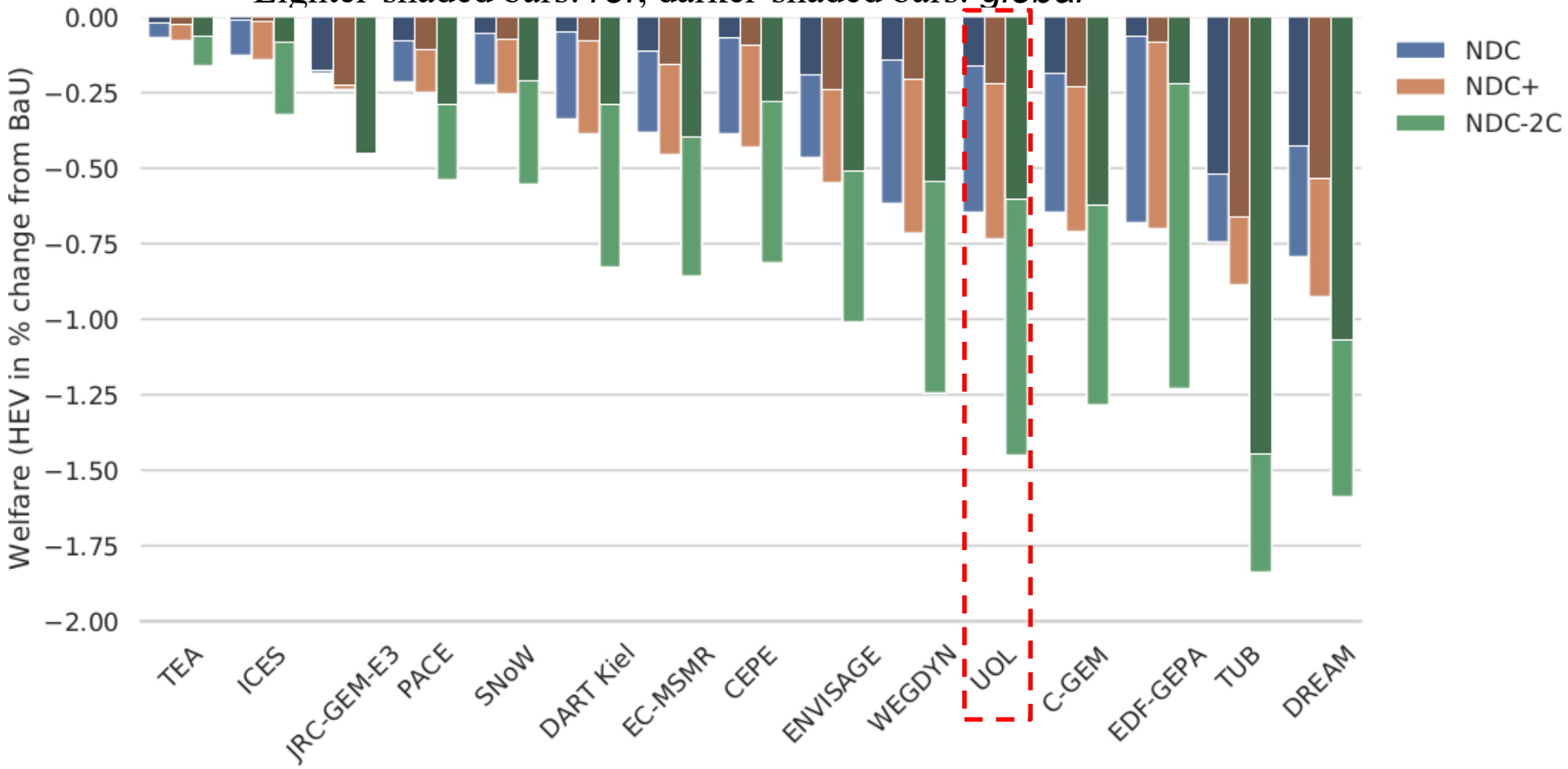
