Challenges for low stabilization of climate change: The complementarity of non-CO_2 greenhouse gas and aerosol abatement to CO_2 emission reductions

thesis defense

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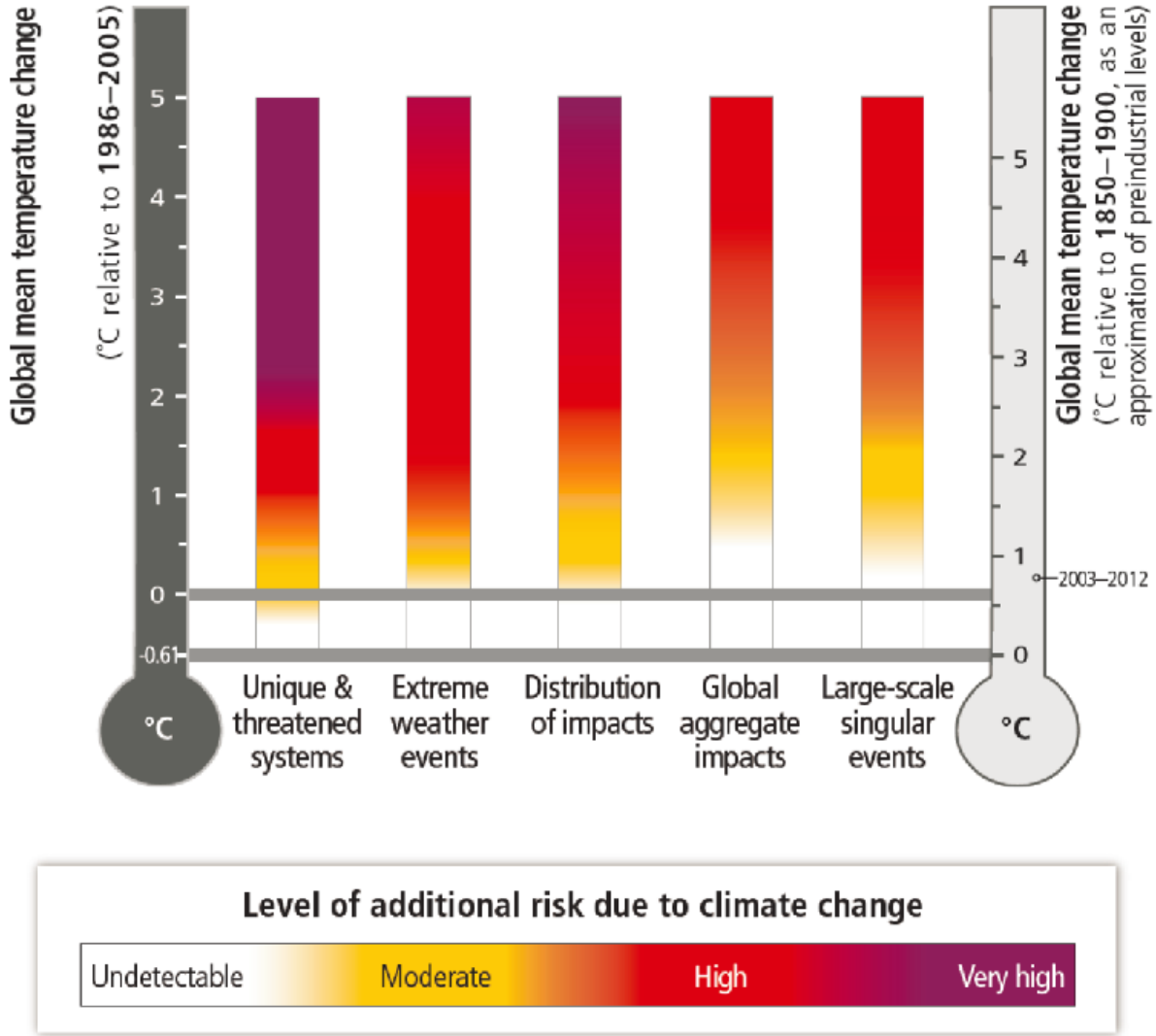
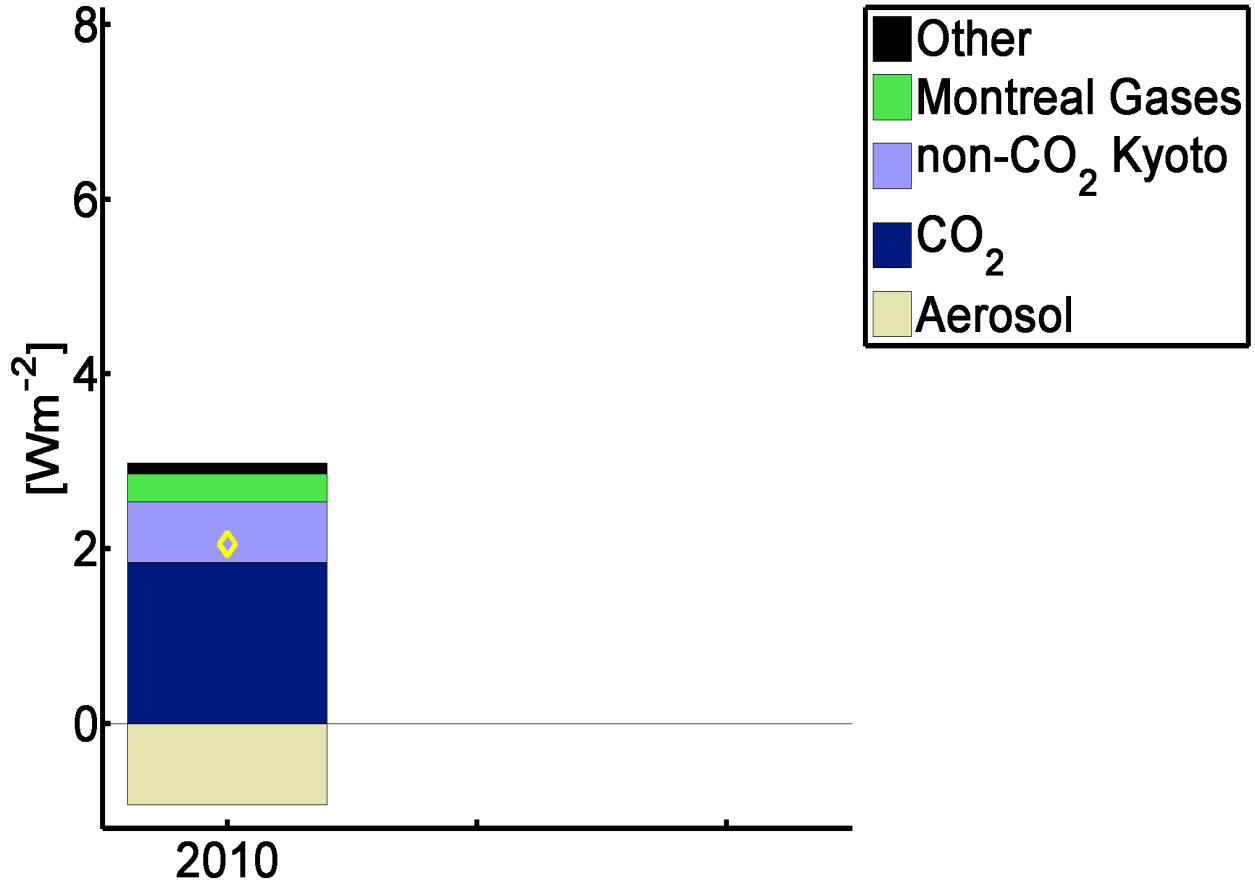
Risks of climate change

- Low stabilization: below 2° C
- UNFCCC: avoid dangerous anthropogenic interference with the climate system
- Copenhagen Accord: 2° should not be exceeded



From: IPCC AR5, WG2 SPM

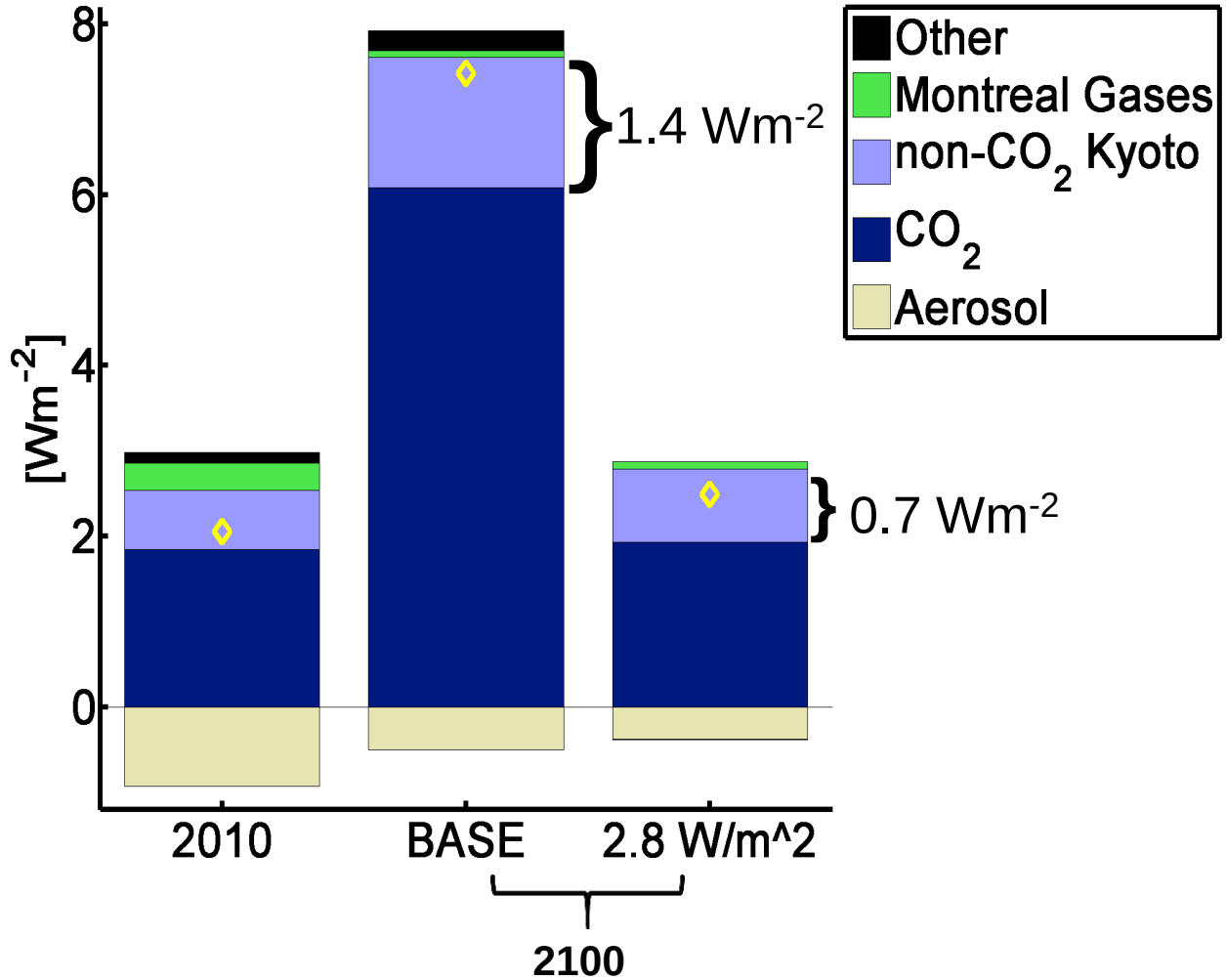
Radiative forcing



- Significant contribution from non-CO_2 Kyoto gases (CH_4, N_2O, F-gases)
- Significant negative contribution from aerosols

Data from EMF27, model REMIND

Radiative forcing



Data from EMF27, model REMIND

- Significant contribution from non-CO_2 Kyoto gases (CH_4, N_2O, F-gases)
- Significant negative contribution from aerosols
- CO_2 not only from the energy sector, but also from industry. Negative emissions from bioenergy + carbon capture and storage (BECCS).

