International Institute for Applied Systems Analysis
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science for global insight

Key uncertainties in future non-Kyoto emissions

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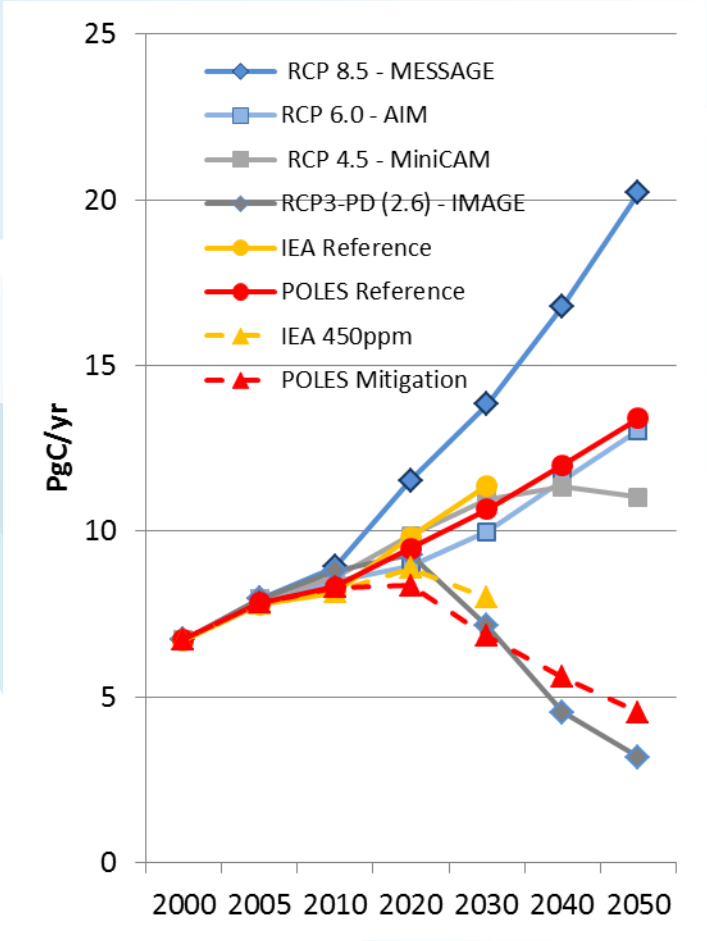
Workshop on Climate Change Impacts and Integrated Assessment (CCI/IA)
Snowmass, Colorado July 23–August 3, 2012

Things that come to my mind as relevant… beyond economic growth

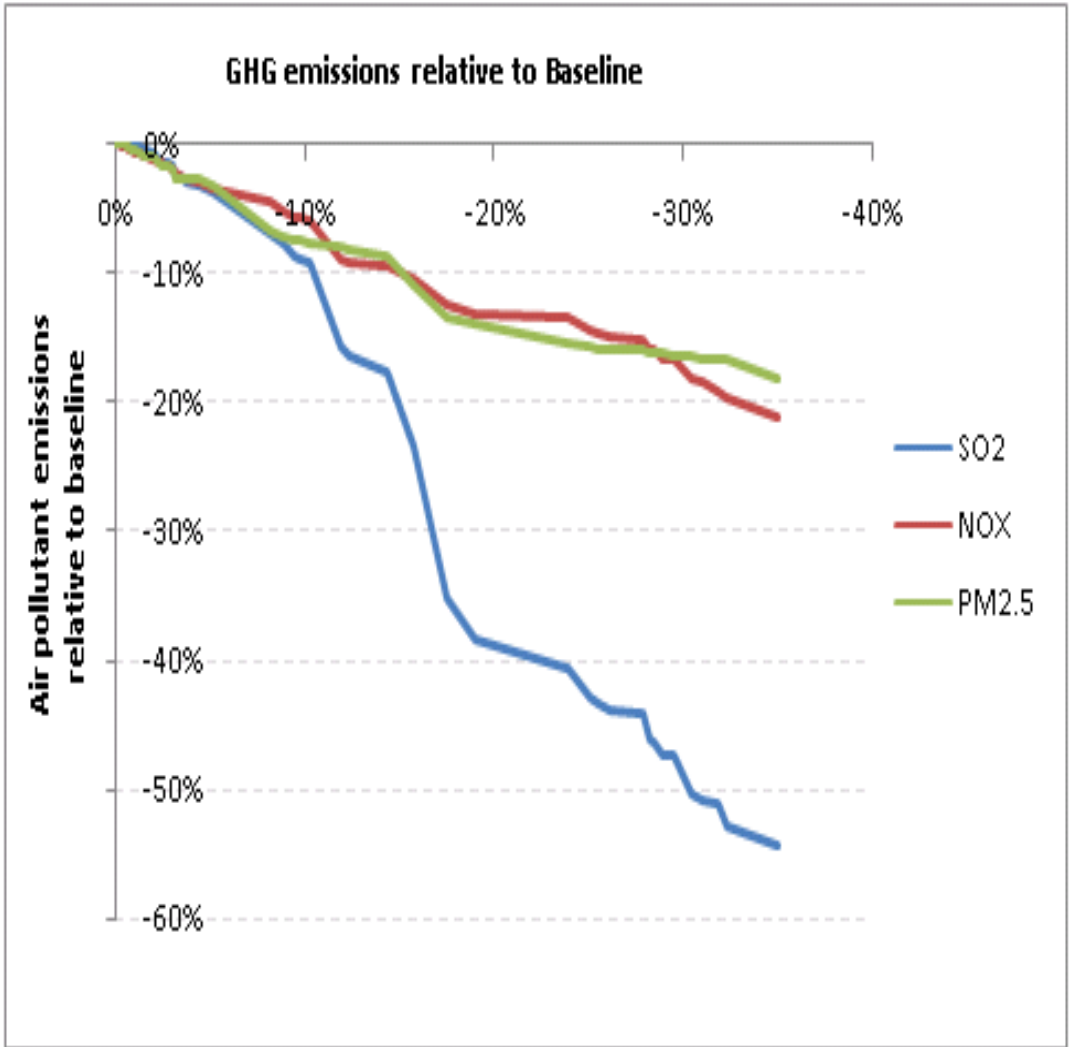
- Stringency and efficiency of legislation
- Real-life performance of technology and availability of new tech
- High emitting vehicles
- Brick kilns, coke ovens, flaring in oil and gas industry
- Stoves…of course
- What do we know about Africa and Latin America?
- Solvent use emissions
- Open burning of agricultural waste

- International shipping (Arctic)
- Human diet and improved N use efficiency
- Change in regional and sectorial importance
- Co-emitted species; consistency of emission scenarios
- There is no clear relationship between implementation of environmental technology and economic growth

One CO_2 slide:
RCP vs IEA/POLES scenarios implemented in GAINS



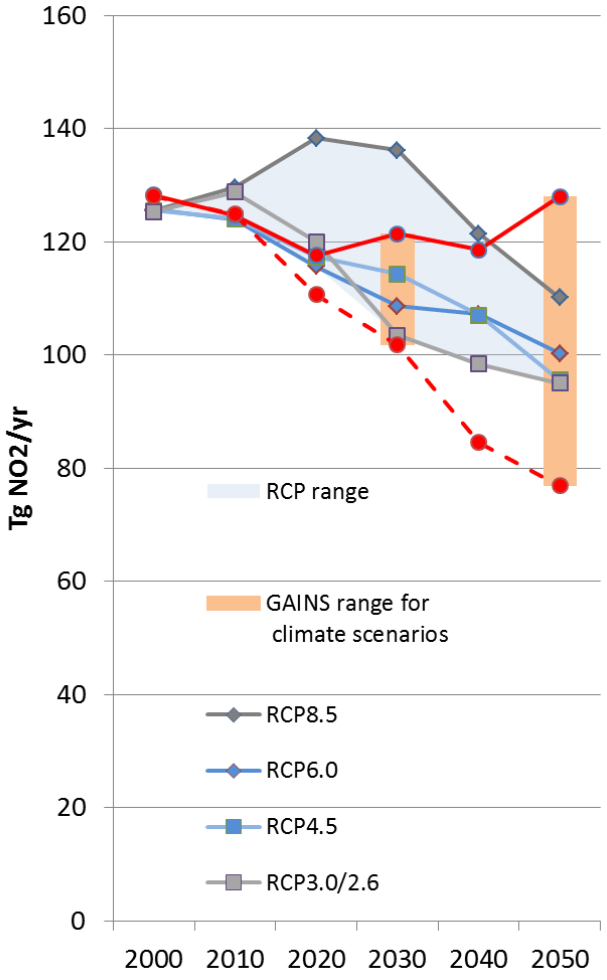
Annex I countries, 2020; GAINS calculation

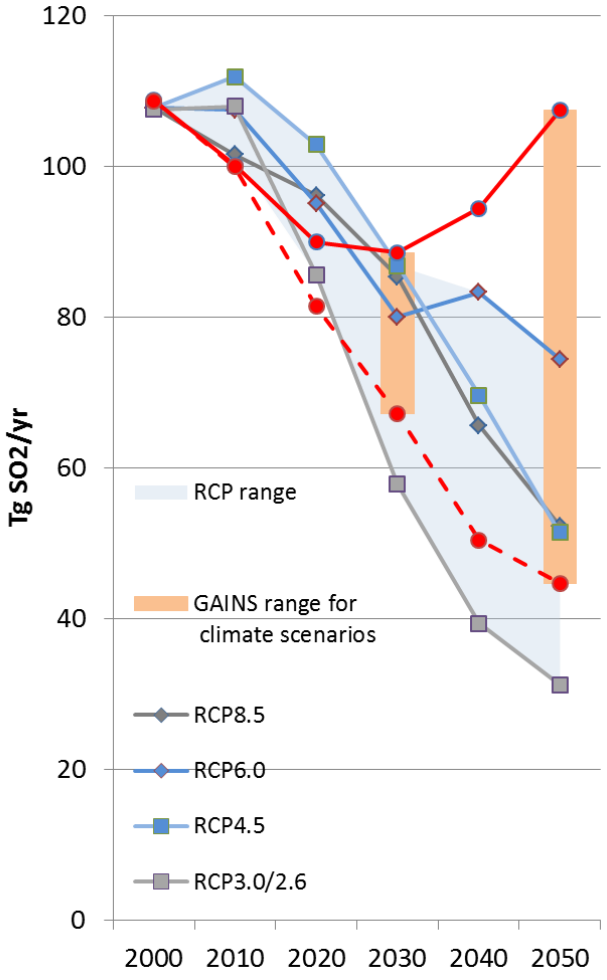


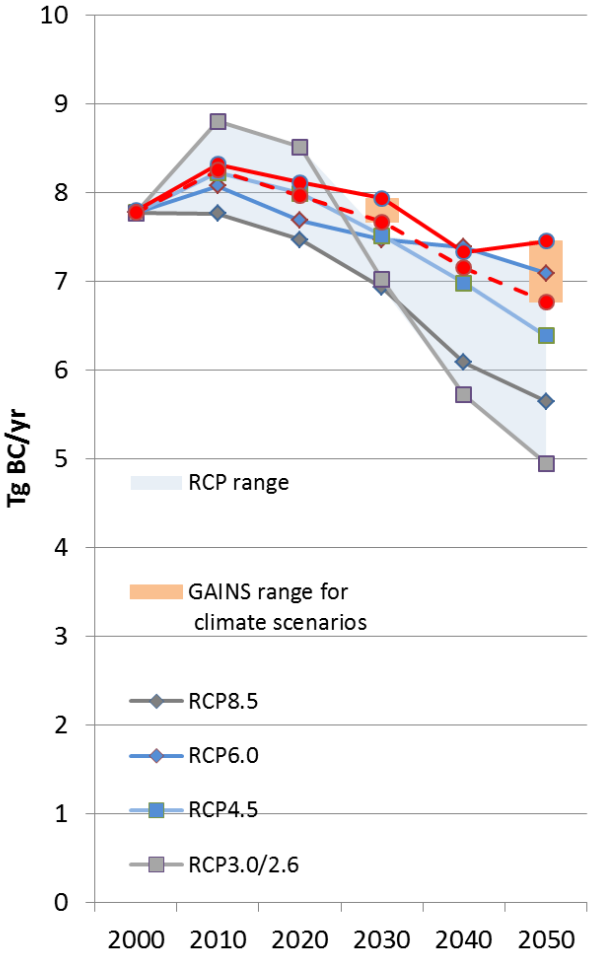
The **GAINS** multi-pollutant/multi-effect framework (**G**HG-**A**ir pollution **IN**teractions and **S**ynergies)