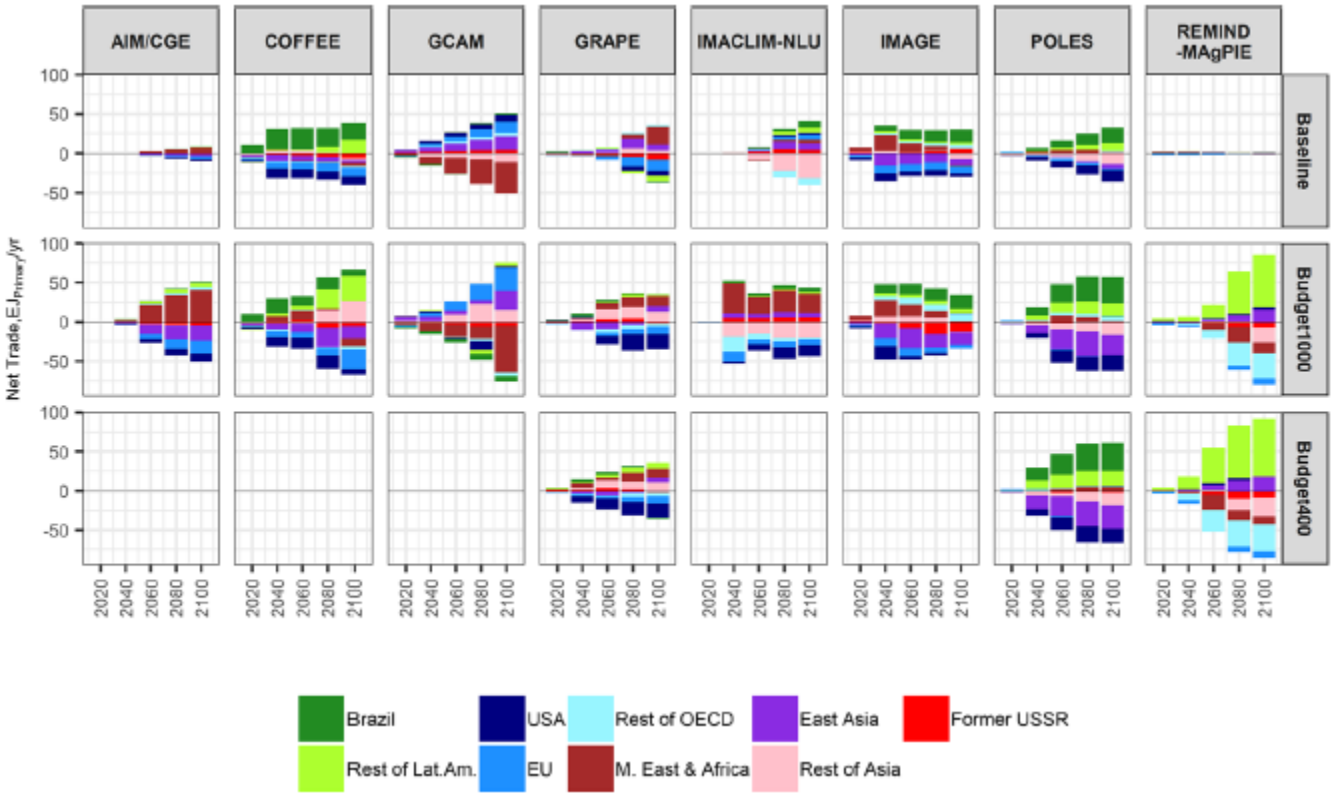