Mitigation potentials

To achieve low stabilization targets mitigation potentials besides CO_2 from the energy sector have to be realized:

- Aerosols
- Non-CO_2 Kyoto gases (CH_4, N_2O)
- CO_2 from industrial processes
- Negative CO_2 emissions (BECCS)

Research questions

Aerosols
Can air pollutant controls accellerate global warming?
(Chapter 6)

Non-CO_2 Kyoto gases (CH_4, N_2O):
How does the choice of greenhouse gas emission metrics affect global and regional economic costs? (Chapter 4)

CO_2 from industrial processes:
How high are residual CO_2 emissions that cannot be avoided?
(Chapter 3)

Negative CO_2 emissions (BECCS):
How do bioenergy deployment and revenues depend on the availability of CCS, stringency of the climate target, and bioenergy supply? (Chapter 5)

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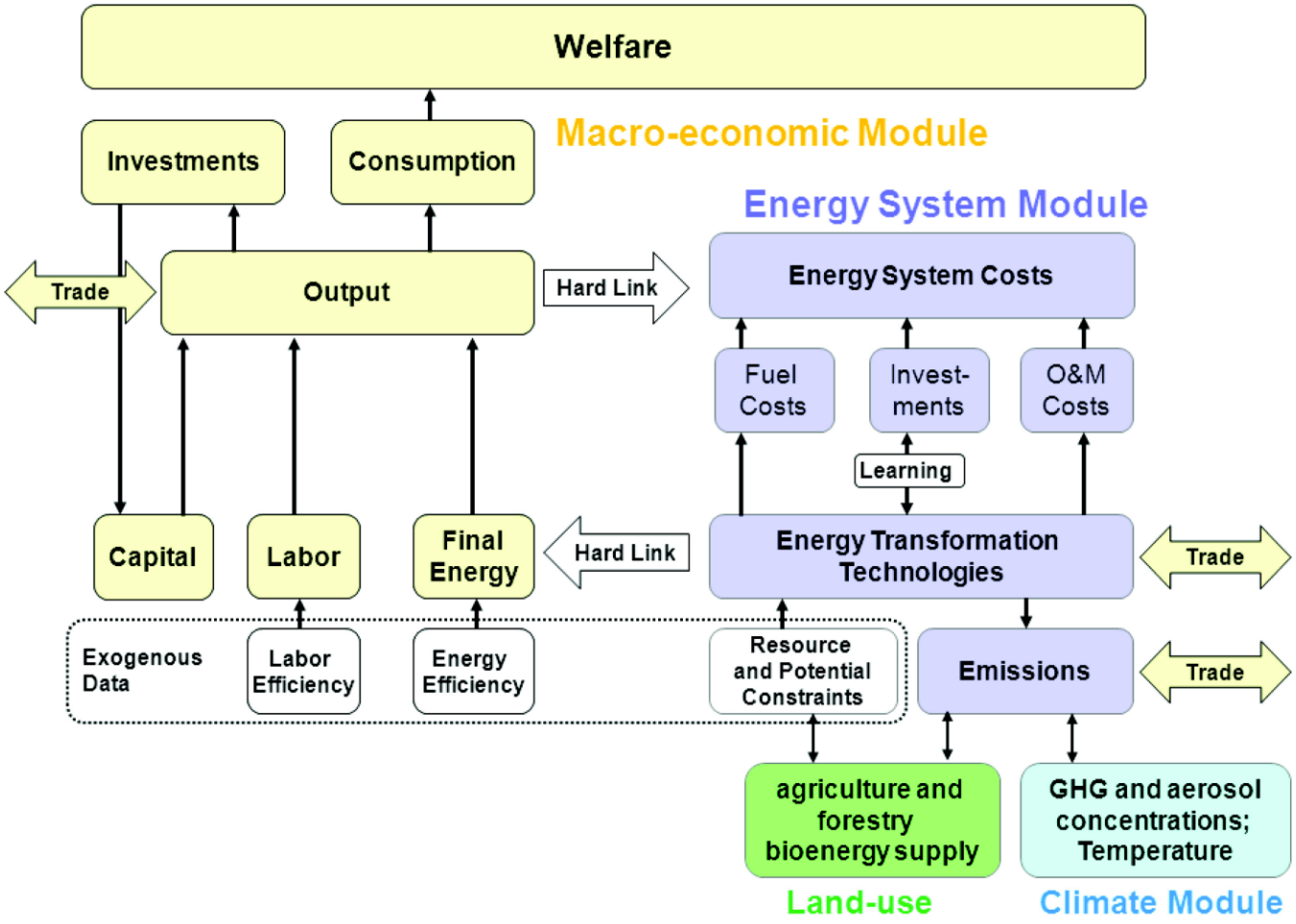
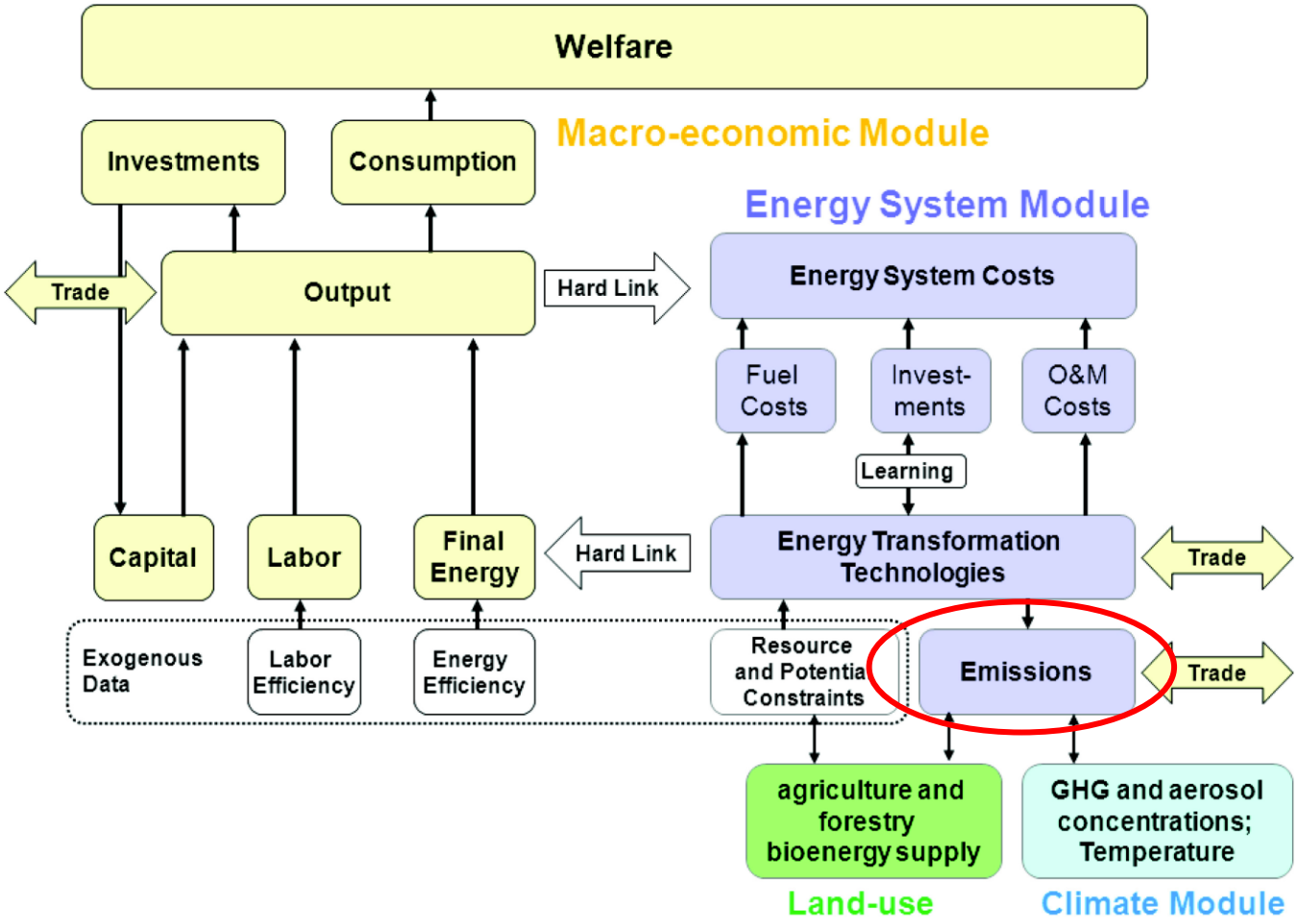
Methods