	PM (BC, OC)	SO_2	NO_x	VOC	NH_3	CO	CO_2	CH_4	N_2O	HFCs PFCs SF_6
Health impacts: PM (Loss in life expectancy)	√	√	√	√	√					
O_3 (Premature mortality)			√	√		√		√		
Vegetation damage: O_3 (AOT40/fluxes)			√	√		√		√		
Acidification (Excess of critical loads)		√	√		√					
Eutrophication (Excess of critical loads)			√		√					
Climate impacts: Long-term (GWP100)							√	√	√	√
Near-term forcing (in Europe and global mean forcing)	√	√	√	√	√	√				
Black carbon deposition to the arctic	√									

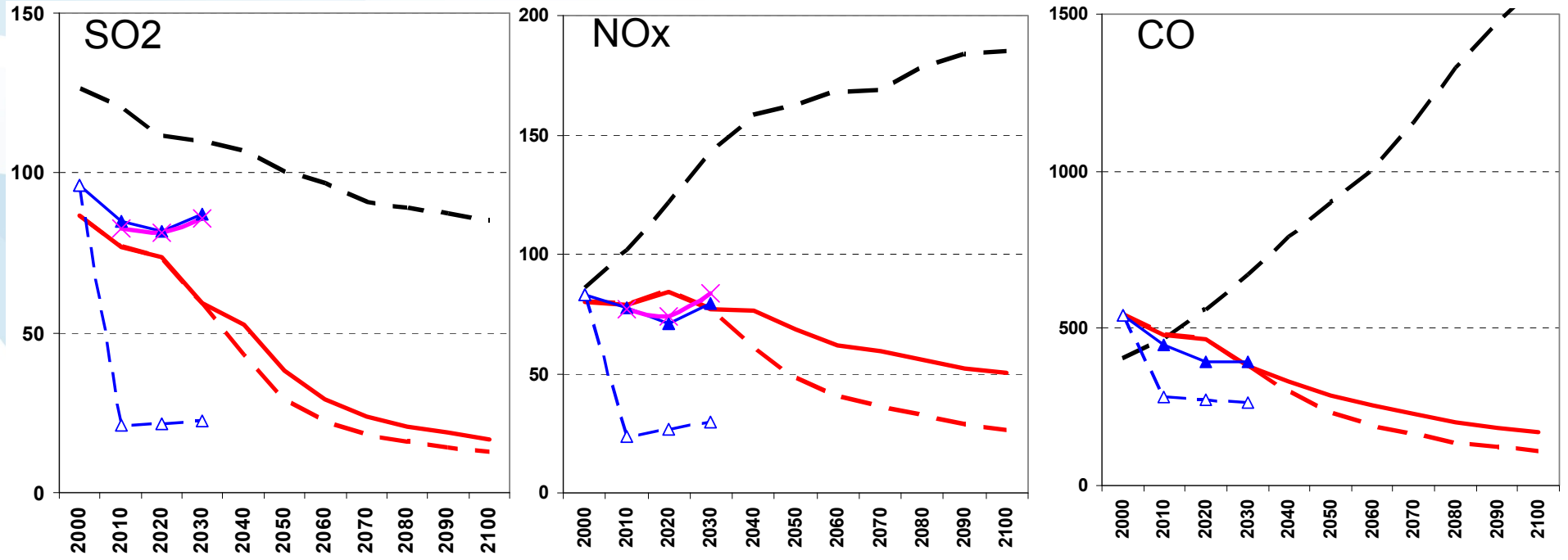
RCP and GAINS (current legislation – CLE)
NO_X ,SO_2 , and BC







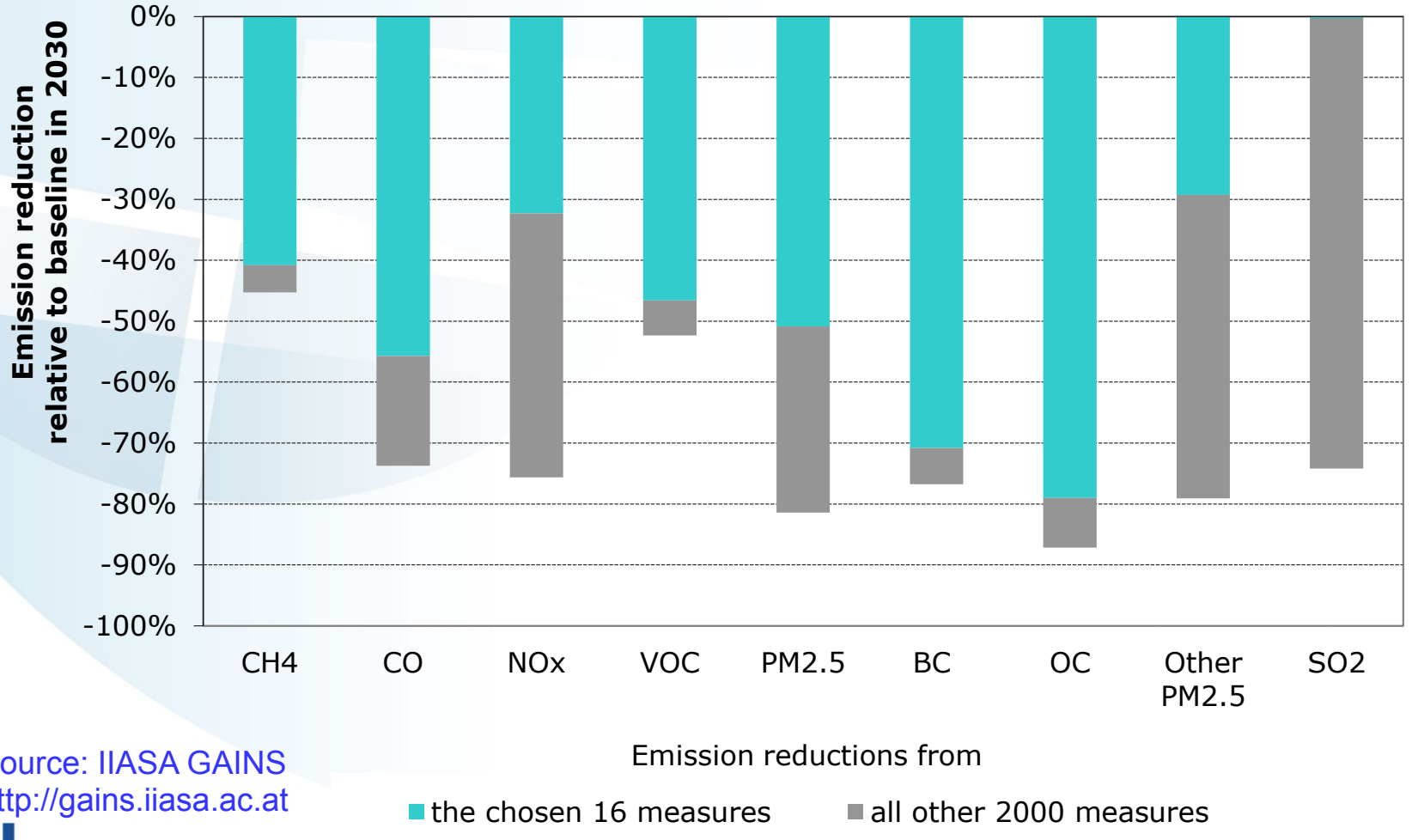
Comparison of original SRES B2 with its 'modified' implementations in RAINS/MESSAGE models



Sources:
Nakicenovic et al., 2000; Cofala et al. 2007, 2009; Klimont et al., 2009; Rafaj et al., 2010.

Considering co-emission of pollutants at technology level results in different mixes (ratios) of pollutants depending on chosen strategy

Example: Mitigation potentials in 2030 in in two scenarios developed in UNEP (2011) study



Source: IIASA GAINS
http://gains.iiasa.ac.at

Decomposition of emissions:

Factors contributing to changes in air pollution level

$$\Delta EMIS = GDP * \Delta\left(\frac{ENE_u}{GDP}\right) * \Delta\eta_{(final-useful)} * \Delta\left(\frac{EMIS}{ENE_f}\right) * (1 - eff) * \Delta X$$