**Fig. 3.** Global welfare effects for three different ambition levels (*NDC, NDC+, NDC-2C*) and two polar cases of emissions trading (*ref, global*). Note: The lighter shaded bars represent welfare changes in *ref*. The darker shaded bars represent welfare changes in *global*.

- NDC/ref: ➔ NDC-2C/ref: - 0.43% ➔ - 0.94% (mean)
- NDC/global ➔ NDC-2C/global: - 0.15% ➔ - 0.47% (mean)

***Insight: Cost savings from carbon trading pays for 2°C compatible NDC pledges***

# EMF 36: Net Trade Of Primary Bioenergy, In EJ/Year, Positive Values Indicate Net Exports.




(Vassilis Daioglou, et al., Climatic Change https://doi.org/10.1007/s10584-020-02877-1)

# EMF 36: Implications Of Climate Change Mitigation Strategies on International Bioenergy Trade

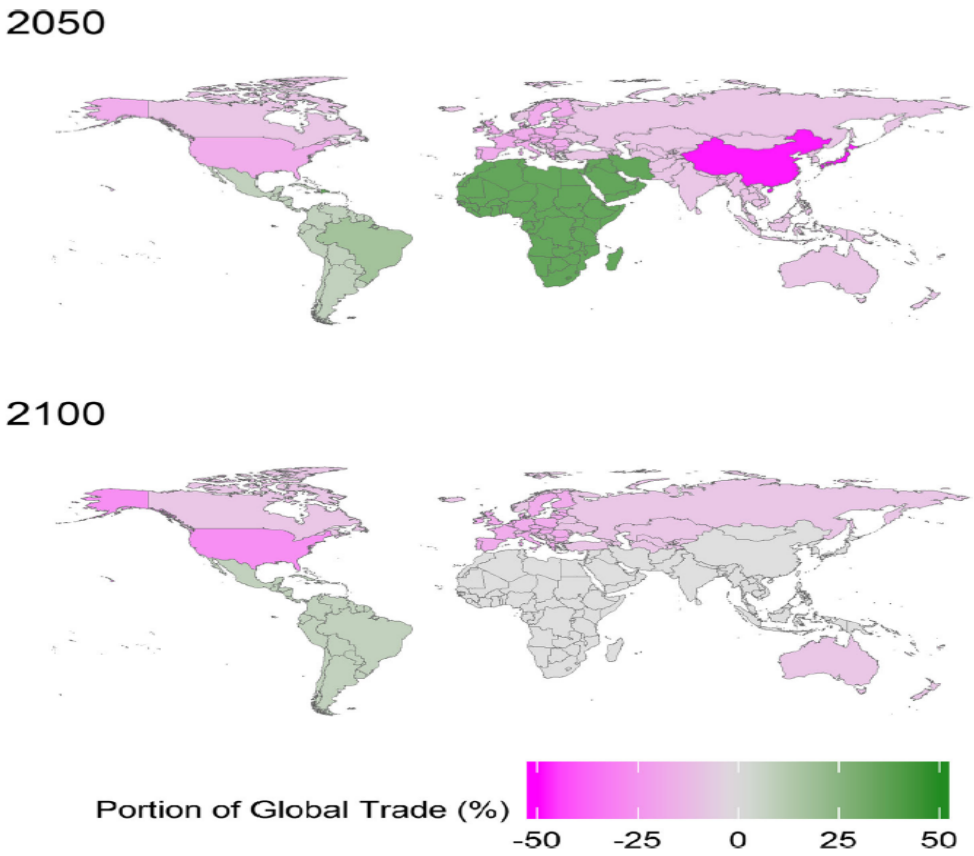


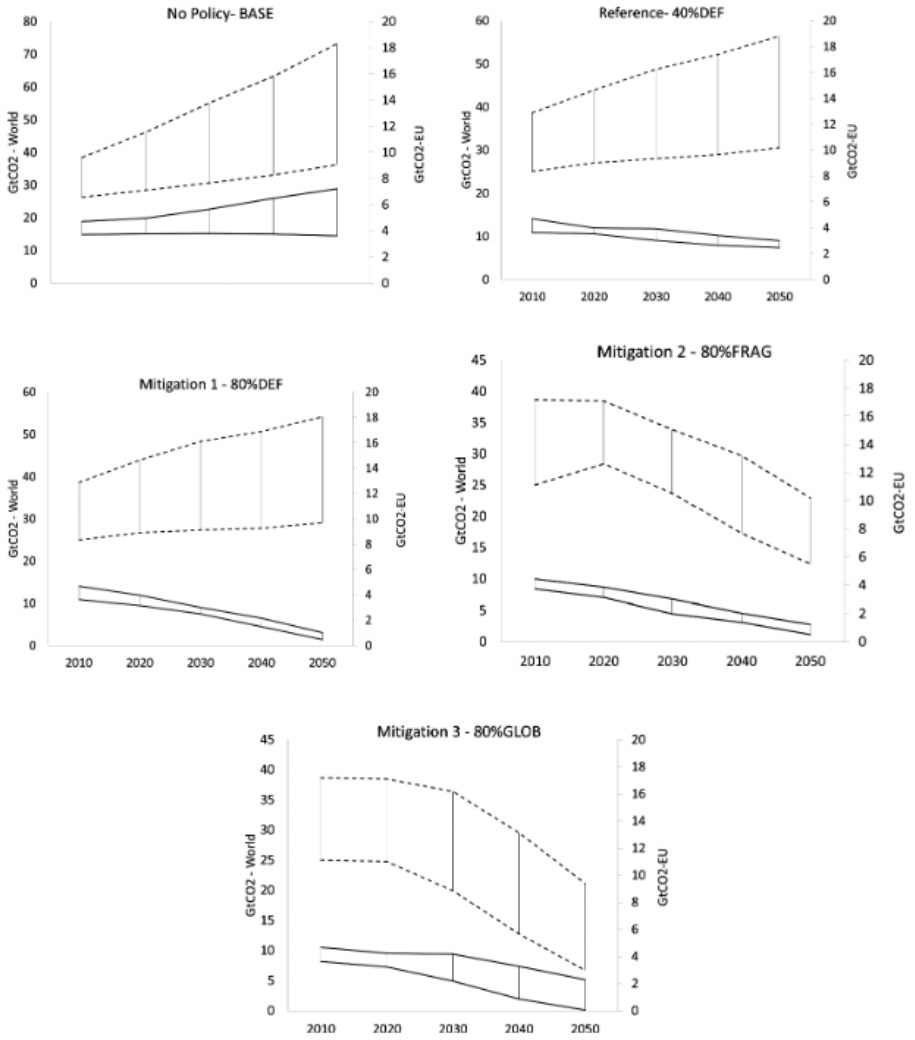

Fig. 2 Regional importance in projected international bioenergy trade for 2050 and 2100 for the Budget1000 scenario. Pink regions are net importers and green regions are net exporters with at least 5/8 models agreeing on the direction of trade. Gray regions indicate less than 5/8 models agree. The intensity of pink/green indicates net imports/exports each region is responsible for with respect to global bioenergy trade, median across agreeing models