Structure of REMIND



Structure of REMIND

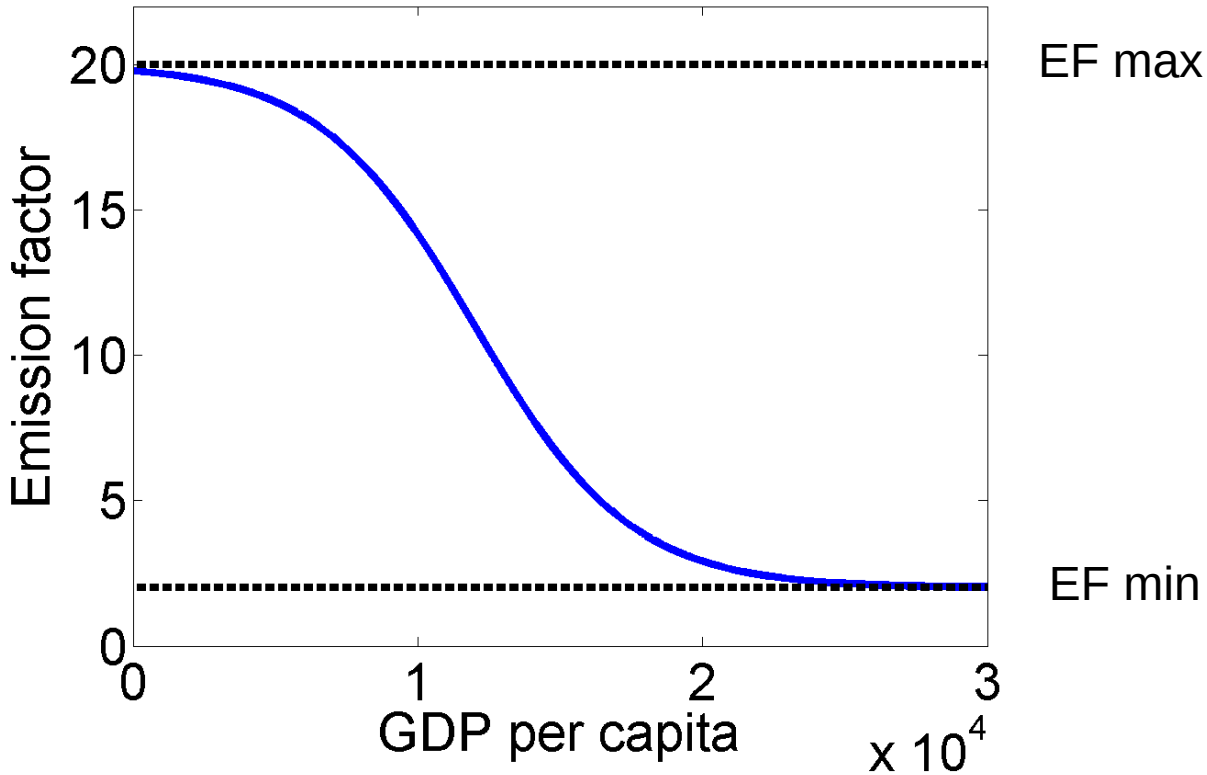


Emissions

- Implemented source-based emissions
- Emission factors are region- and technology-specific
- Greenhouse gases:
  - Included CO_2 from cement production, CH_4 and N_2O by source
  - Reduction via source-specific marginal abatement cost curves
- Aerosols:
  - Included most important species by source
  - Reduction of emission factors due to e.g. scrubbers
  - Economic development results in higher demand for clean air
  - Reduction of emission factors coupled to GDP

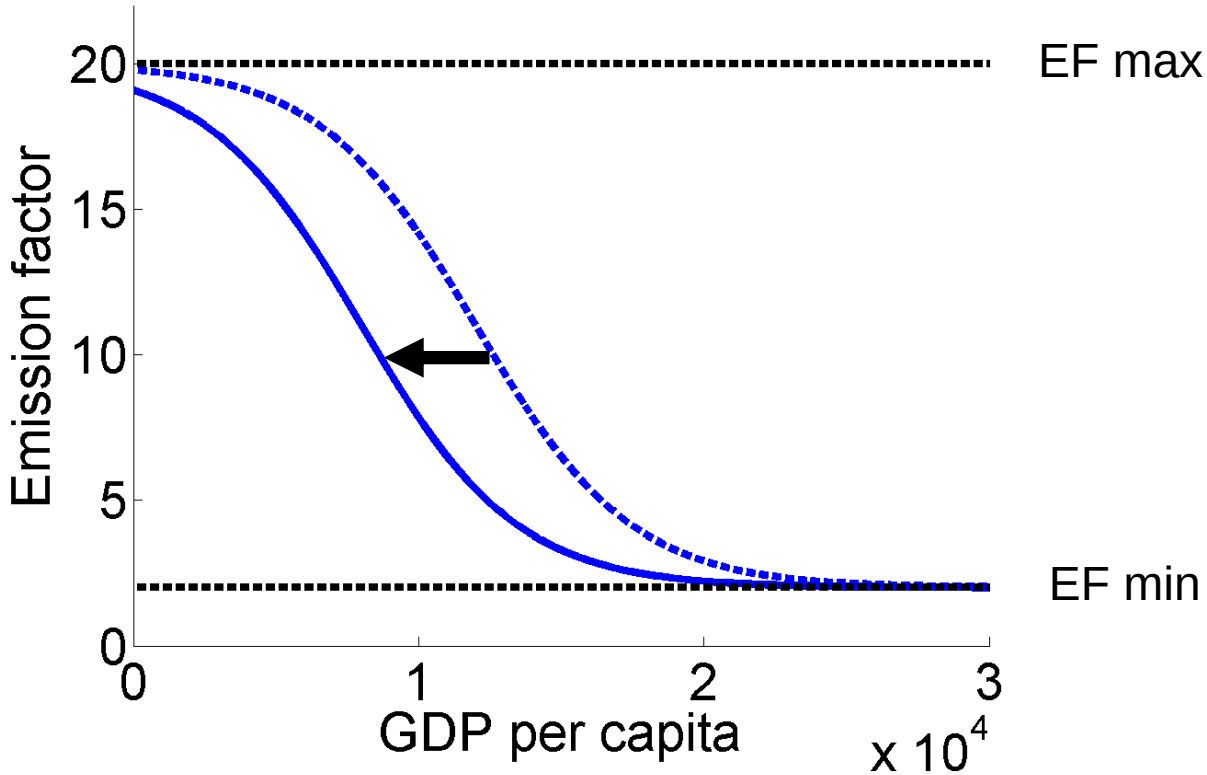
Aerosols

- Development of emission factor coupled to GDP
- Decreases over time



Aerosols

- Development of emission factor coupled to GDP
- Decreases over time
- More stringent air pollution policy: earlier deployment of aerosol removal technologies



Research questions

Aerosols
Can air pollutant controls accellerate global warming?
(Chapter 6)

Other Kyoto gases (CH_4, N_2O):
How does the choice of greenhouse gas emission metrics affect global and regional economic costs? (Chapter 4)

CO_2 from industrial processes:
How high are residual CO_2 emissions that cannot be avoided?
(Chapter 3)

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Can air pollutant controls accelerate global warming?

Structure

- Introduction
- Scenarios
- Emissions
- Forcing
- Temperature

Aerosols

Sulfate

- Cooling
- Heart-lung diseases, negative effects for ecosystems

Black Carbon (BC, soot)

- Warming
- 2 million deaths from indoor smoke (WHO)

Introduction

- Aerosols in total have a cooling effect
- Reduction of aerosols could result in accelerated warming (e.g. Ramanathan & Feng, PNAS, 2008)
- Clean air and climate protection antagonists?
- Some proposed to take out BC first to reduce pollution and warming at the same time (e.g. Schellnhuber, PNAS, 2008; Schindell et al., Science, 2012; UNEP)
- How to achieve this if aerosols are often co-emitted?

Reseach questions

- How do air pollution policies and climate policies affect each other?
- Can air pollution policies lead to a faster increase in global mean temperature?
- Could the design of air pollution policies change this?
- Can tailored air pollution policies buy time?

Scenarios

Additional air pollution policies targeting		*small-scale sources (residential and transport)*		
		Weak	**Medium**	**Stringent**
large-scale sources (power sector and industry)	**Weak**	WEAK		SMALL
	Medium		STD	
	Stringent	LARGE		STRGT

All air pollution scenarios are run without (BASE) and with (POL) additional climate policy

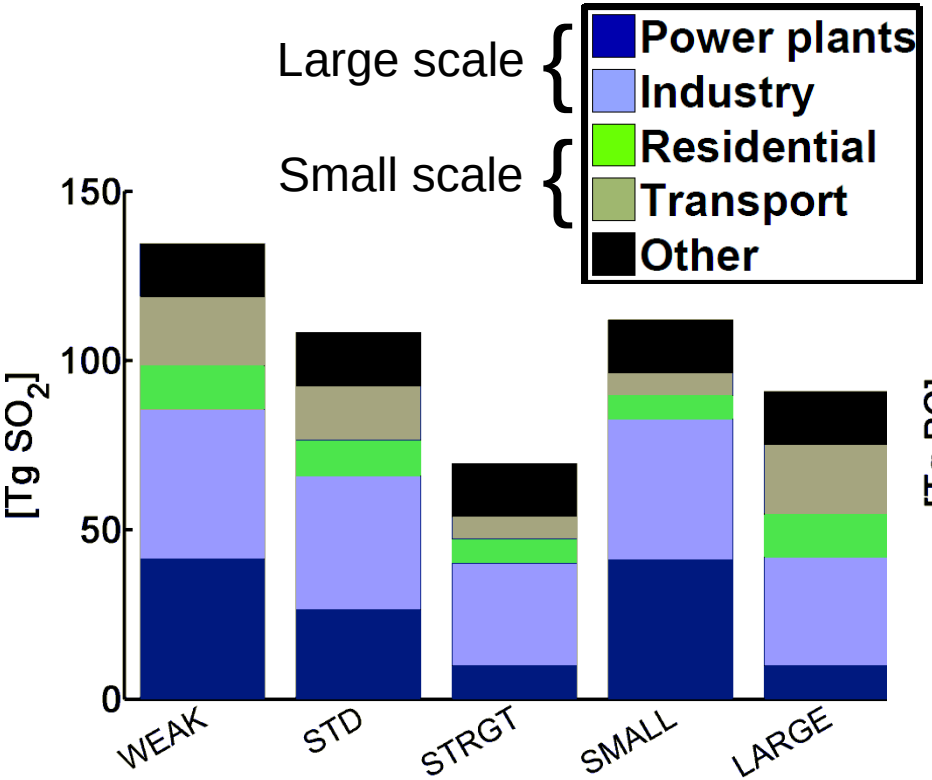
BASE Emissions in 2030

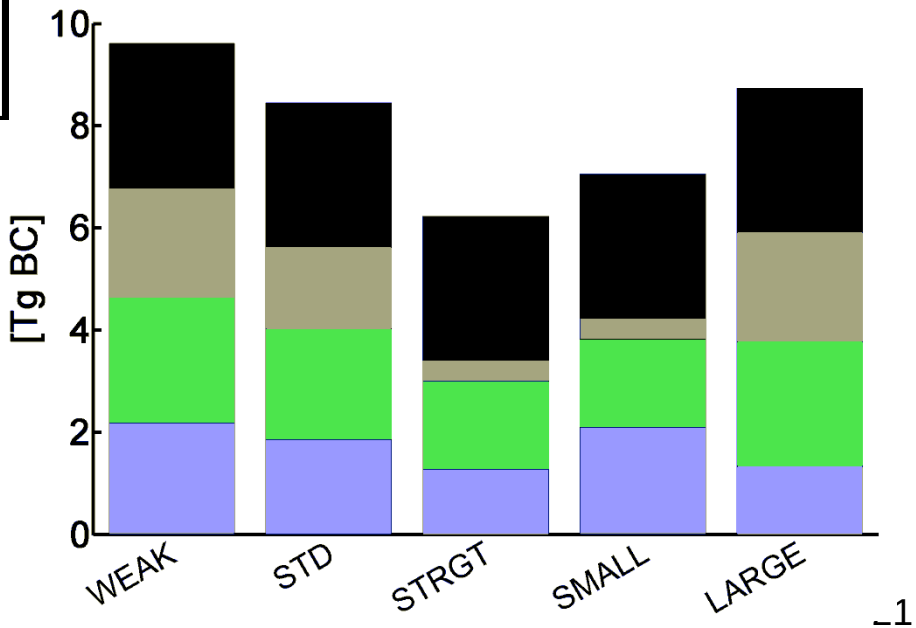
Sulfur

mainly from industry and power sector (large-scale)