Change in the energy intensity

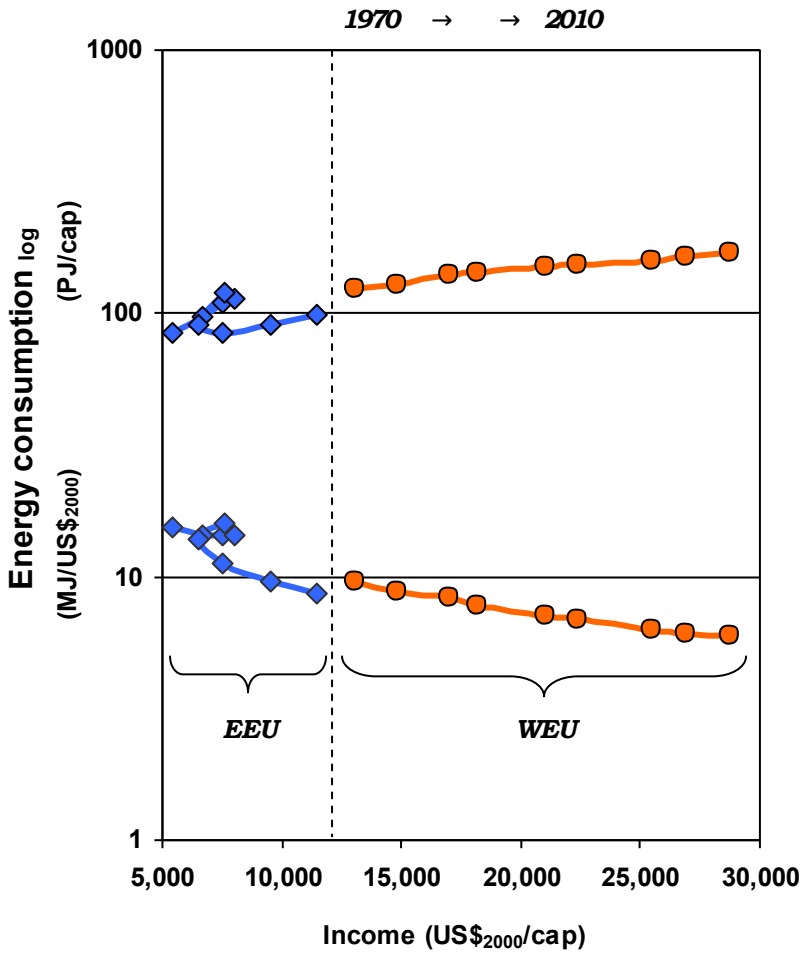
Efficiency improvement

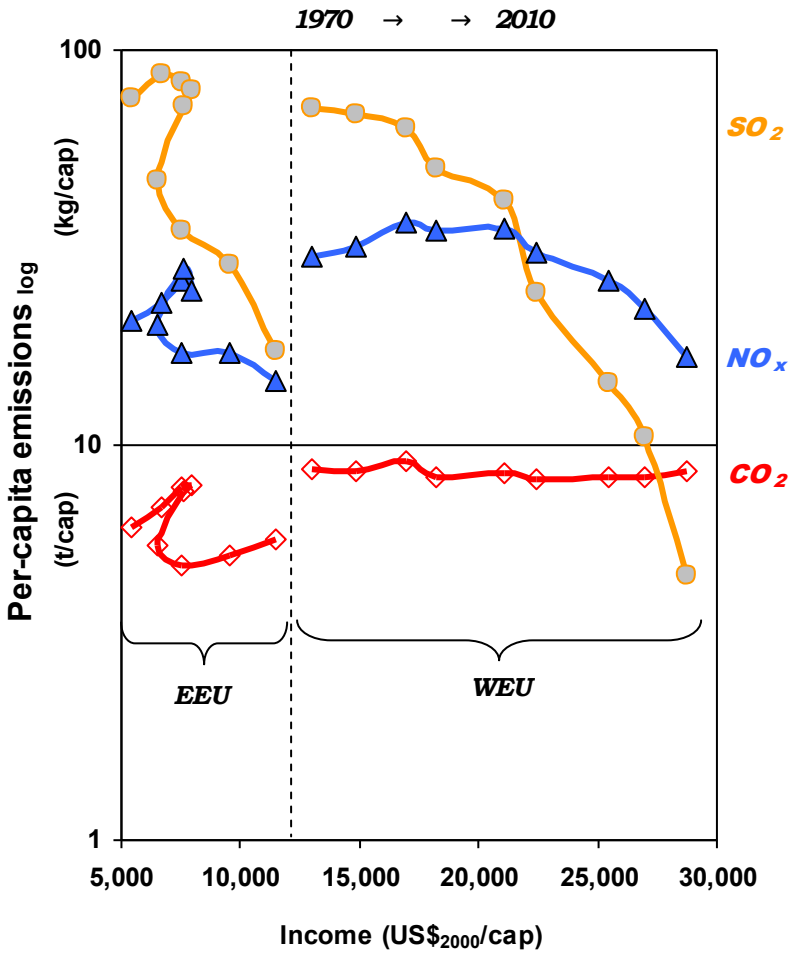
Fuel switch

Abatement with removal efficiency eff and application rate X

Source: Rrafaj et al., 2010; Rafaj et al., in preparation

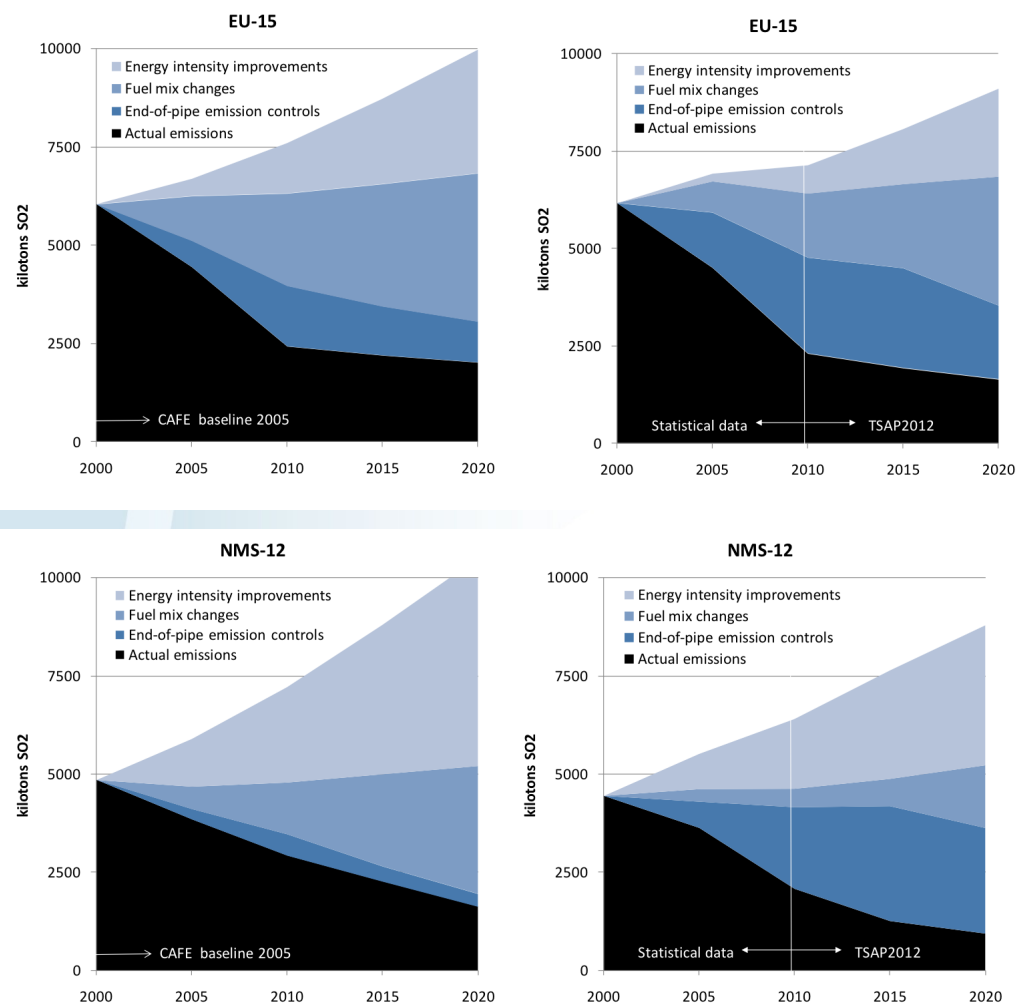
Emissions and energy use per capita, energy intensity in Europe between 1970-2010





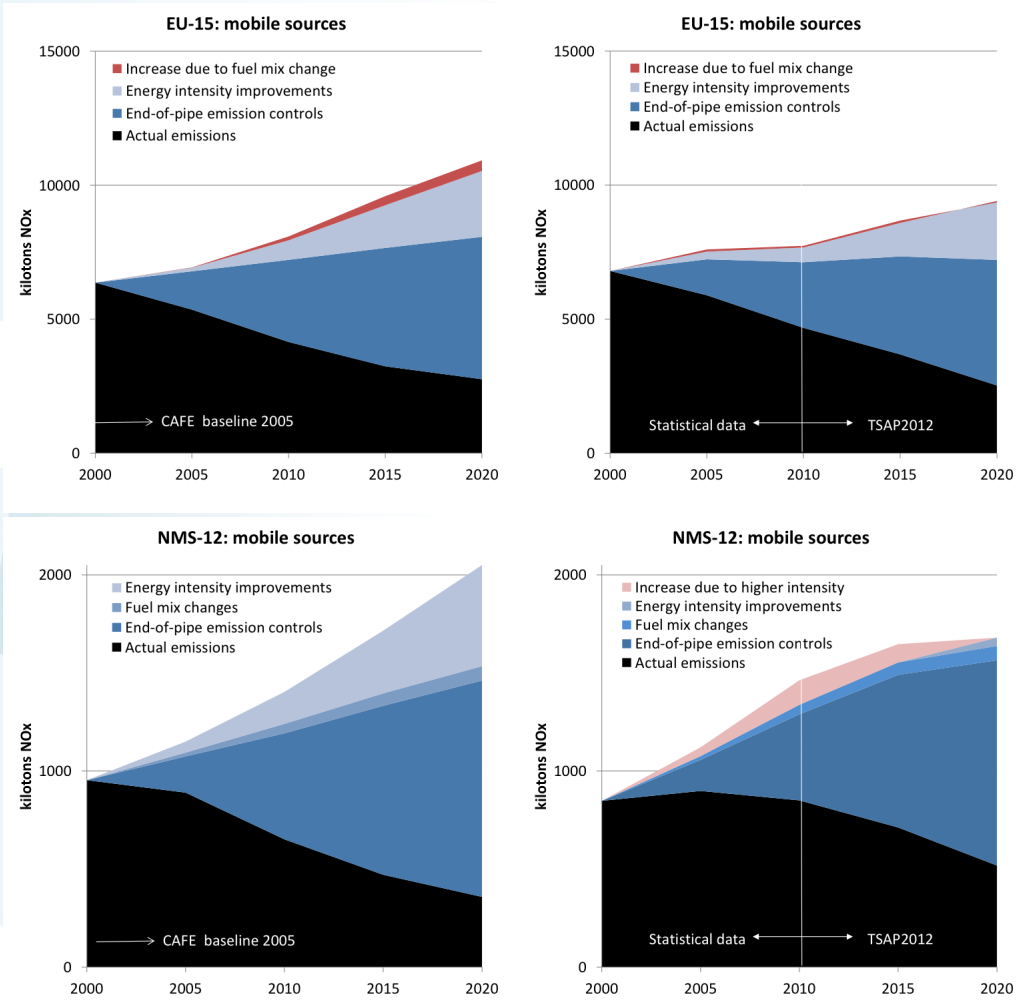
Source: Rafaj et al., in preparation

Decomposition of EU-27 SO_2 emissions; projection and 'reality'



Source:
EU CAFE strategy and Amann et al., 2012

Decomposition of EU-27 NOx emissions; projection and 'reality'



Source: EU CAFE strategy and Amann et al., 2012

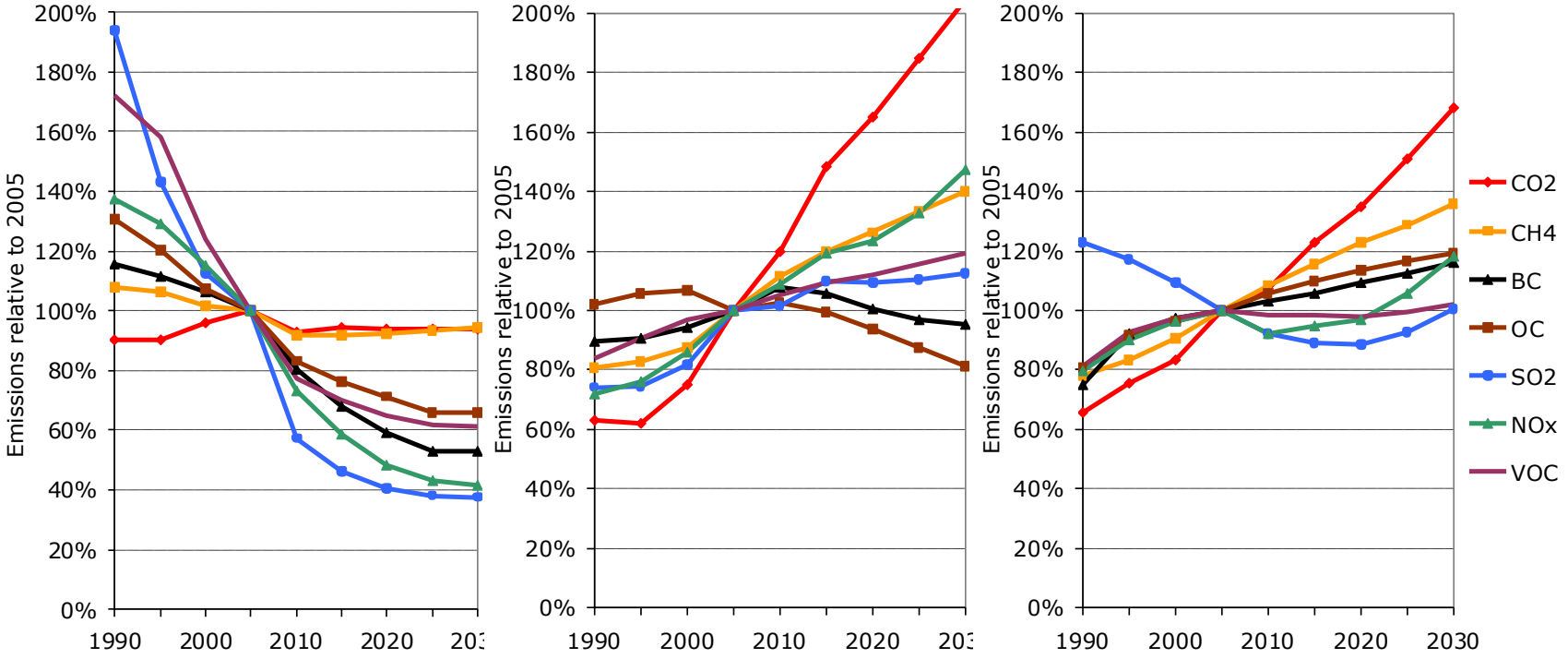
Regional/sectoral differences

- Effective implementation of current air pollution policies will exhaust reduction potential for several technologies in some regions
- Poorly characterized (non-regulated) sources become more important (e.g., off-road, residential)
- Power sector and industry; NA, Europe reduces while most other regions continue to increase
- Brick production; mostly south Asia although locally important in several development countries
- Flaring in oil and gas industry; most of the activity concentrated in few areas but emissions in high latitudes occur in clean environment