# Definitions of Some Key EMF-28 Scenarios

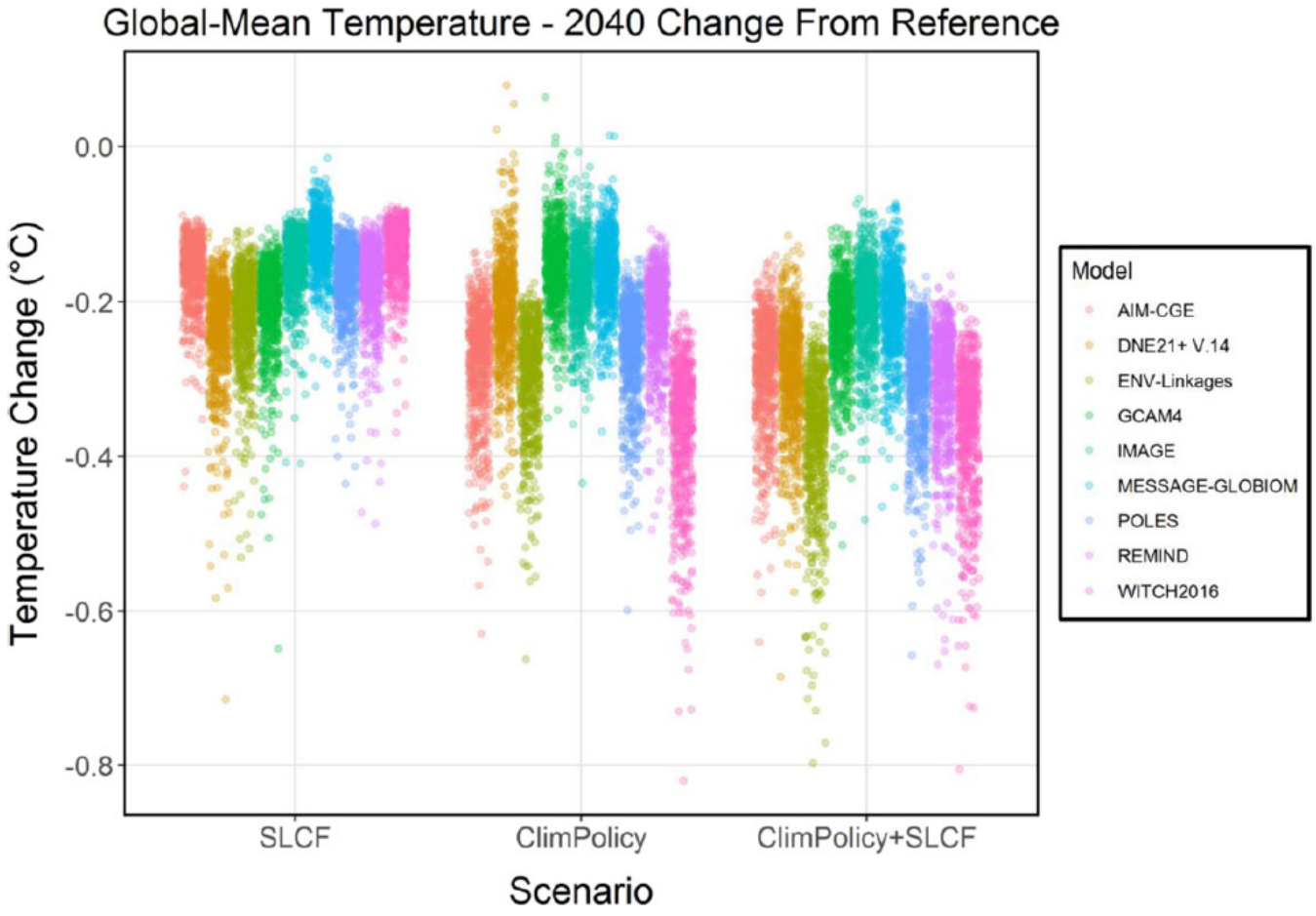
| Climate policy dimension | Policy dimension for the EU | Policy dimension for the Rest of the World (ROW) | Default | Higher energy efficiency |
|---|---|---|---|---|
| No Policy Baseline | No policy | No policy | BASE | |
| Reference | Including the 2020 targets and 40% GHG reduction by 2050 | Moderate policy scenario; no emission trading across macroregions (but trade within macroregions e.g., within EU) | 40% DEF | 40% EFF |
| Mitigation 1 | 80% GHG reduction by 2050 (with Cap and Trade within the EU, a carbon market in the EU only) | Moderate policy scenario; no emission trading across macroregions (but trade within macroregions e.g., within EU) | 80% DEF | 80% EFF |
| Mitigation 2 | 80% GHG reduction by 2050 (with Cap and Trade within the EU, 2 separate carbon markets) | IMAGE 2.9 scenario; full emission trading for ROW, but no emission trading between ROW and EU. Regional relative contributions to mitigation based on the Mitigation 1 scenario | 80% FRAG | 80% FRAG_EFF |
| Mitigation 3 | 80% GHG reduction by 2050 (with full Cap and Trade, 1 global carbon market) | IMAGE 2.9 scenario; emission trading is allowed between all regions | 80% GLOB | 80% GLOB_EFF |

Enrica De Cian, Ilkka Keppo, Johannes Bollen, Samuel Carrara, Hannah Förster, Michael Hübler, Amit Kanudia, Sergey Paltsev, Ronald D. Sands, and Katja Schumacher. "European-Led Climate Policy Versus Global Mitigation Action: Implications On Trade, Technology, and Energy." *Climate Change Economics*, Vol. 4, Suppl. 1 (2013).

# CO2 Emissions in the No Policy Baseline, Reference, and Mitigation Scenarios for EU-27 (solid lines, right axis) and the World (dashed lines, left axis) in the Default Technology Case