Black Carbon

mainly from residential and transport sector (small-scale)





POL Emissions in 2030

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mainly from industry and power sector (large-scale)

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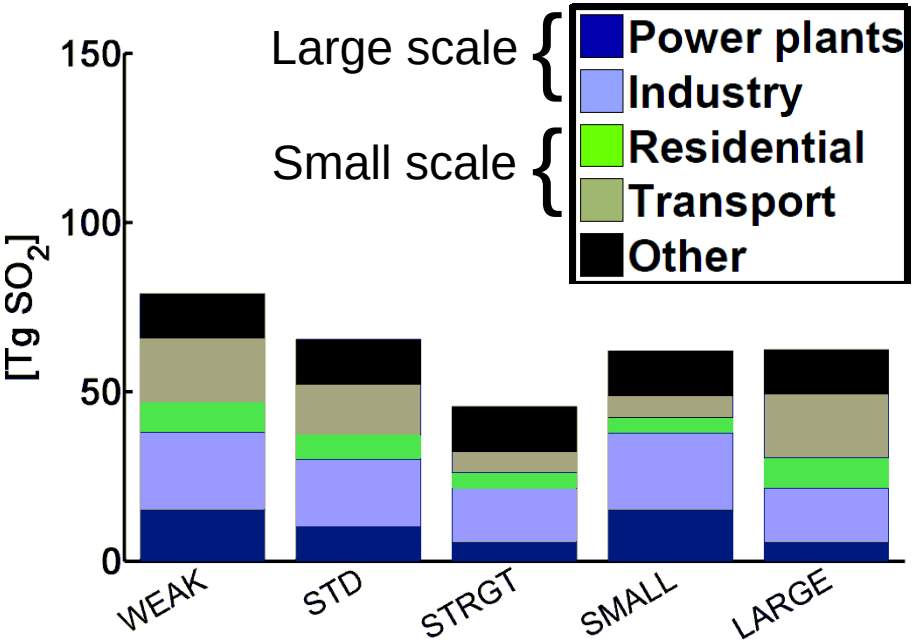
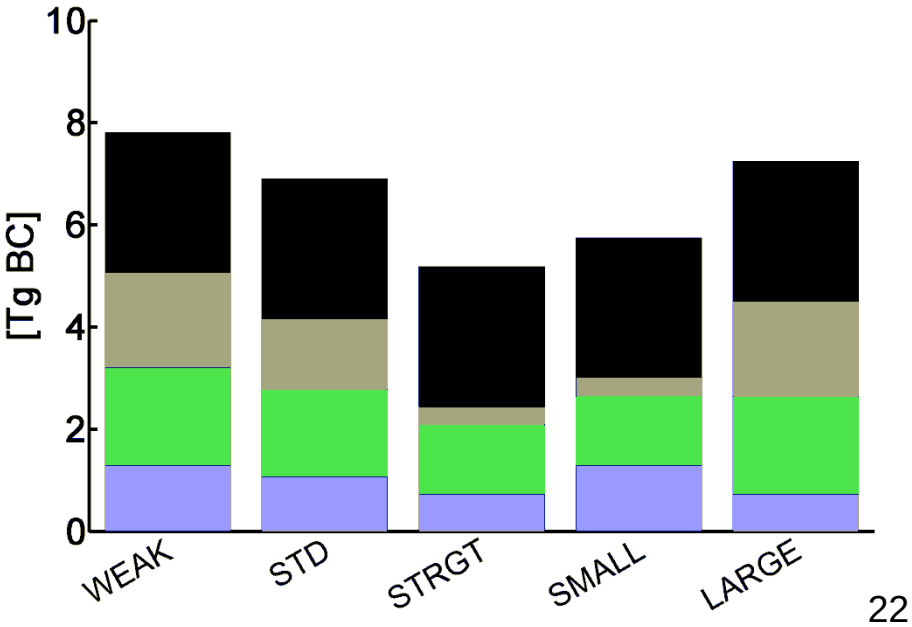
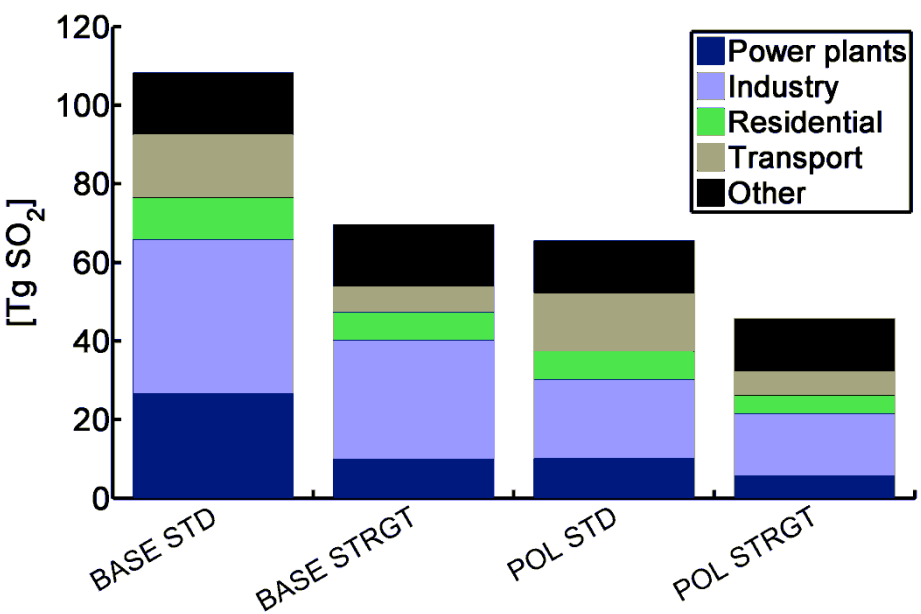