Emission trends 1990-2030

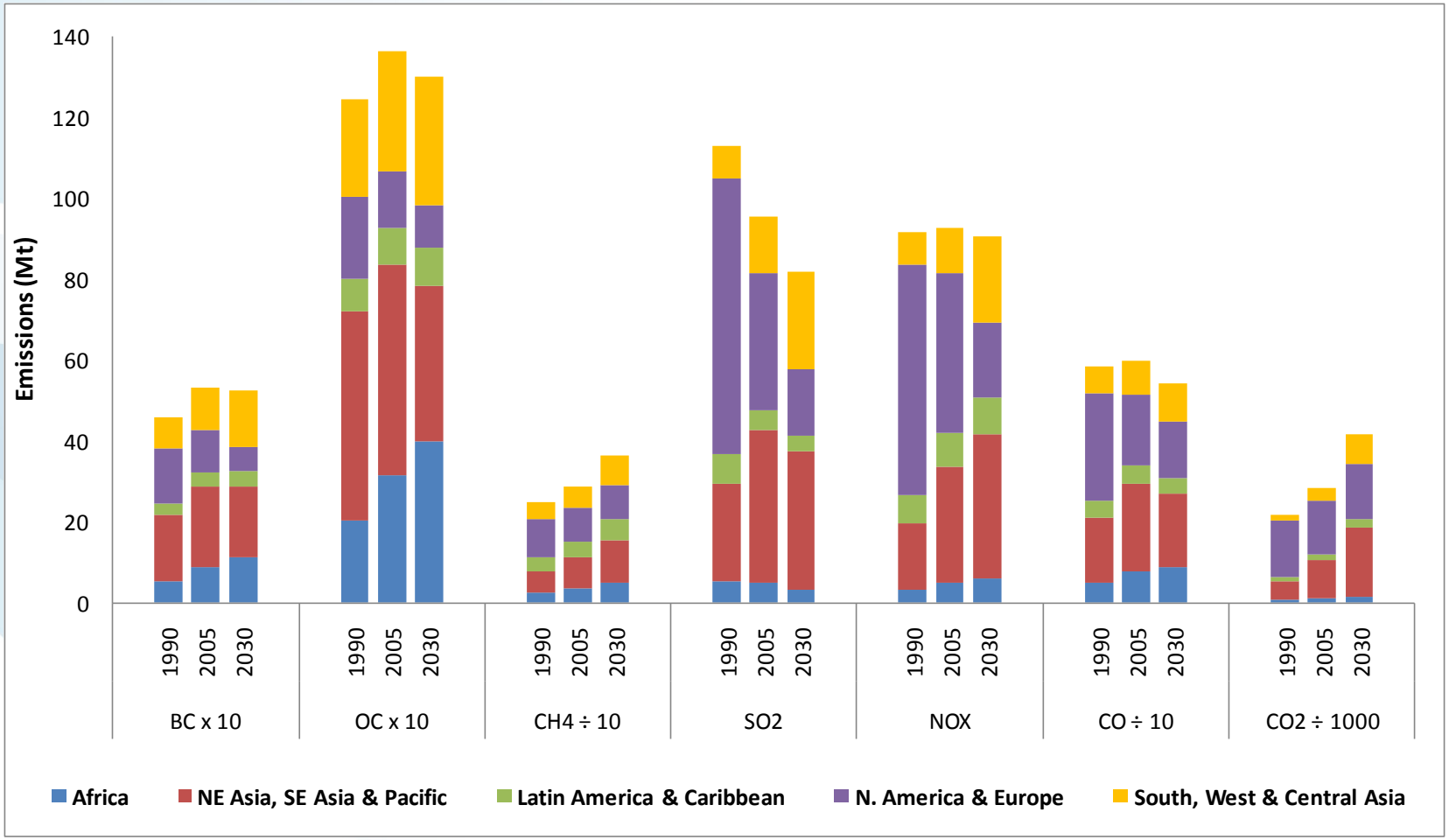
GAINS calculation for IEA World Energy Outlook 2009

OECD BRICS Others



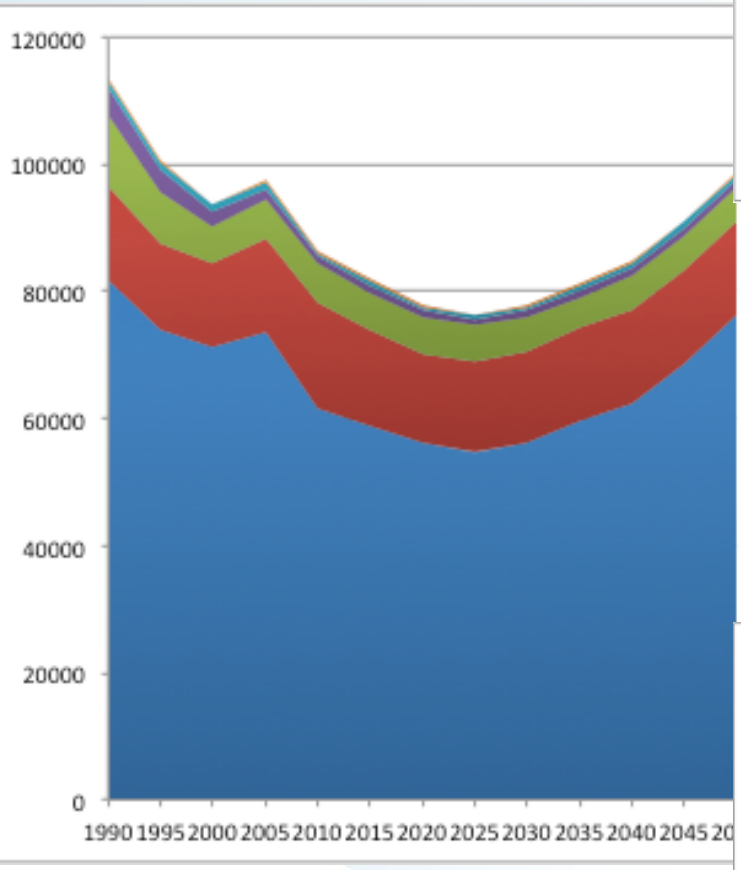
Baseline emission projections

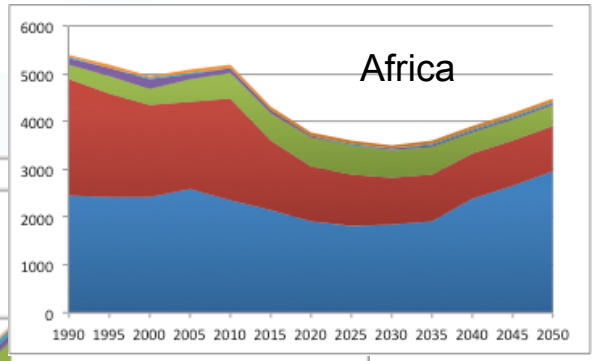
(WEO2009 + CLE; GAINS model results used in UNEP, 2011)

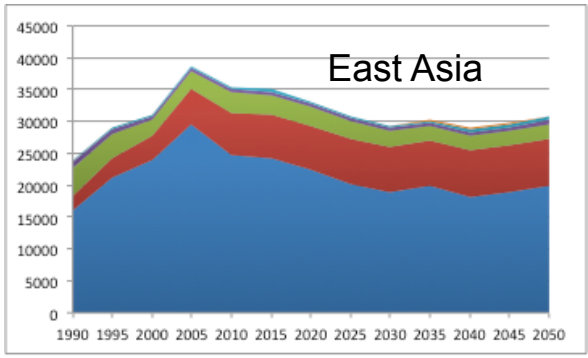


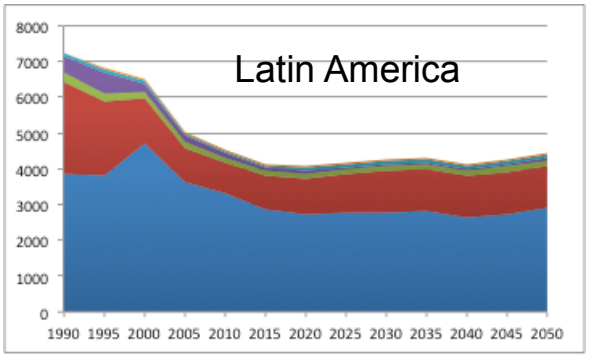
Change in sector contribution in SO2 emissions [kt SO2]

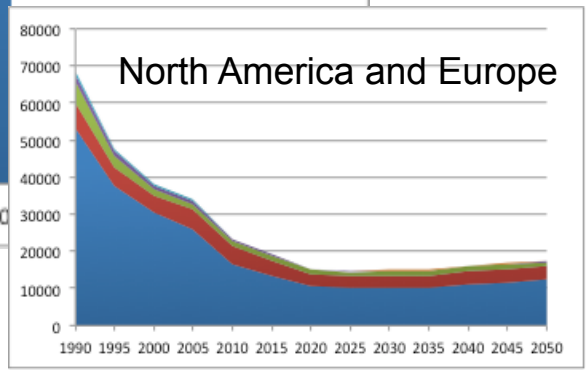
GAINS-POLES; current legislation scenario (draft)

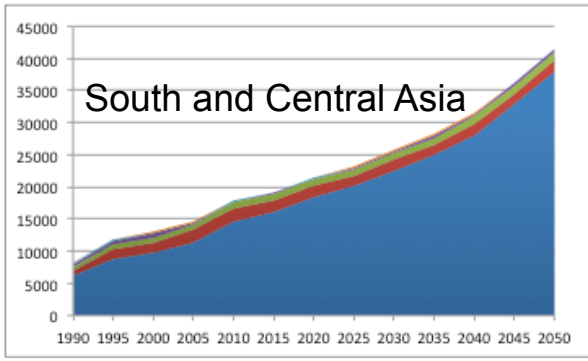






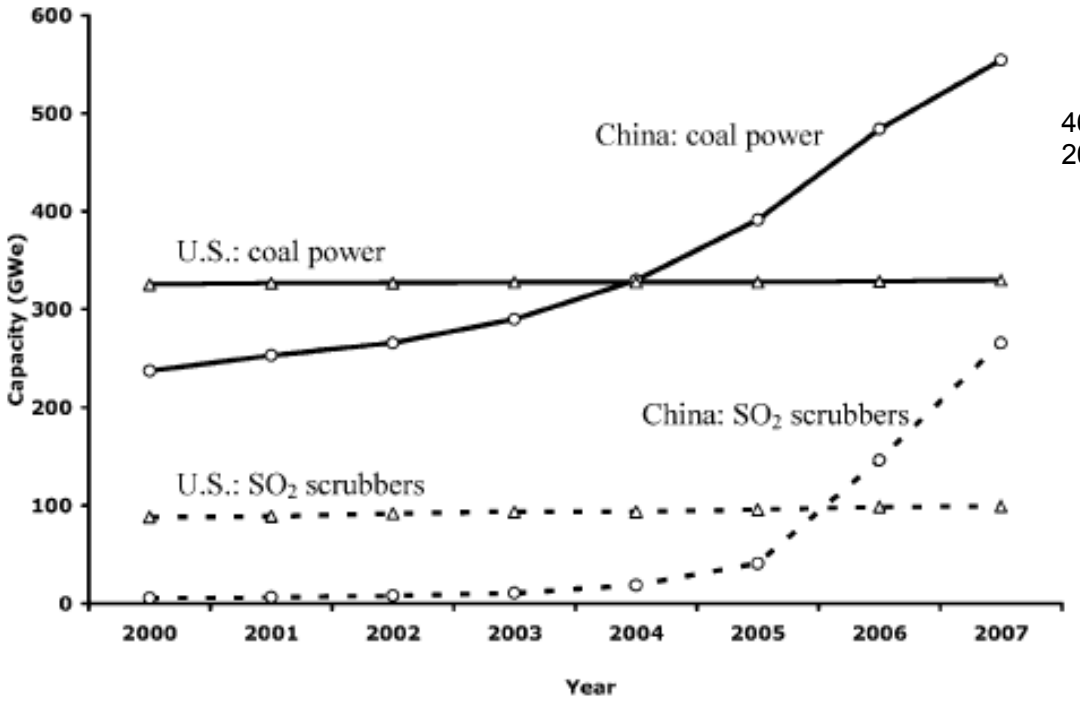






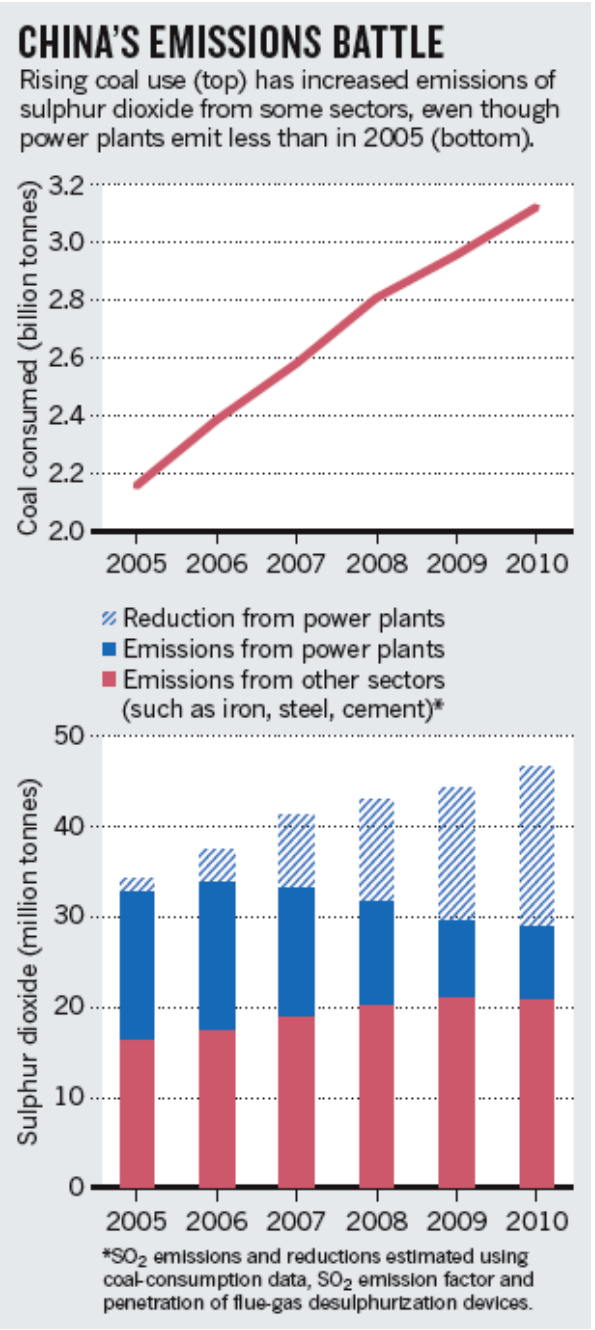
Chinese SO_2 started to decline

- Radical SO_2 policies to control power plants show effect (with delay)