# EMF 30: Short Lived Climate Forcers Uncertainty Analysis for 2040 Temperature Change, Relative to Reference Scenario

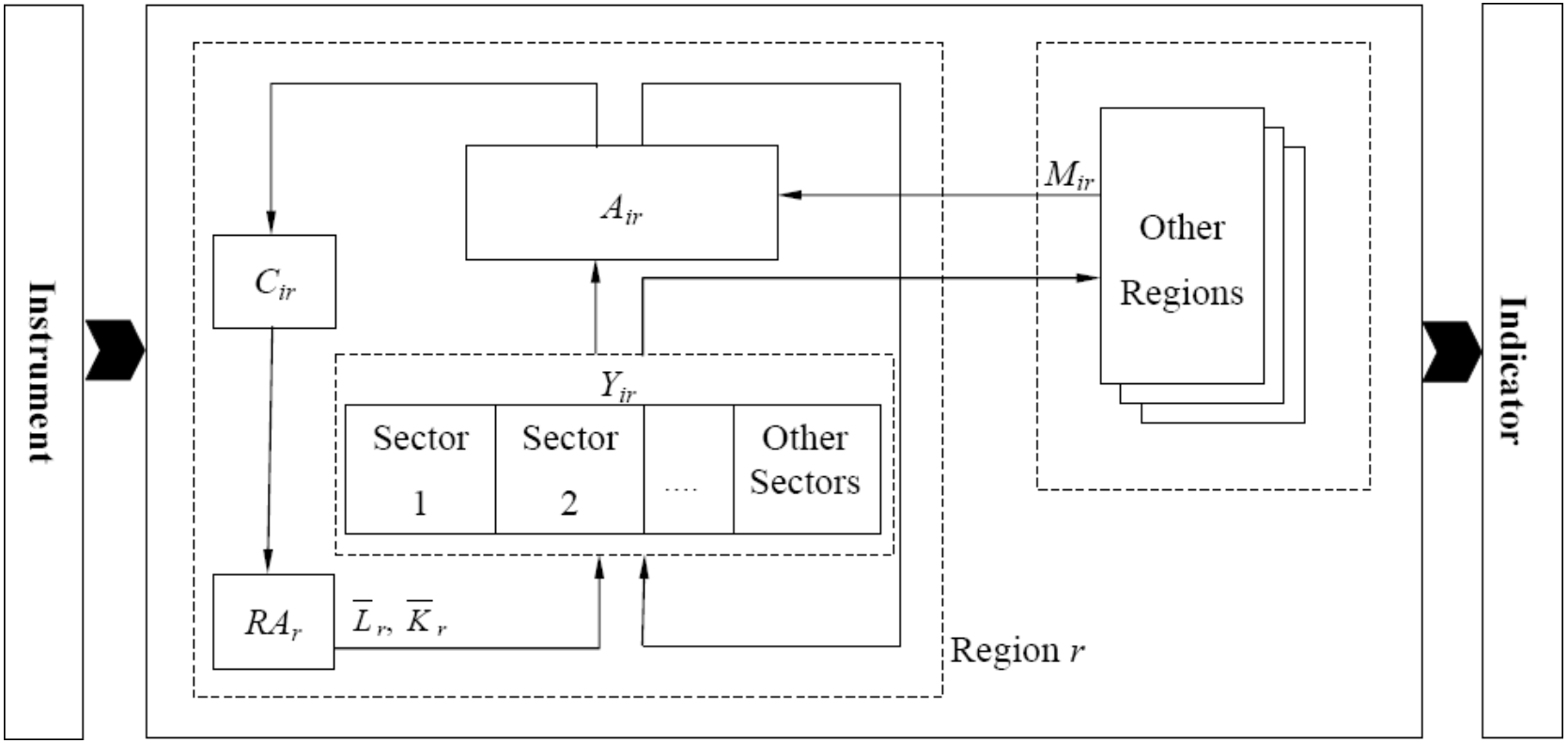



Steven Smith, et al. (2020). "Impact of methane and black carbon mitigation on forcing and temperature: a multi-model scenario analysis." *Climatic Change,* 163:1427–1442, https://doi.org/10.1007/s10584-020-02794-3

# The End
# Thank You

# Computable General Equilibrium Models

- Microeconomic foundation: welfare analysis
- Comprehensive coverage of market interactions: intermediate demands and bilateral trade
- Origination and spending of income: expenditure and income effects
- Calibration of technologies and preferences based on empirical data: cost shares and elasticities




Key:
*i*: commodity; *r* (alias *s*): region
*M*: import; *C*: consumption, *Y*: production; *A*: Armington composite;
*RA*: Income of representative agent, *L*: labor endowment; *K*: capital endowment

Source: Böhringer and Löschel (2006)

# Incidence Across Households

EMF

| Model | Specification | Specific country |
|---|---|---|
| BC3 | Single-country | Spain |
| IEG | Single-country | India |
| TEA | Multi-region | Brazil |
| CEPE | Multi-region | Belgium, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Latvia, Lithuania, Poland, Portugal, Slovakia, Slovenia, Spain, United Kingdom, Bulgaria, Croatia, Romania |
| JRC-GEM-E3 | Multi-region + soft-link* | Austria, Belgium, Czech Republic, Germany, Estonia, Greece, Spain, Finland, France, Italy, Romania |
| SNoW | Multi-region | Norway |
| DREAM | Multi-region | China |
| UOL | Multi-region | Germany |

* JRC-GEM-E3 feeds its macroeconomic results for 11 European countries into the EUROMOD-ITT (Indirect Tax Tool) in order to perform the household impact assessment.

- Decomposition of aggregate expenditure and income across income deciles
- Lump-sum recycling of $CO_2$ revenues in equal shares across households