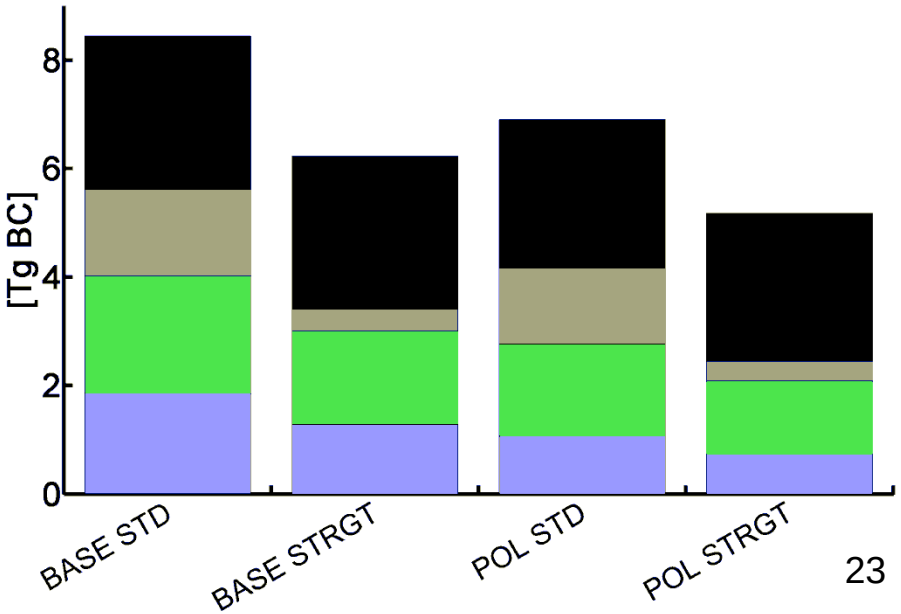


Emissions in 2030

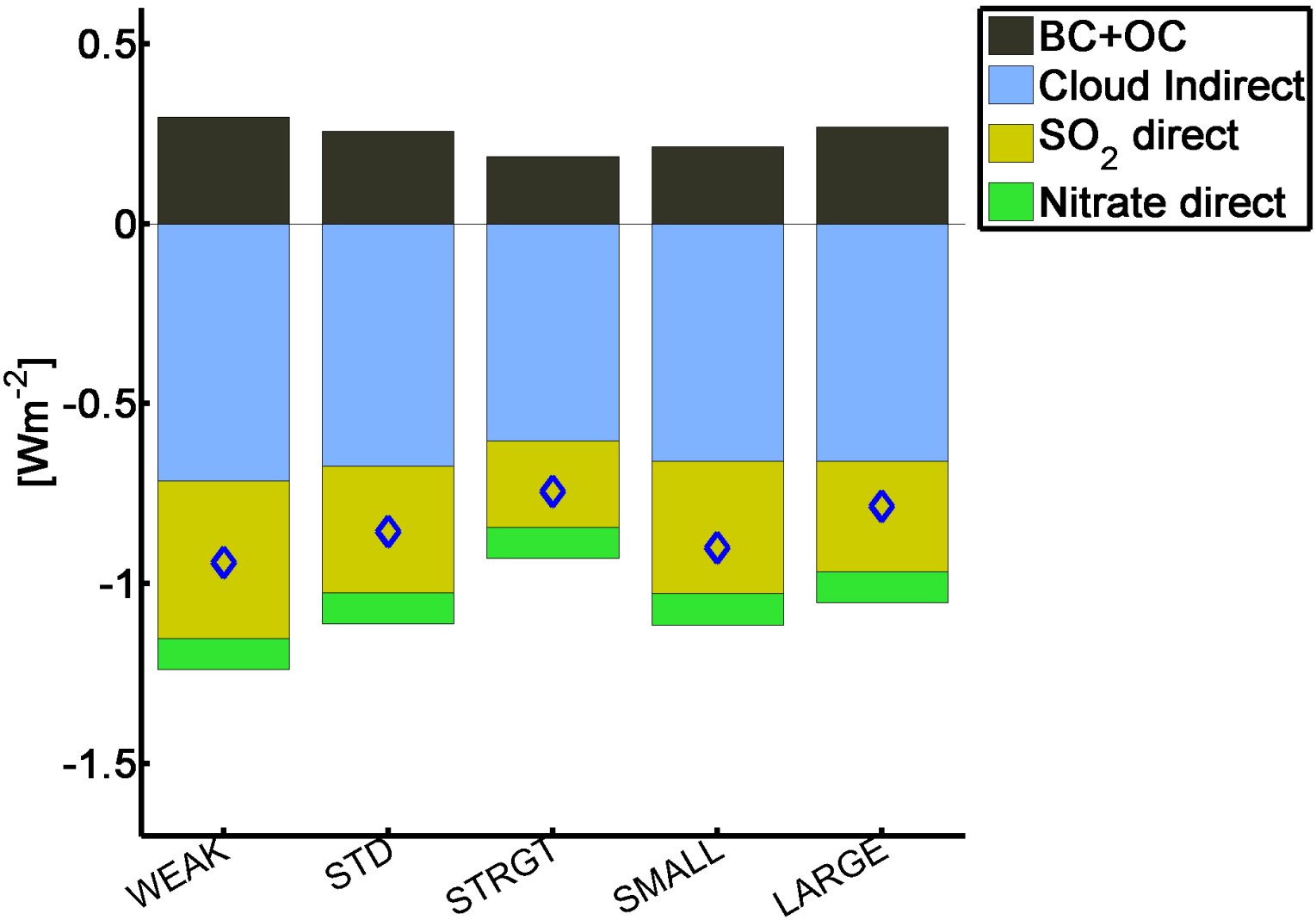
Sulfur **Black Carbon**

Synergies between climate and air pollution policies

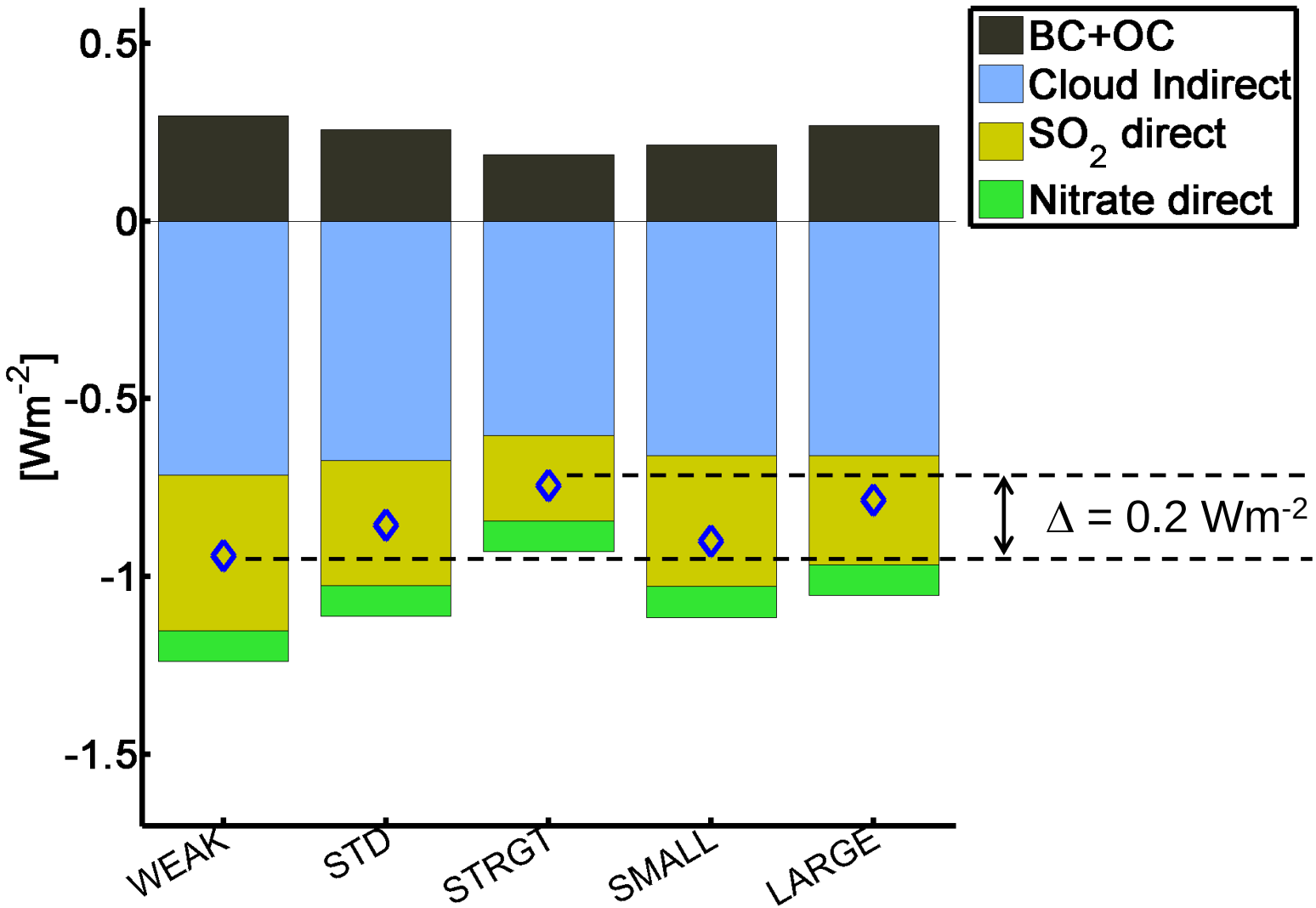




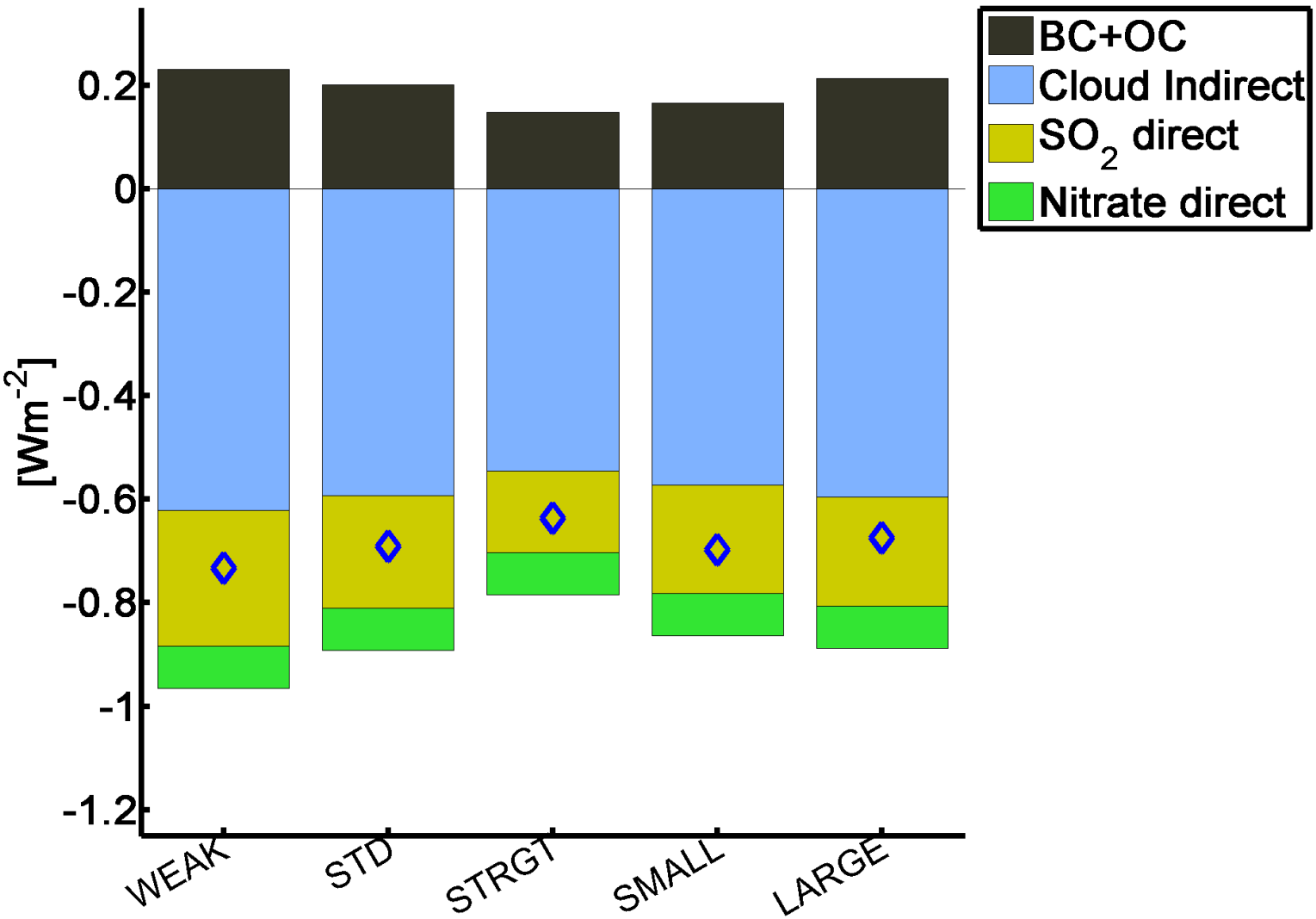
BASE aerosol forcing in 2030



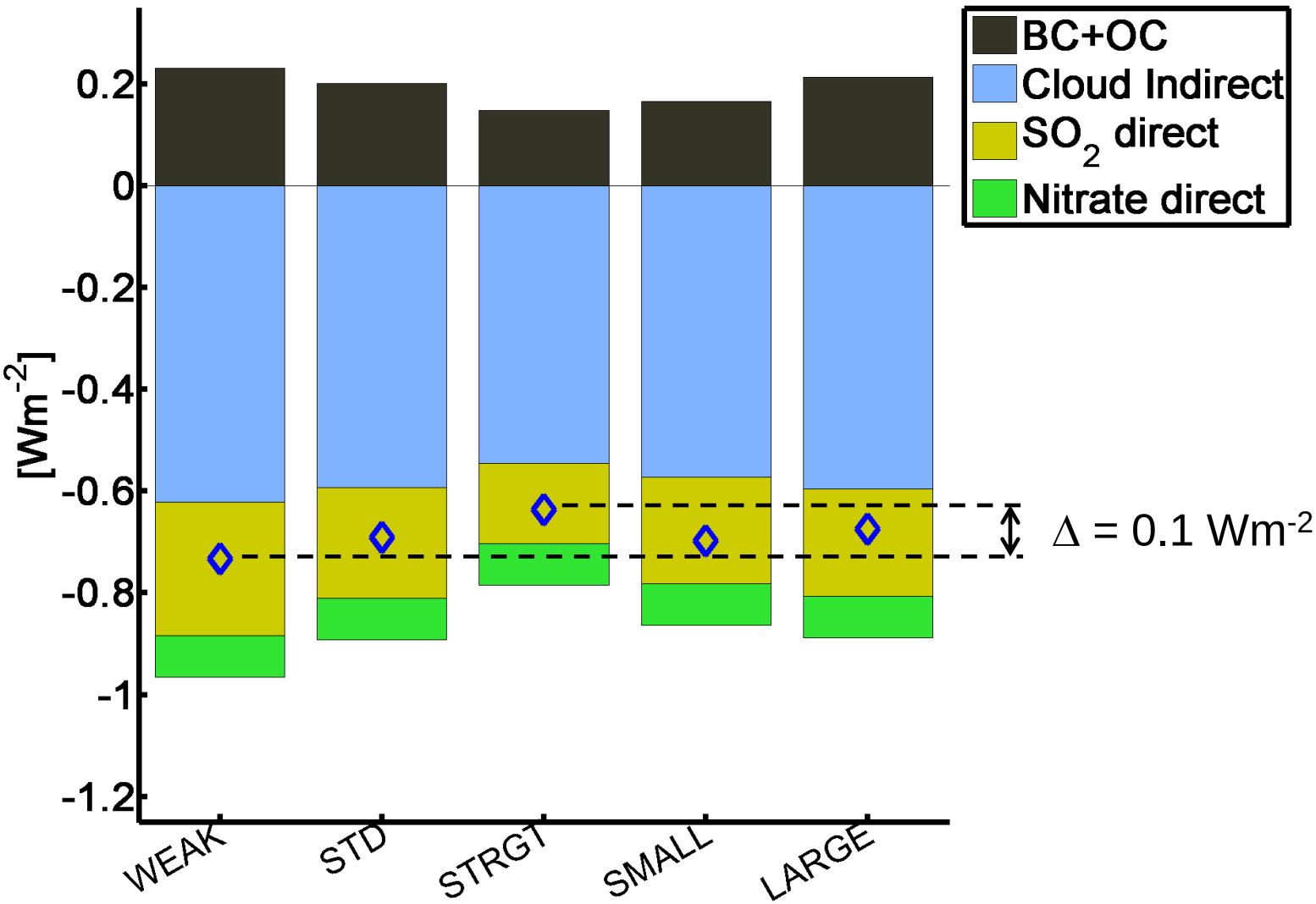
BASE aerosol forcing in 2030



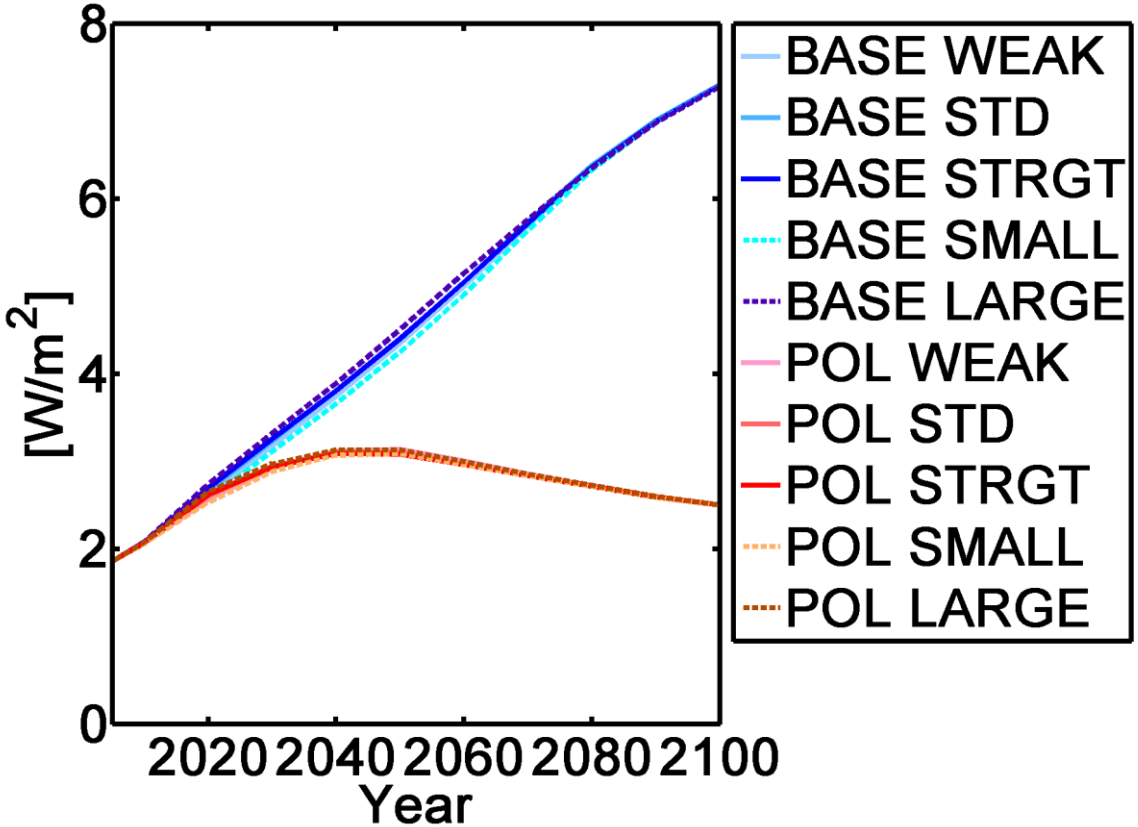
POL aerosol forcing in 2030



POL aerosol forcing in 2030



Total forcing



- Almost no difference in peak forcing
- No difference in 2100 forcing
- Small differences in the first decades

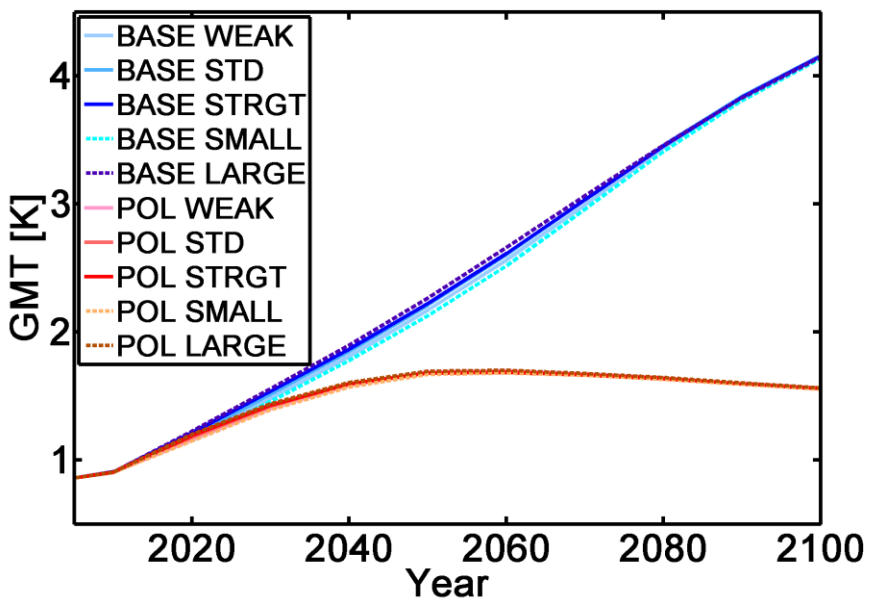
Temperature change

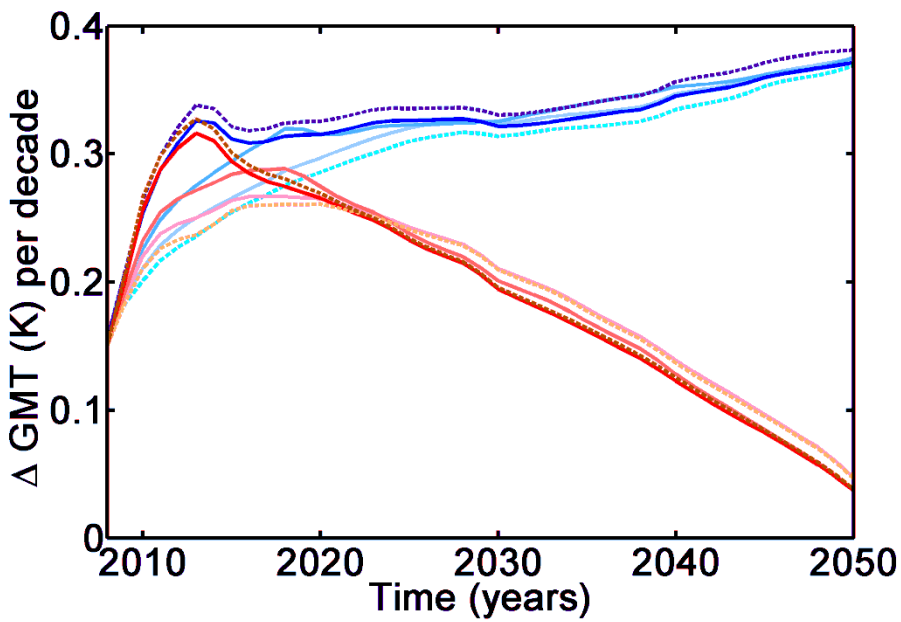
Temperature change

- No noticeable difference in POL
- Small difference in BASE in mid-term

Rate of temperature change

- Difference up to 0.1 °K/decade in the first decade
- After 2020/2030 only climate policy relevant





Conclusions Aerosols

- Air pollution policies can reduce pollutant emissions substantially
- There are synergies from climate policies
- Air pollution policies do not affect long-term climate targets: neither make them unachievable nor buy time
- There is no tradeoff between clean air and climate policies
- Air pollution policies may affect the rate of climate change in the short term

Research questions

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How does the choice of greenhouse gas emission metric affect global and regional economic costs?

Structure

- Introduction
- Permit prices
- Emissions
- Global mitigation costs
- Regional mitigation costs

History

- Already the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 had the objective to „stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system“

- Kyoto protocol of 1997 takes all long-lived greenhouse gases into account (CO_2, CH_4, N_2O, F-gases)

- All have different lifetimes in the atmosphere, different impacts in terms of radiative forcing

- How to integrate these different gases?

- Kyoto protocol: one budget for all gases

Metrics

- Make different gases comparable, define exchange ratio
  e.g. 1 t $CH_4 \rightarrow$ 25 t CO_2eq

- Kyoto protocol: Germany to reduce ~ 260 Mt CO_2eq by 2012

- 260 Mt CO_2 or 10.5 Mt CH_4

- Metric also defines price ratio

Global Warming Potential

- GWP is a simple metric: $GWP_H(x) = \frac{(\quad)}{(\qquad)}$

- Criticism e.g.
  - Time horizon H is important, yet arbitrary
  - Temperature is closer to impacts / damages
  - Economic damages themselves should be considered

- Numerous alternative metrics have been proposed

- Choice of metric implies value judgements:

  Include rate of temperature change? Include non-economic damages?