461 GWe in 2009

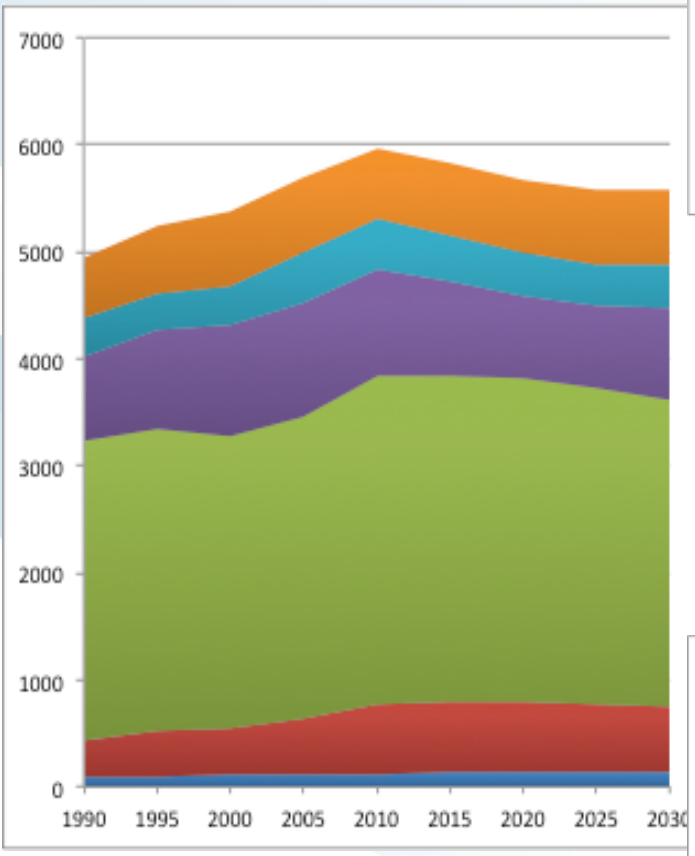
Source: Xu et al. (EES, 2009; EST, 2012)

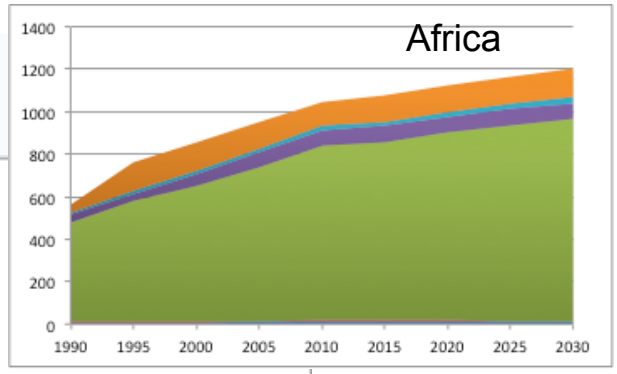


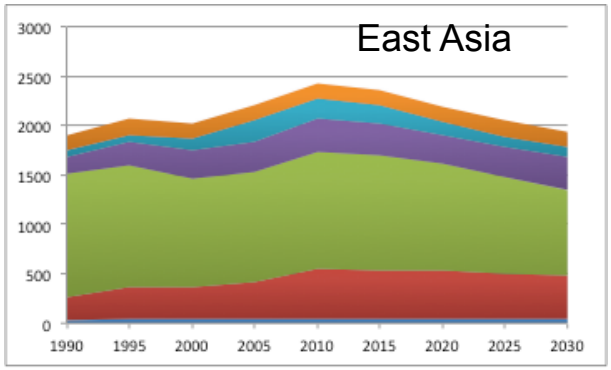
Source: Zhang et al. (Nature 484, 2012)

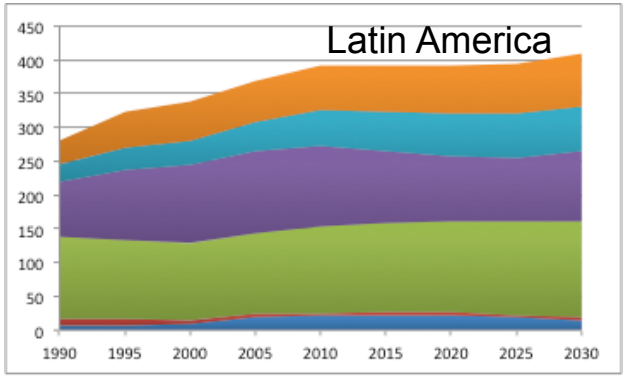
Change in sector contribution in BC emissions [kt BC]

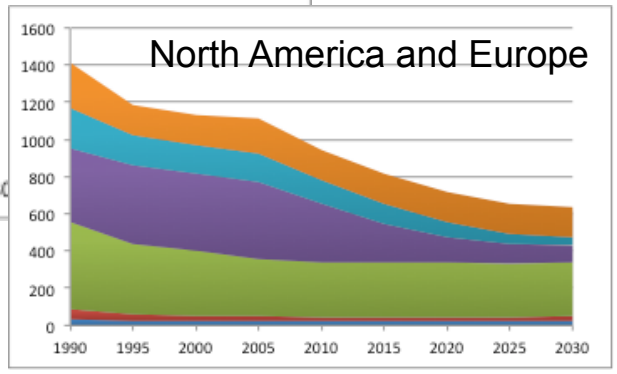
GAINS-POLES; current legislation scenario (draft)