# Incidence Across Households (*NDC/ref*) EMF

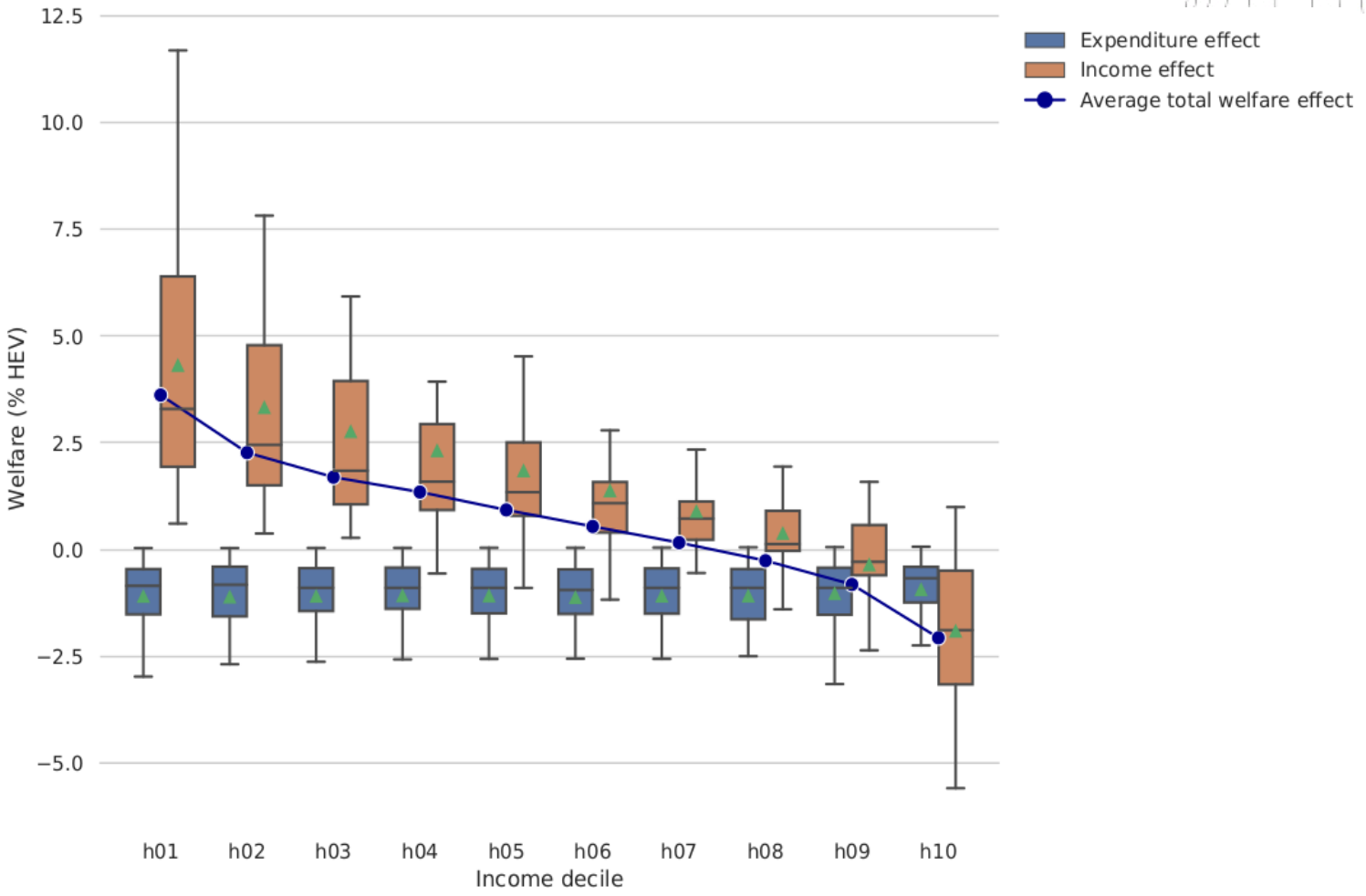


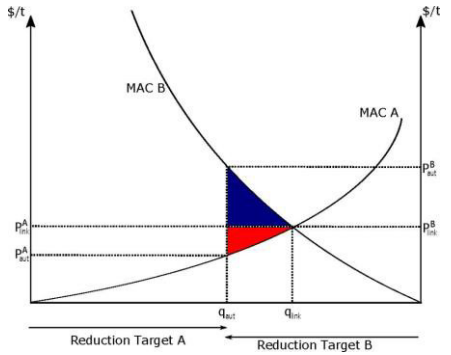

**Fig. 10.** Summary on decomposition of households' total welfare into expenditure and income effects across models and regions. Note: Box–Whisker plot shows the median (line), mean (green triangle), the first and third quartile (box), and whiskers showing the last datapoints within 1.5 times the interquartile range (IQR). Outliers omitted. Graph incorporates values from the models BC3 (Spain), IEG (India), UOL (Germany), SNoW (Norway), JRC-GEM-E3-EUROMOD-ITT (11 European countries), and CEPE (21 European countries).

- Progressive income effect dominates regressive expenditure effect

***Insight: Lump-sum recycling of carbon rents offsets regressive emissions pricing***

# EMF36 Insights: Pledge, Trade and Recycle

- Cost savings from carbon trading pays for 2°C compatible NDC pledges




- Lump-sum recycling of carbon rents offsets regressive emissions pricing

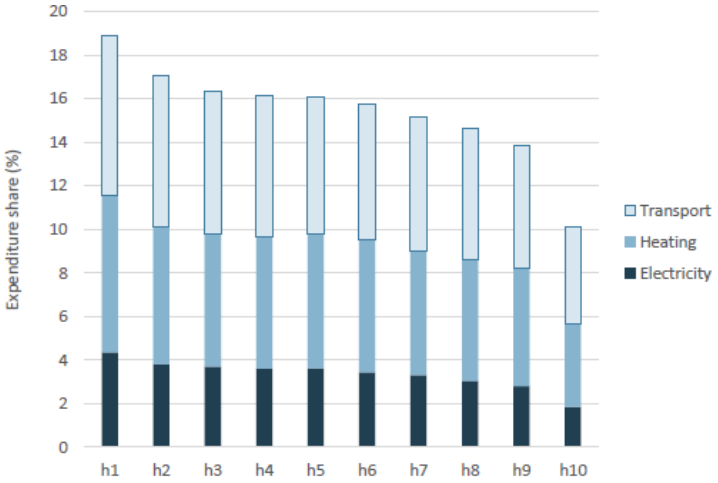



Fig. 3.4 Household expenditure shares for electricity, heat and transport (%) in 2013. Based on Income and Consumption Statistics (EVS) 2013.