Alternative metrics

- Global Temperature change Potential (GTP)
  - Compares effects of different gases on temperature change
  - Specific point in time instead of integral
  - Time-dependent
  - Broadly discussed as possible alternative

- Global Cost Potential (GCP)
  - Endogenous to the model
  - Ratio of shadow prices
  - Depends on climate target
  - Efficient metric given a climate target
  - This study: 2° in 2100 → similar to GTP

Research questions

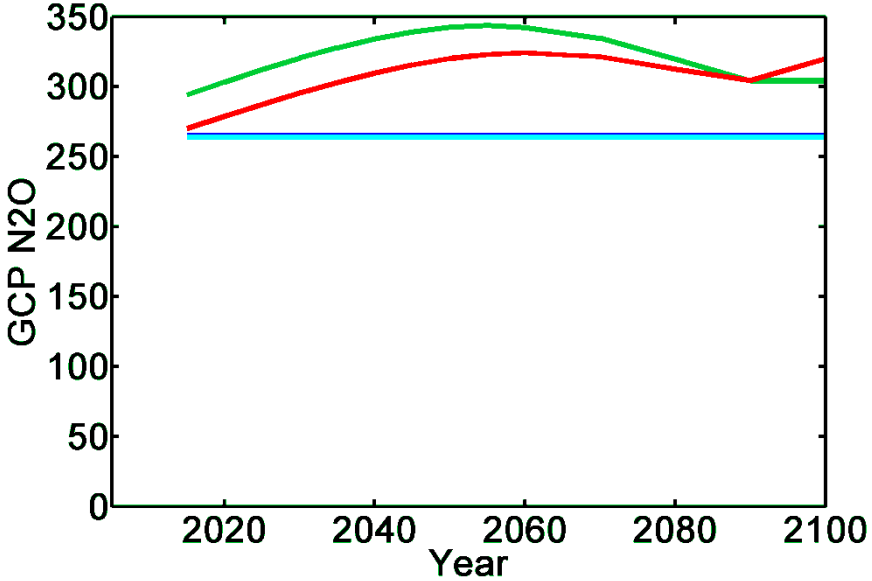
- Which effect does the choice of metric have on emissions trajectories?
- Effect on global economic costs?
- Distributional effects?

Exchange ratio

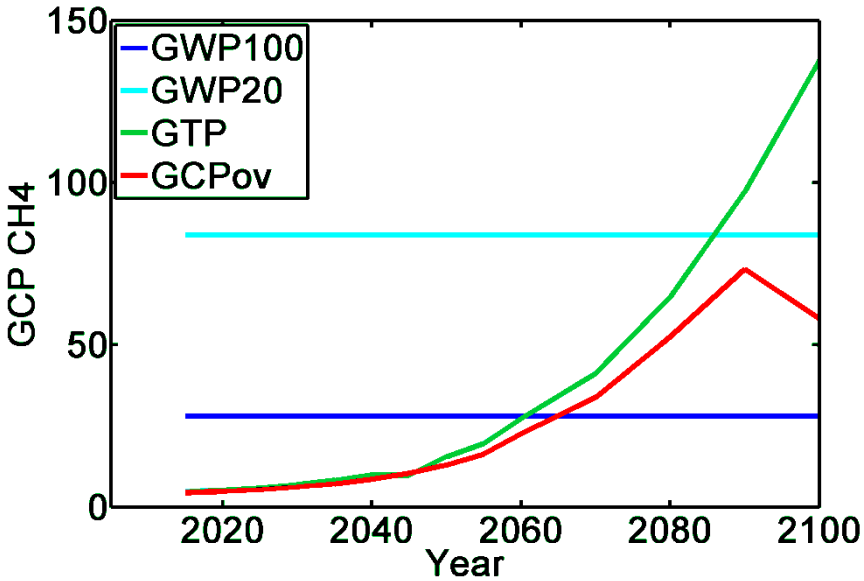
- Exchange ratio of N_2O relatively similar among almost all metrics due to its long lifetime

- Time-dependent exchange ratios of CH_4 show exponential increase due to its shorter lifetime

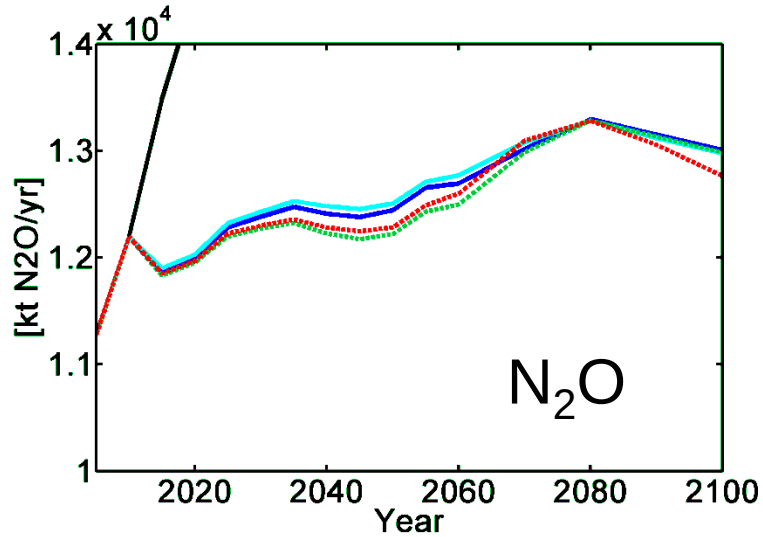
N_2O

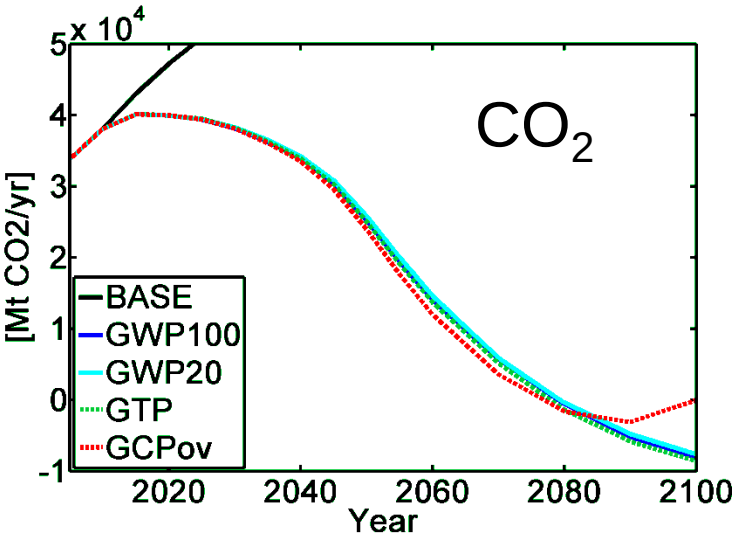


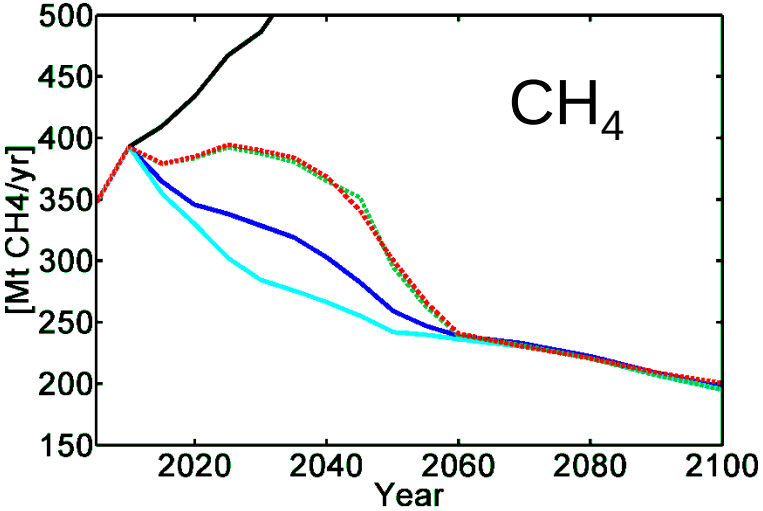
CH_4

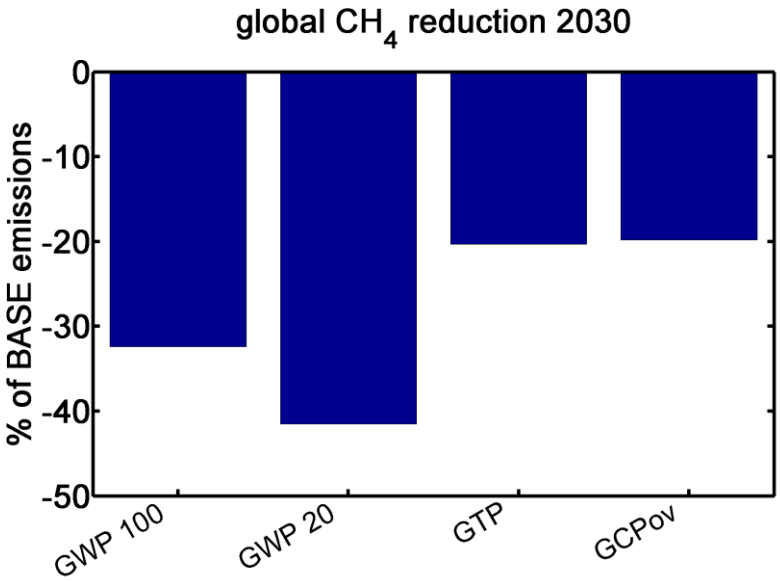


Emissions

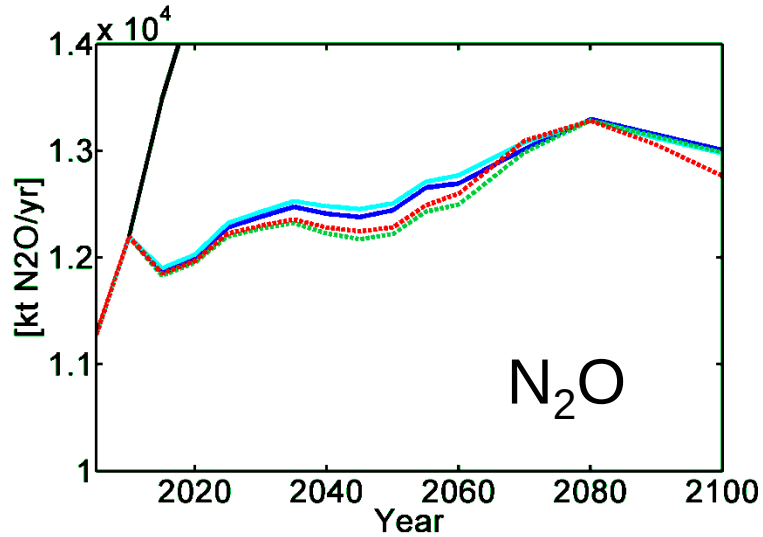

x 10^4
1.4
1.3
1.2
1.1
1
[kt N2O/yr]
N2O
2020
2040
2060
2080
2100
Year


x 10^4
5
4
3
2
1
0
-1
[Mt CO2/yr]
CO2
BASE
GWP100
GWP20
GTP
GCPov
2020
2040
2060
2080
2100
Year