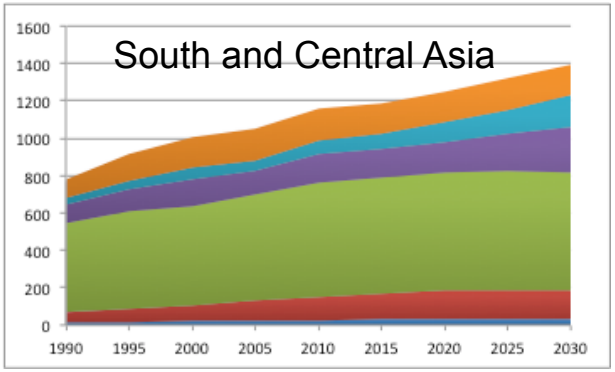




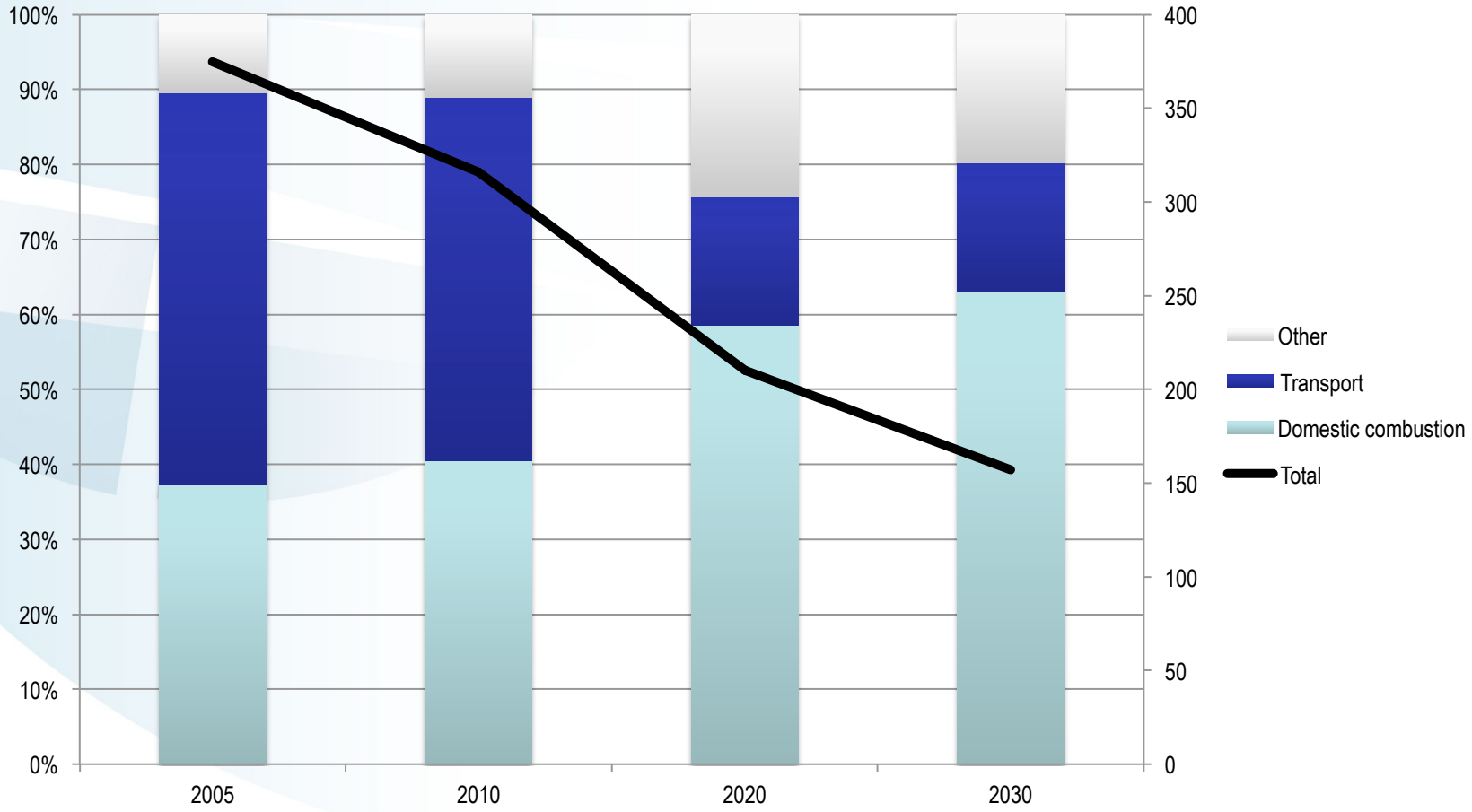






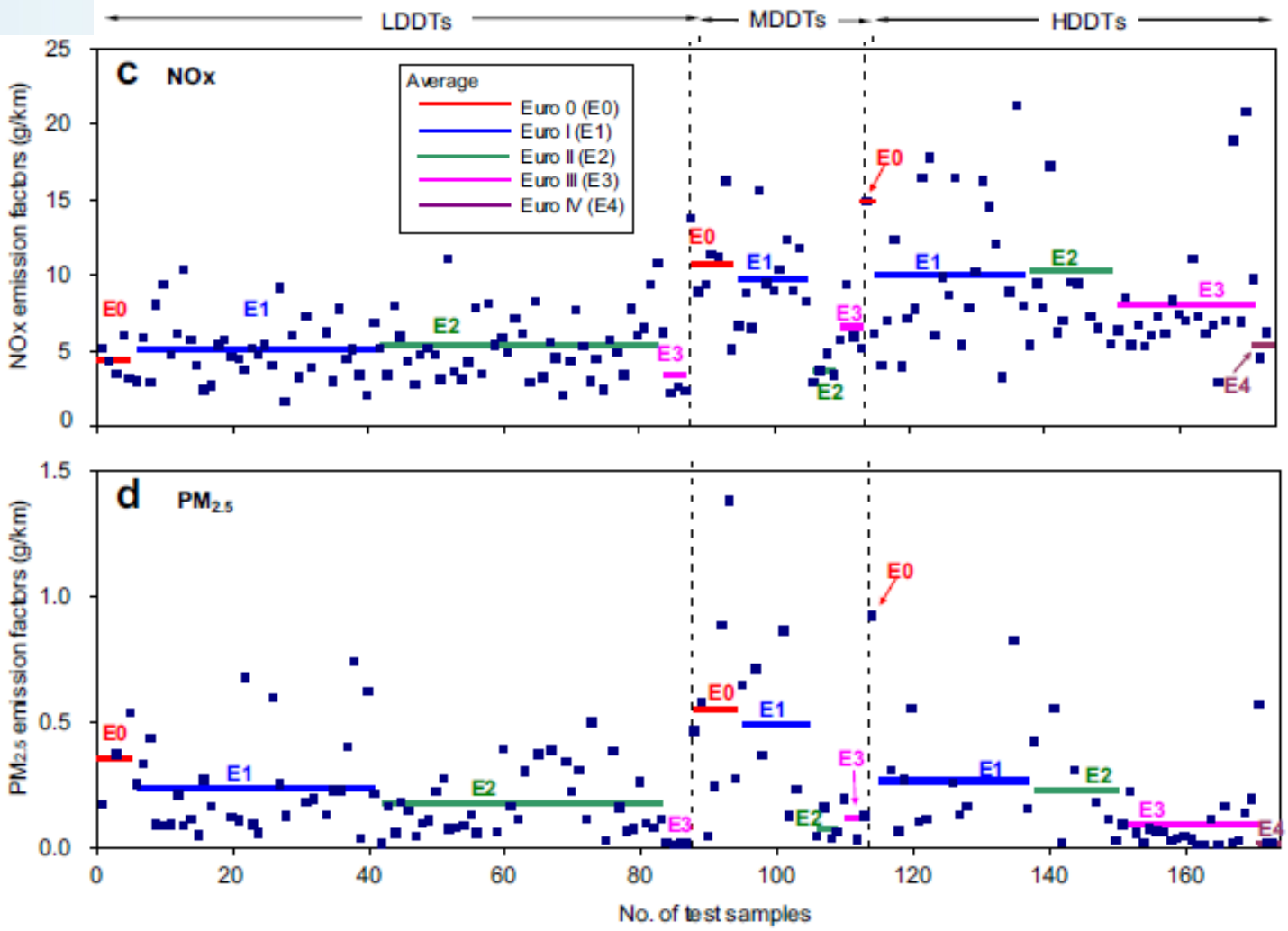


BC emissions in the EU-27, baseline, thousand tons *Source:* GAINS model



Déjà vu: Does the technology work?

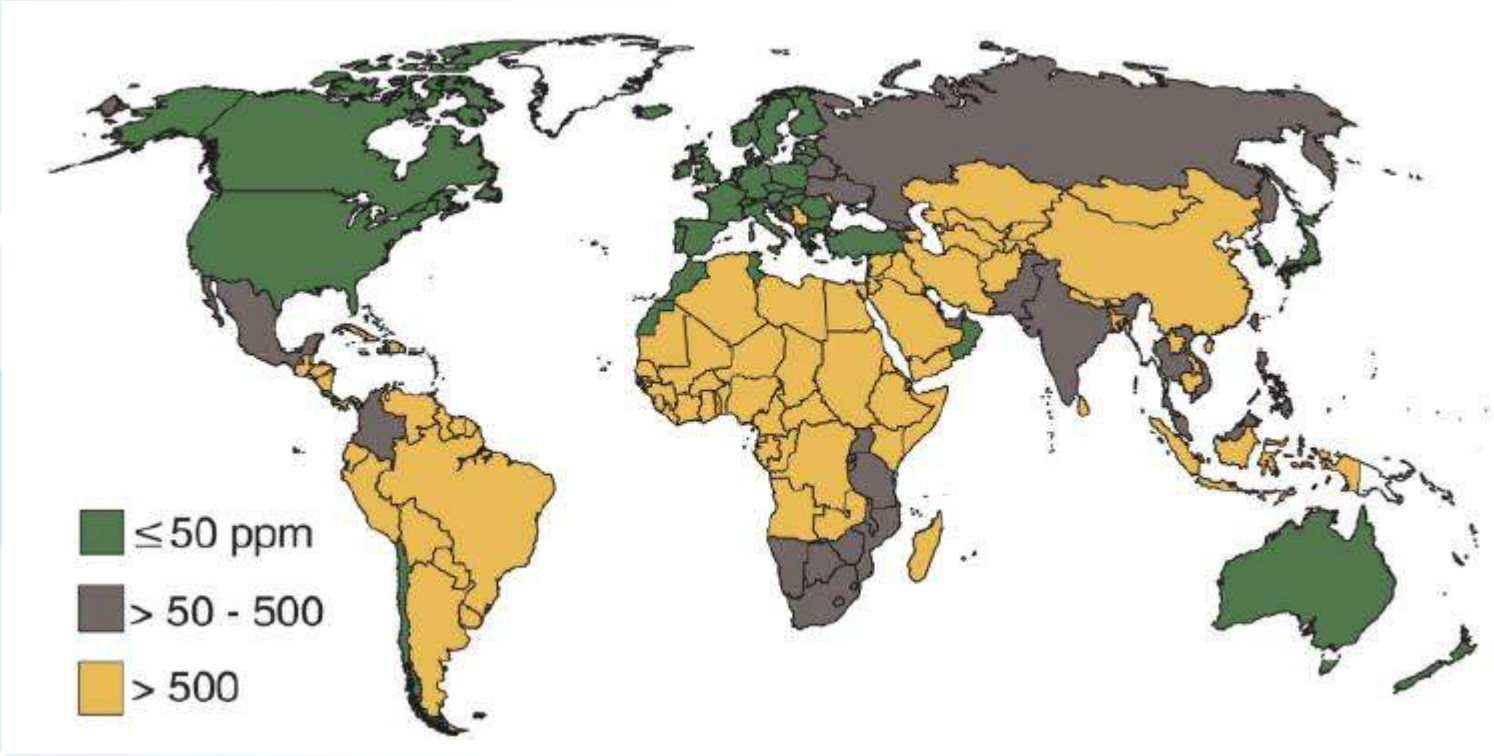
Emission performance of Chinese trucks



Source: Huo et al. (AE 54, 2012)

Some technologies deliver only when other pieces of legislation timely implemented

Sulfur content of diesel fuel



Partnership for Clean Fuels and Vehicles

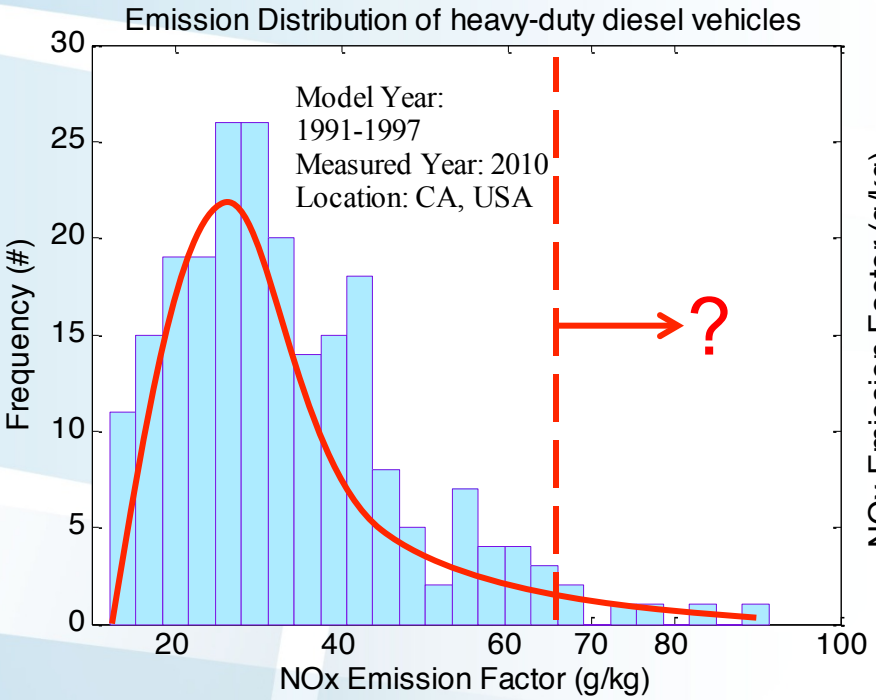
Poorly known, poorly allocated

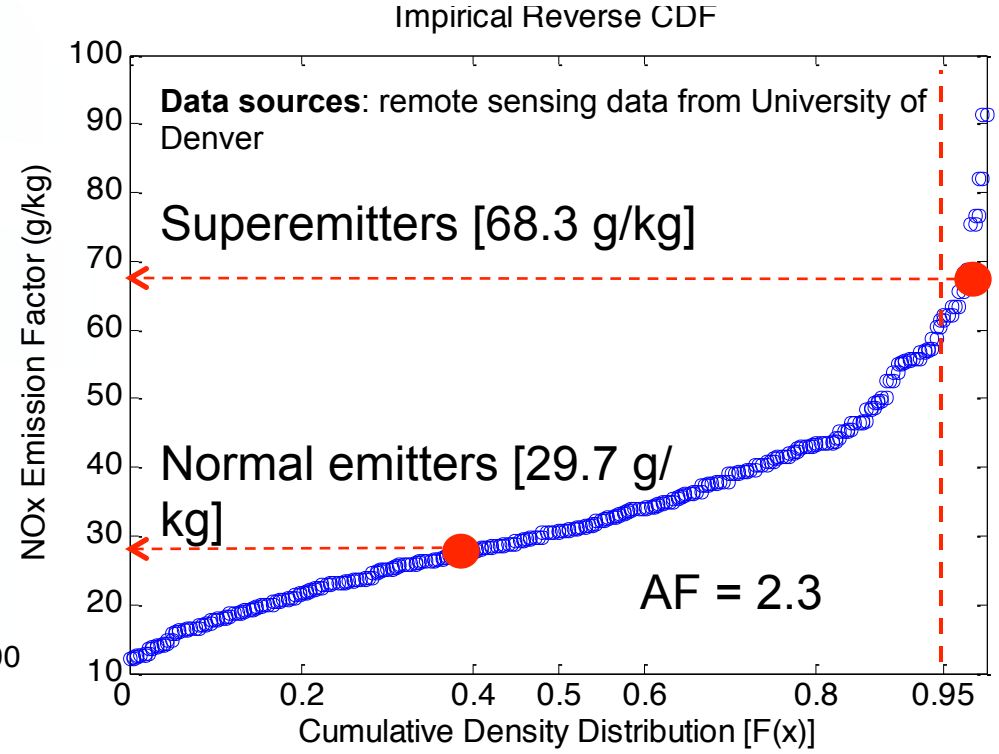
- High emitters
- Flaring in oil and gas industry
- Coke ovens
- Impact of ‘improved stoves’
- Brick production
- Solvent use emissions

- Need much more work to understand current contributions and future evolution

Contribution of the 'unknown' ~2010, %

Activity	BC	OC	SO2	NOx
High emitters	6	2	-	10
Flaring	<4	<0.4	0	0.3
Coke ovens	5	4	0.6	-
Bricks	6	3	3	-
Agr. burning	6	10	0.2	.3
TOTAL	**~25**	**~20**	**~4**	**~11**
Regional range				
High emitters (of transport)	3-30 (15-50)	2-12 (10-45)	-	3-20 (10-30)
Flaring	0.1-8	0.3-1	0	0.1-1
Coke ovens	0.1-12	0.1-9	0.2-10	0-0.1
Bricks	0.1-10	0.1-5	0-7	-
Agr. burning	3-10	5-20	0.1-0.2	0.2-1





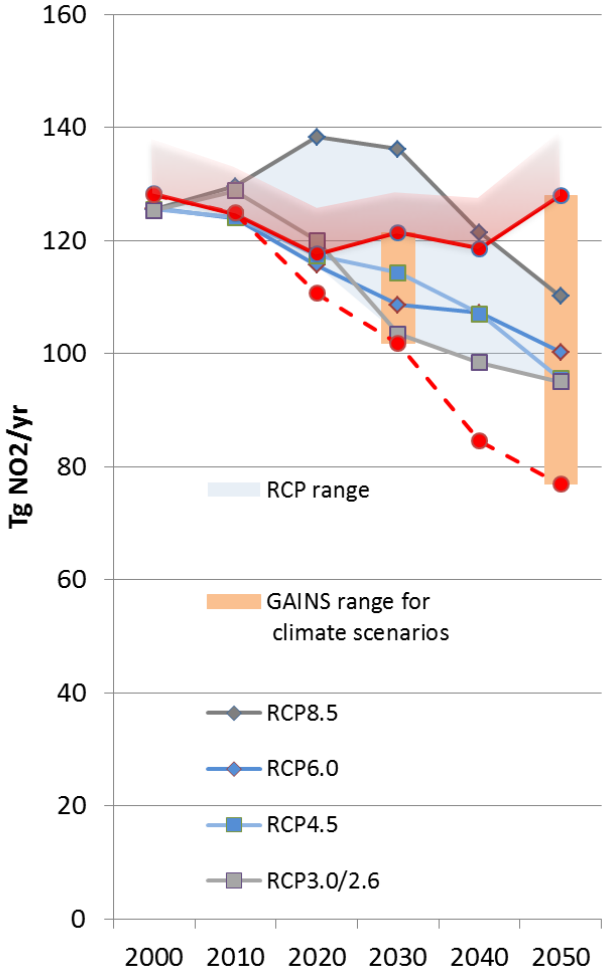
1st approach to quantify high emitter emission contribution:

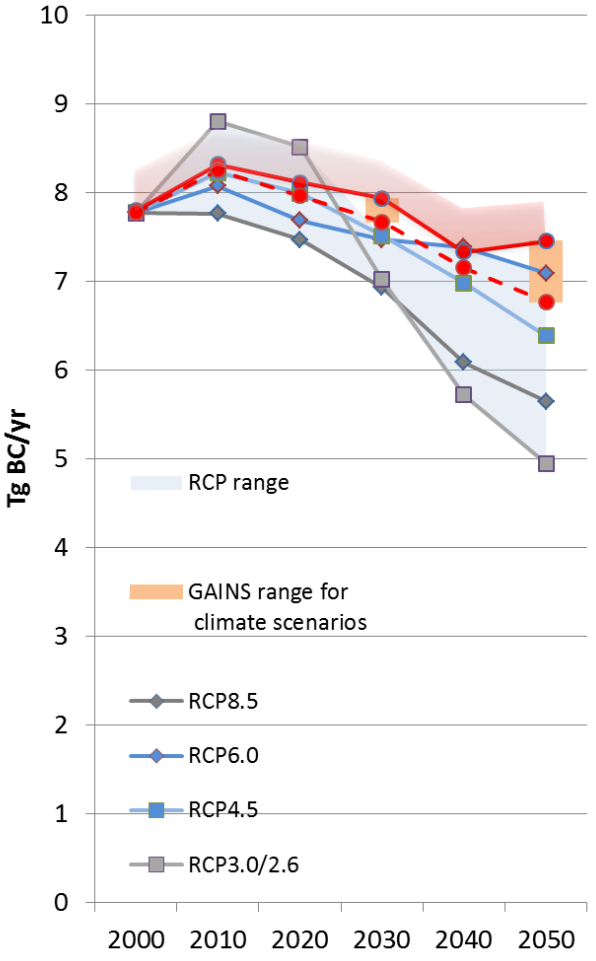
- **Bench mark**: 5% of high emitters in the U.S. (Bond *et al.*, 2004; CRC E-23 study; Ban-Weiss *et al.*, 2000)
- **Definition of emission factors (EF)** : median above (superemitter)/below (normal emitter) 95%;
- **Amplification factor (AF):** ratio between EF of super and normal emitters

PROBLEM of this approach and motivation for further work: a statistical cutoff (e.g. 5%) can be fitted to any kind of distribution and does not necessarily refer to high emitters only. There remains a need for a more technical definition for high emitters.

High emitters

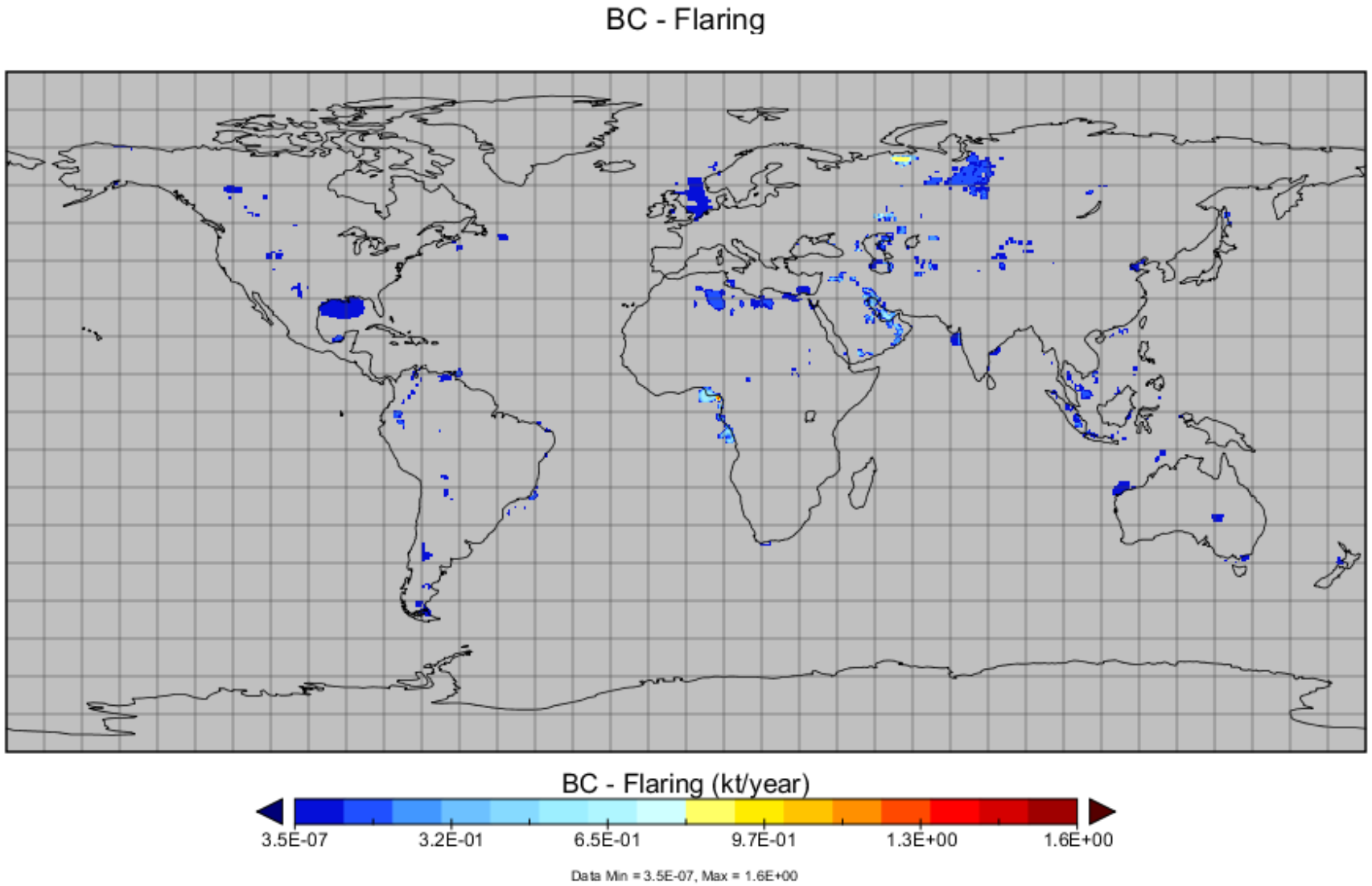
GAINS estimate for NOx and BC





Are aerosol emissions from flares included?
How are they changing over time?
Consequences of increasing production in the arctic?

Location of flares: Source: *NASA, World Bank, GAINS model*



Stoves… it is not only emission factors

- "Chimney stoves help, but not enough" (Kirk's Guatemala study)
- "New stoves aren't adopted" (MIT study)
- "More black carbon from some stoves" (Ram's Surya study)
- Lab improvements not seen in the field (our [T.Bond et al.] study)

Summary courtesy of Tami Bond

- *Consistent assessment of co-emitted species missing*

Measuring emission factors…
How do we include such information (if available)?

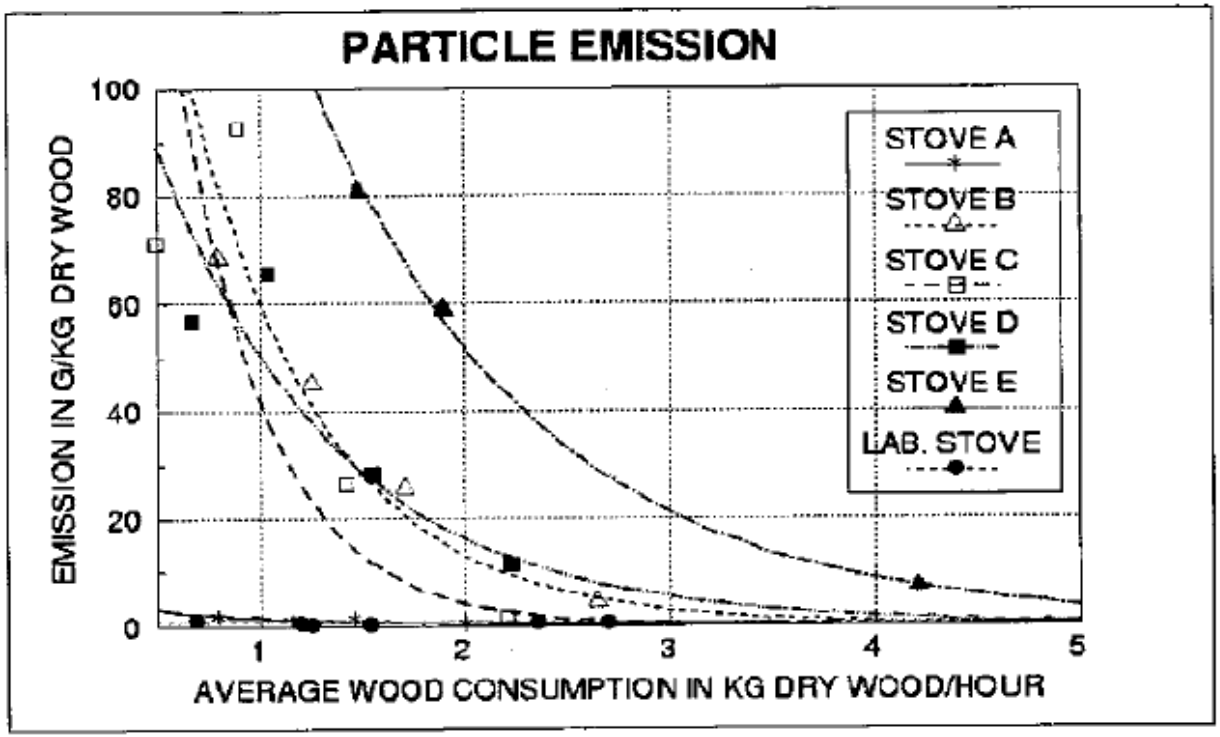
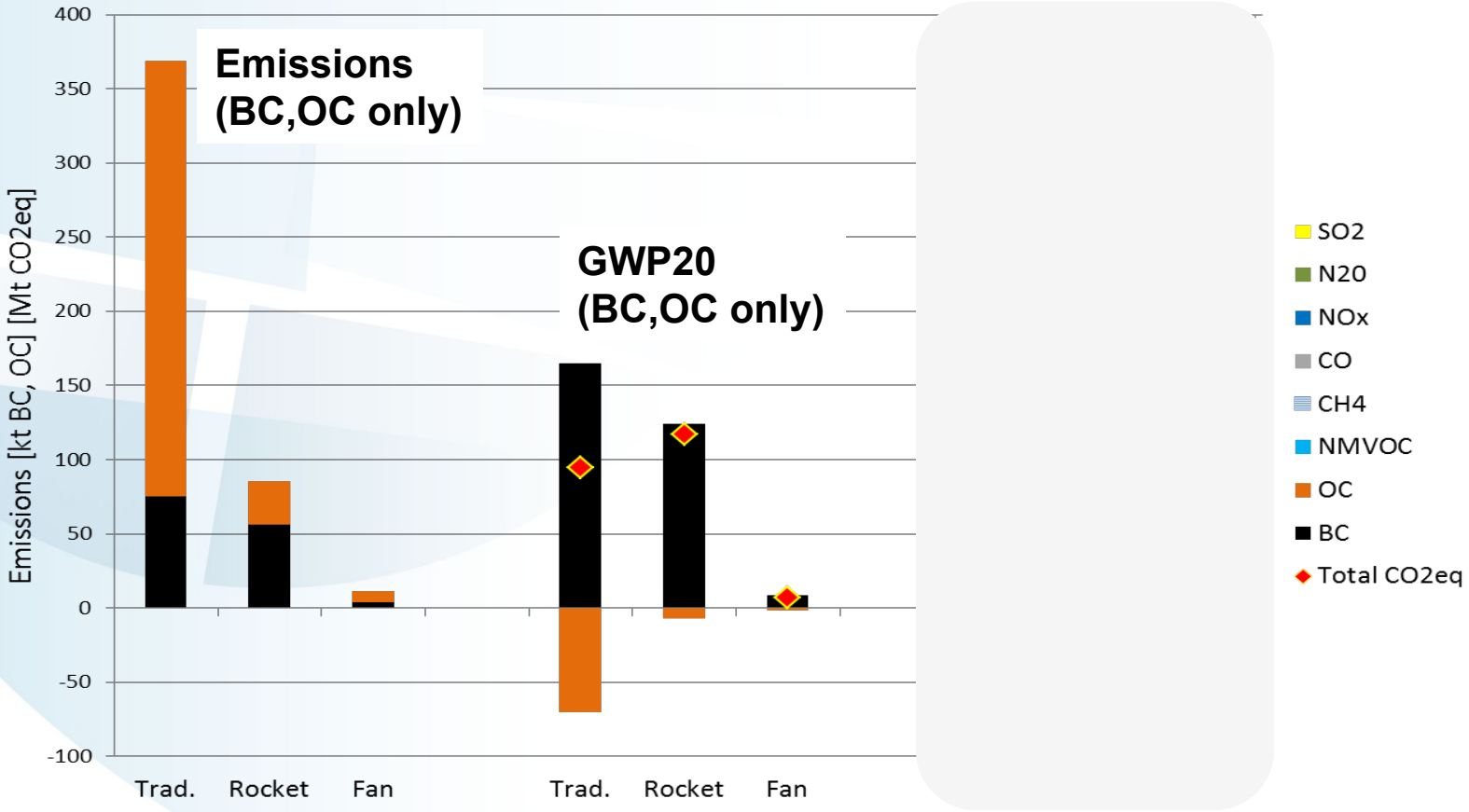