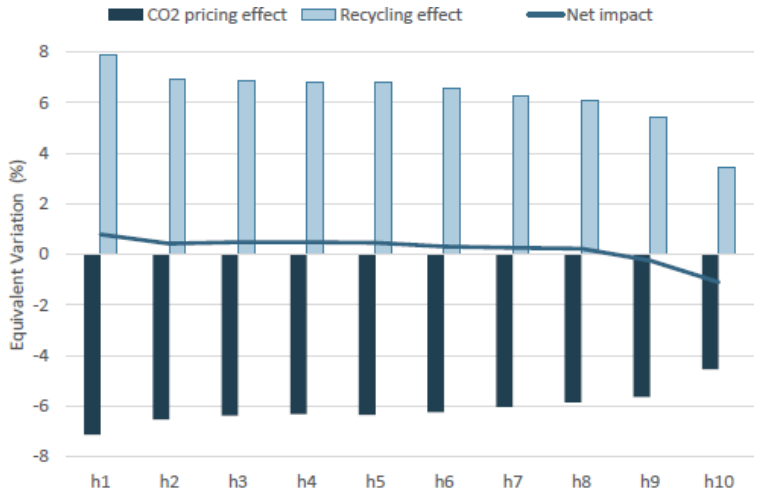



Fig. 4.4 Incidence of a $CO_2$ price of 100€/t$CO_2$ – model variant: IO

Source: Böhringer et al. (2022)

**Table 1**
Expert teams participating in the EMF36 model comparison study.

| Model | Institution | People |
|---|---|---|
| CEPE[b] | ETH Zürich | Florian Landis, Gustav Fredriksson, Sebastian Rausch |
| ICES[c] | Euro-Mediterranean Center on Climate Change (CMCC) | Ramiro Parrado |
| DART Kiel[c] | Kiel Institute for the World Economy (IfW) | Sonja Peterson, Malte Winkler, Sneha Thube |
| DREAM[c] | Fudan University | Haoqi Qian, Shuaishuai Zhang, Libo Wu |
| EC-MSMR[c] | Environment and Climate Change Canada | Nick Macaluso, Peter Johnston, Madanmohan Ghosh, Elisabeth Gilmore |
| EDF-GEPA[b] | Environmental Defense Fund (EDF) | Gökçe Akin-Olçum, Ruben Lubowski, Margaret McCallister |
| JRC-GEM-E3[c] | European Commission - Joint Research Centre (JRC) | Toon Vandyck, Matthias Weitzel, Krzysztof Wojtowicz, Luis Rey Los Santos, Anamaria Maftei, Sara Riscado |
| ENVISAGE[c] | Purdue University | Maksym Chepeliev, Israel Osario-Rodarte, Dominique van der Mensbrugghe |
| SNoW[b] | Statistics Norway | Taran Fæhn, Hidemichi Yonezawa |
| TEA[c] | COPPE - Universidade Federal do Rio de Janeiro (UFRJ) | Rafael Garaffa, Bruno Cunha, Talita Cruz, Paula Bezerra, André Lucena, Angelo Gurgel |
| TUB[b] | Technical University (TU) Berlin | Mohammad M. Khabbazan, Christian von Hirschhausen |
| C-GEM[c] | Tsinghua University | Duan Maosheng, Li Mengyu |
| UOL[b] | University of Oldenburg | Christoph Böhringer, Jan Schneider |
| WEGDYN[c] | Wegener Center for Climate and Global Change - University of Graz | Jakob Mayer, Anna Dugan, Gabriel Bachner, Karl Steininger |
| PACE[b] | Zentrum für Europäische Wirtschaftsforschung (ZEW) | Sebastian Rausch |
| IEG[a,c] | Institute of Economic Growth India (IEG) | Basanta Pradhan, Joydeep Ghosh |
| BC3[a,b] | Basque Centre for Climate Change (BC3) | Xaquín Garcia Muros, Iñaki Arto, Mikel González-Eguino |

[a]Single-country model.
[b]Static model.
[c]Recursive-dynamic model.

# EMF 36 Regions and Sectors

**Table 2**
EMF36 sectors and regions.

| Countries and regions | Sectors |
|---|---|
| *Countries* | *Energy* |
| United States (USA) | Coal |
| Canada (CAN) | Petroleum and coal products |
| Japan (JPN) | Crude oil |
| South Korea (KOR) | Natural gas |
| Russia (RUS) | Electricity |
| China (CHN) | *Other sectors/aggregates* |
| India (IND) | Energy-intensive and trade-exposed (EITE)[b] |
| Brazil (BRA) | Transport |
| *Aggregated regions* | Agriculture |
| Australia and New Zealand (ANZ) | Other manufacturing |
| Europe (EUR)[a] | Services |
| Middle East (MEA) | |
| Africa (AFR) | |
| Other Americas (OAM) | |
| Other Asia (OAS) | |

[a]Includes EU27 + UK + EFTA members.

[b]Includes chemical products; basic pharmaceutical products; rubber and plastic products; non-metallic minerals; mining of metal ores; iron and steel; non-ferrous metals; paper, pulp, and print.