500
450
400
350
300
250
200
150
[Mt CH4/yr]
CH4
2020
2040
2060
2080
2100
Year


global CH4 reduction 2030
0
-10
-20
-30
-40
-50
% of BASE emissions
GWP 100
GWP 20
GTP
GCPov

Emissions


x 10^4
1.4
1.3
1.2
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1
[kt N2O/yr]
N2O
2020
2040
2060
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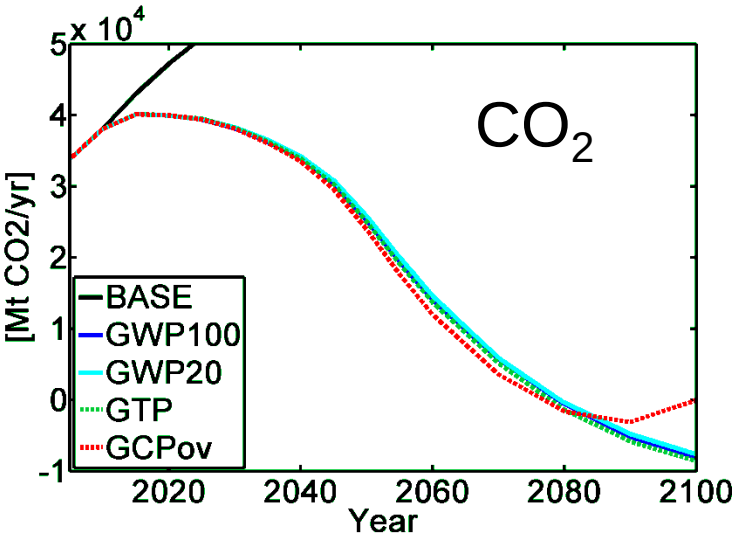
2100
Year


x 10^4
5
4
3
2
1
0
-1
[Mt CO2/yr]
CO2
BASE
GWP100
GWP20
GTP
GCPov
2020
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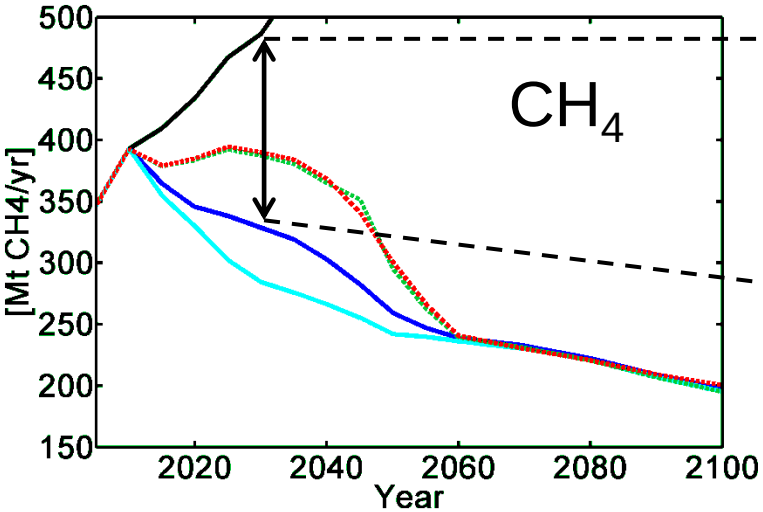
2080
2100
Year


500
450
400
350
300
250
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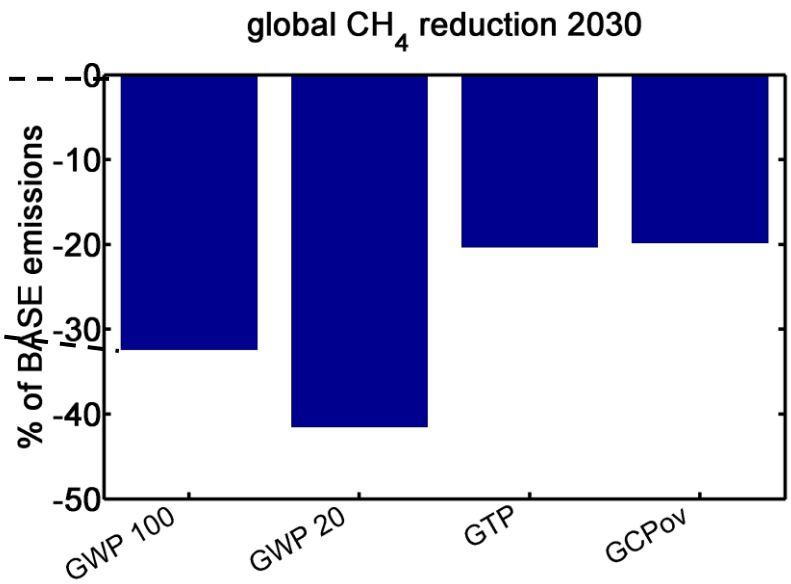
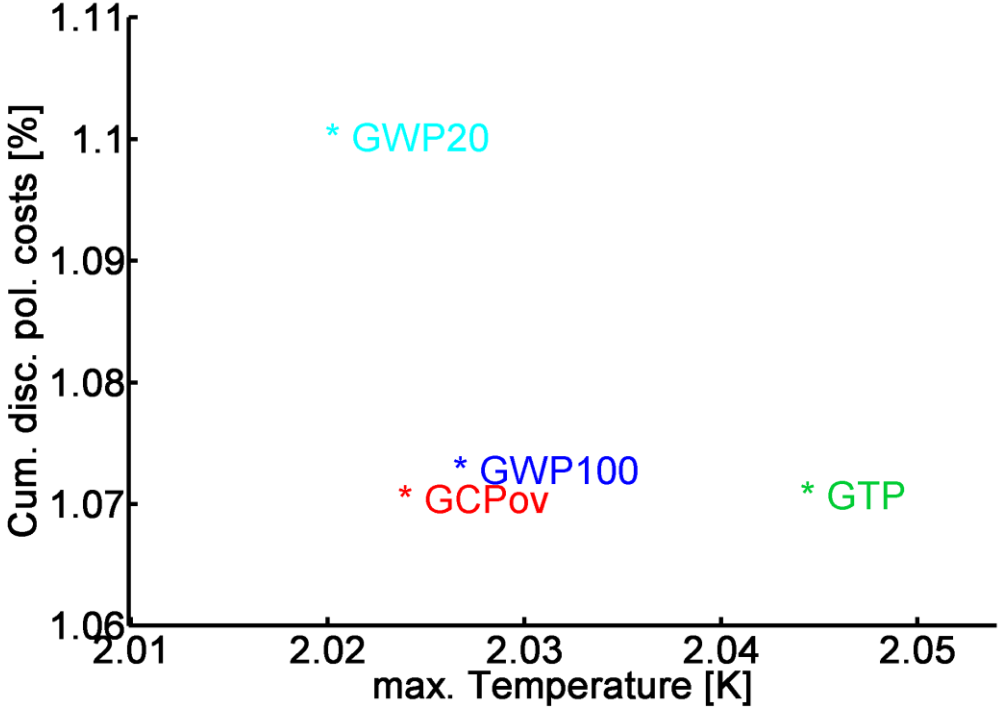
150
[Mt CH4/yr]
CH4
2020
2040
2060
2080
2100
Year


global CH4 reduction 2030
0
-10
-20
-30
-40
-50
% of BASE emissions
GWP 100
GWP 20
GTP
GCPov

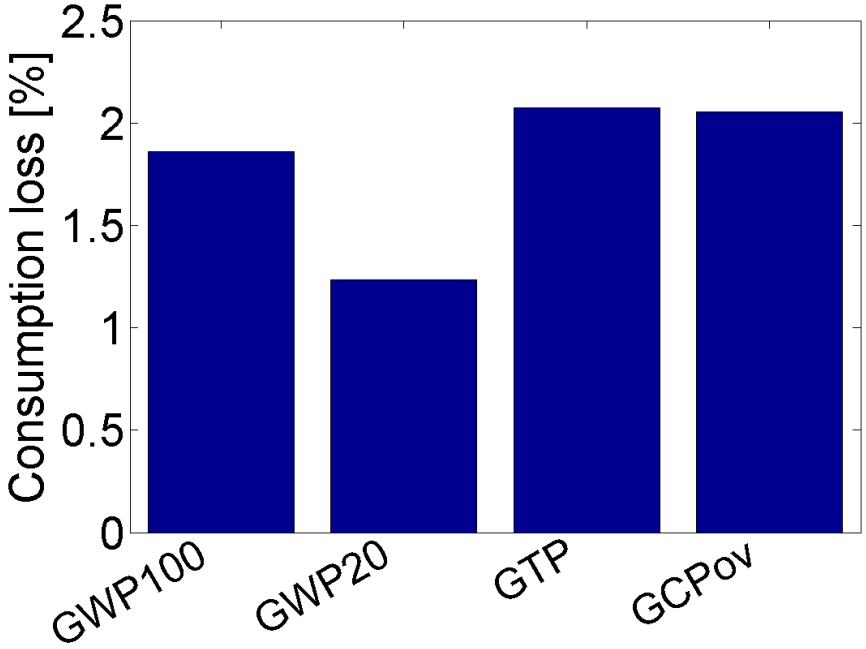
Global mitigation costs



- Trade-off between economic costs and peak temperature
- GCPov is the efficient metric
- GWP100 very close

Regional mitigation costs

Middle East and North Africa



Possibly large redistributional effects due to

- Non-CO_2 abatement costs
- CO_2 abatement costs
- Energy trade
- Financial transfers induced by emissions trading

Conclusions metrics

- The choice of metric determines medium term CH_4 emission levels
- GWP100 performs well in terms of global costs despite its simplicity
- Global costs are only weakly affected by alternative metrics
- Alternative metrics may lead to regional redistributions due to trade effects of fossil fuels and shifts in emissions permit trade
- Distributional issues should be addressed explicitly via the choice of regional and sectoral emission caps

Conclusions

Can air pollutant controls accellerate global warming?

- Synergies between air pollution policies and climate policies
- Air pollution policies may affect the rate of temperature change in the first decades, but not long-term climate targets
- Hence there is no conflict of objectives between clean air and climate protection policies

How does the choice of greenhouse gas emission metrics affect global and regional economic costs?

- Little influence on global costs, regional redistributions can occur
- Could be solved explicitly via regional emission caps
- GWP100 performs well despite its simplicity.

Thanks for your attention!