Figure 12. PM emission of 6 wood fired stoves. Dependency of wood consumption rate. A: catalytic stove, B-D: old stoves, E: open fireplace (Haakonsen and Kvingedal, 2001).

It matters which stoves are going to 'make it'*

Importance of considering all pollutants

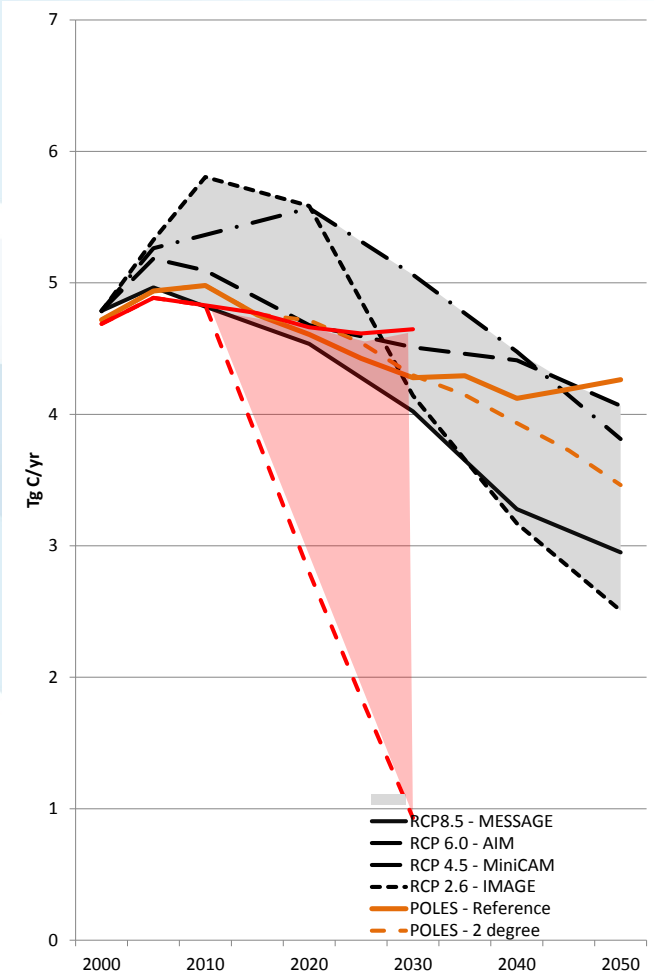
Example: *Fuelwood cooking stoves (fuel efficiency improvement considered)*



* The GWP20 is used for demonstration purpose. While the choice of GWP (100 or 20 years) would not change the conclusion about the selected measures the shown here CO_{2eq} emissions were not used in the analysis, i.e., the emissions of various pollutants for specific measures were put directly into the climate model.

Global BC emissions from anthropogenic sources

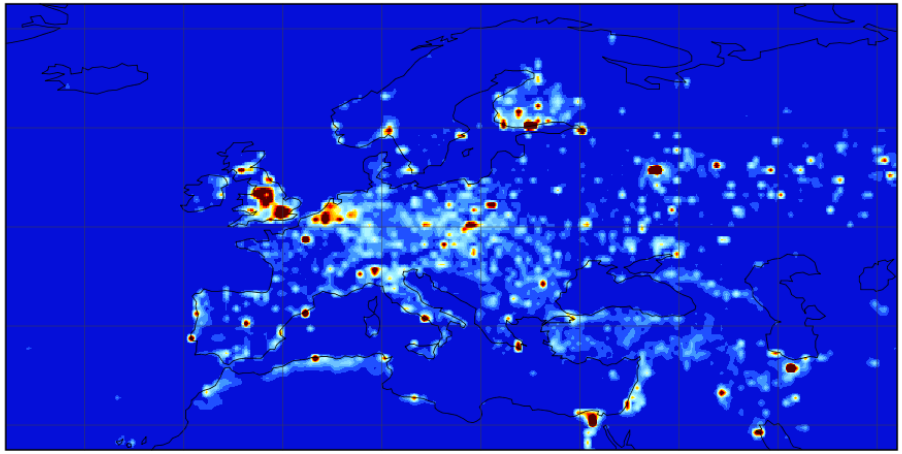
Can I add a chart with the rocket stove vs fan stove for BC and OC? Maybe I should use the RCP slide chart with red POLES? To demonstrate that?



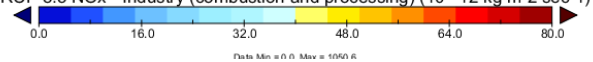
- RCP scenarios suggest declining anthropogenic BC emissions in the longer run
- No correlation between climate mitigation and BC emissions – BC control not a co-benefit of climate mitigation
- The 16 UNEP measures would cut BC emissions by up to 80%

Spatial downscaling artifacts:
Change in industrial NOx in Europe from 2005 to 2030

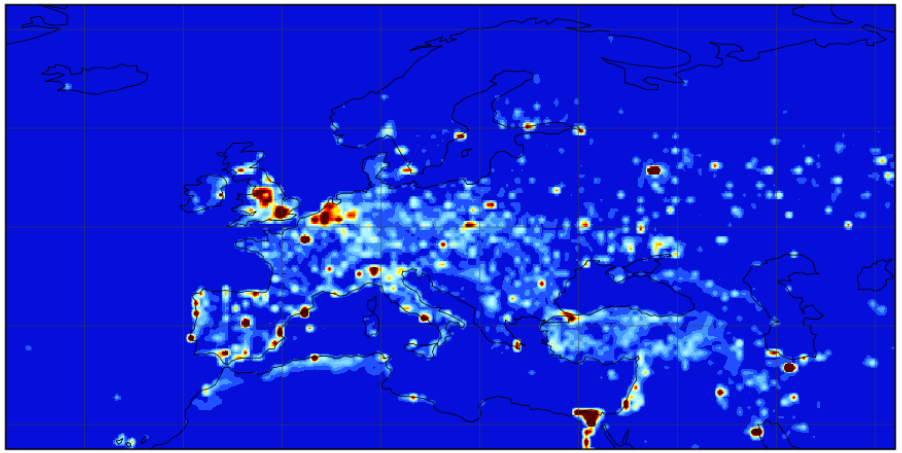
RCP 8.5 NOx - Industry (combustion and processing)



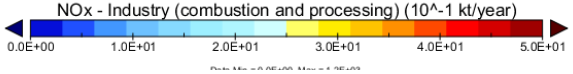
RCP 8.5 NOx - Industry (combustion and processing) (10^-12 kg m-2 sec-1)



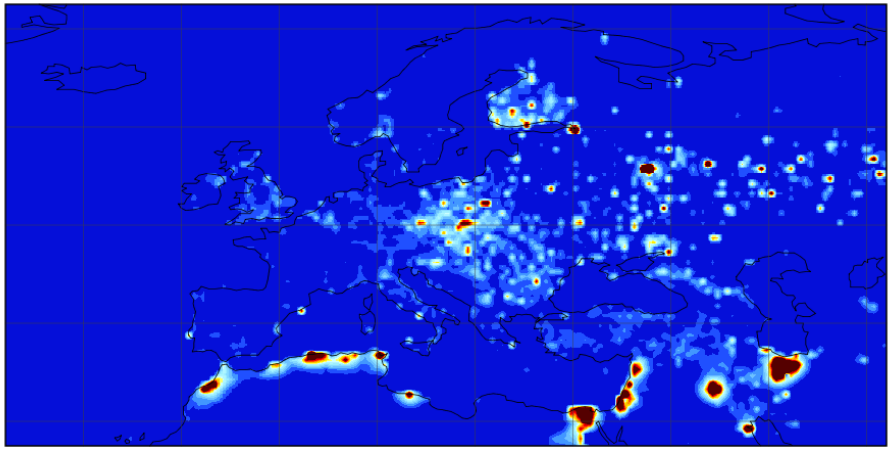
NOx - Industry (combustion and processing)



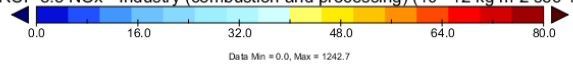
NOx - Industry (combustion and processing) (10^-1 kt/year)



RCP 8.5 NOx - Industry (combustion and processing)

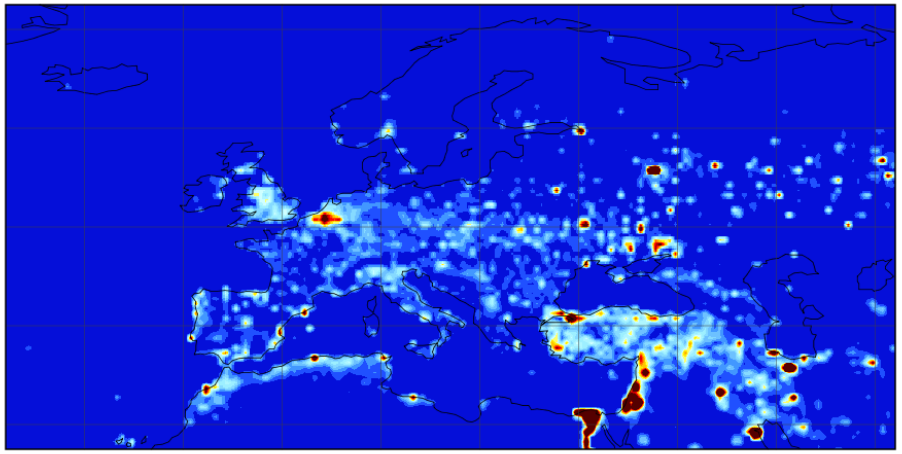


RCP 8.5 NOx - Industry (combustion and processing) (10^-12 kg m-2 sec-1)



Data Min = 0.0, Max = 1242.7

NOx - Industry (combustion and processing)



NOx - Industry (combustion and processing) (10^-1 kt NOx/year)

Data Min = 0.0E+00, Max = 1.6E+03

Concluding remarks

- Impact of current air pollution and climate policies on future emissions
  - Effective implementation of current policies will exhaust reduction potential for several technologies in some regions
  - Significantly different regional structure of emissions in the future will determine further mitigation strategies; there might not be ‘one for all’ recipe
  - Evaluation of projections with increased use of biofuels necessary; considering sustainability
  - Estimated mid-term air pollutants reductions in RCP seem optimistic while ‘CLE’ approaches are on the conservative side but might be not ‘conservative enough’
  - Choice of control policy and measures will determine the mix of pollutants – additional impact of air pollution technologies

Concluding remarks

- Emissions of various pollutants will not be reduced proportionally with increasing wealth; e.g. stationary NOx controls lagging behind FGD
- Understanding future technology transitions is essential, including conscious incorporation in projections, e.g., co-emitted species emissions and reductions
- Tools that build on consistent assumption with respect to pollutant-technology interactions and covering all relevant species should be used more
- Megacities might play an important role in accelerating mitigation of GHG and air pollutants