# NDCs in % from 2030 BaU

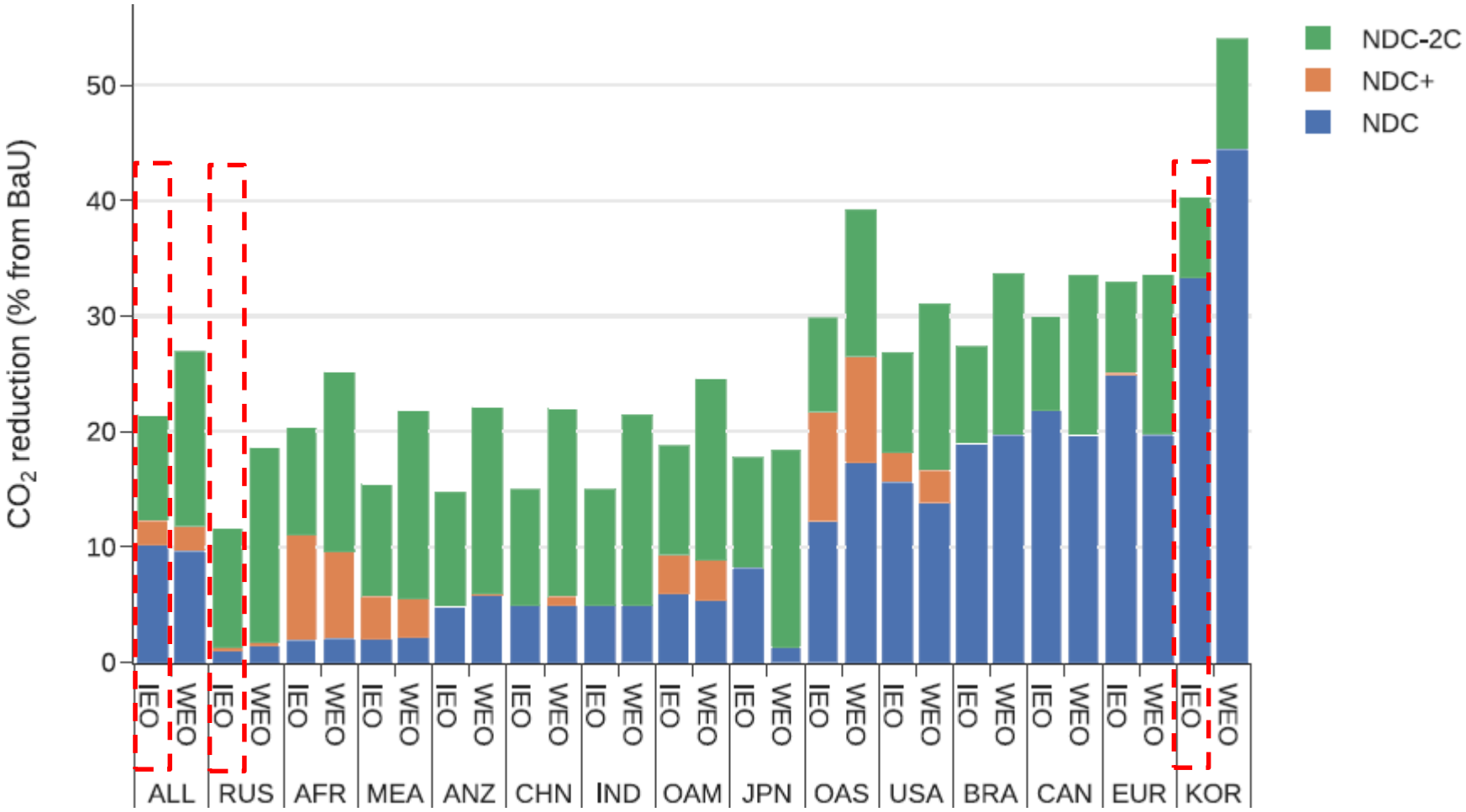



**Fig. 1.** Reduction targets for $CO_2$ emissions from fossil fuel combustion for different ambition levels (in % from 2030 BaU projections based on IEO or WEO). Note: ALL — Global average; AFR — Africa; ANZ — Australia and New Zealand; BRA — Brazil; CAN — Canada; CHN — China; EUR — Europe; IND — India; JPN — Japan; KOR — South Korea; MEA — Middle East; OAM — Other Americas; OAS — Other Asia; RUS — Russia; USA — United States. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

- Substantial differences in NDC (implicit willingness-to-pay) across regions
- Global emissions (IEO): - 10% (12%) NDC (NDC+) as compared to 21% in NDC-2C

# EMF 28 EU Technology and HG Mitigation Scenario Matrix

| | | Default w CCS | Default w/o CCS | Pessimistic | Optimistic | Green |
|---|---|---|---|---|---|---|
| | | on | off | off | on | off |
| | | ref | ref | low | ref | low |
| | | ref | ref | ref | high | high |
| | | ref | ref | ref | high | high |
| | Policy dimension for the Rest of the World (ROW) | | | | | |
| | no policy | EU11 | | | | |
| | a "moderate policy" scenario, e.g. with OECD going for -20%; no emission trading across macroregions (but trade within macroregions e.g. within EU) | EU1 | EU2 | EU3 | EU4 | EU5 |
| | a "moderate policy" scenario, e.g. with OECD going for -20%; no emission trading across macroregions (but trade within macroregions e.g. within EU) | EU6 | EU7 | EU8 | EU9 | EU10 |
| | 450ppme scenario from the global study; full | | | | | |