Modeling Emissions of Carbonaceous Particles

Zbigniew Klimont[1)], Kaarle Kupiainen[2)], Tami Bond[3)]

[1)] International Institute for Applied Systems Analysis, Laxenburg, Austria *(klimont@iiasa.ac.at)*
[2)] Nordic Envicon Oy, Helsinki, Finland *(kaarle.kupiainen@helsinki.fi)*
[3)] University of Illinois, Urbana, IL, USA *(yark@staff.uiuc.edu)*

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Outline

- **Two independent estimation efforts;**
  - **Global [SPEW],**
    Bond et al., submitted to JGR
  - **Regional (Europe) [RAINS],**
    Kupiainen and Klimont, in preparation
- **Method**
- **Snapshots**
- **Results and discussion**
- **Reflection on uncertainties**
- **Further work and conclusions**

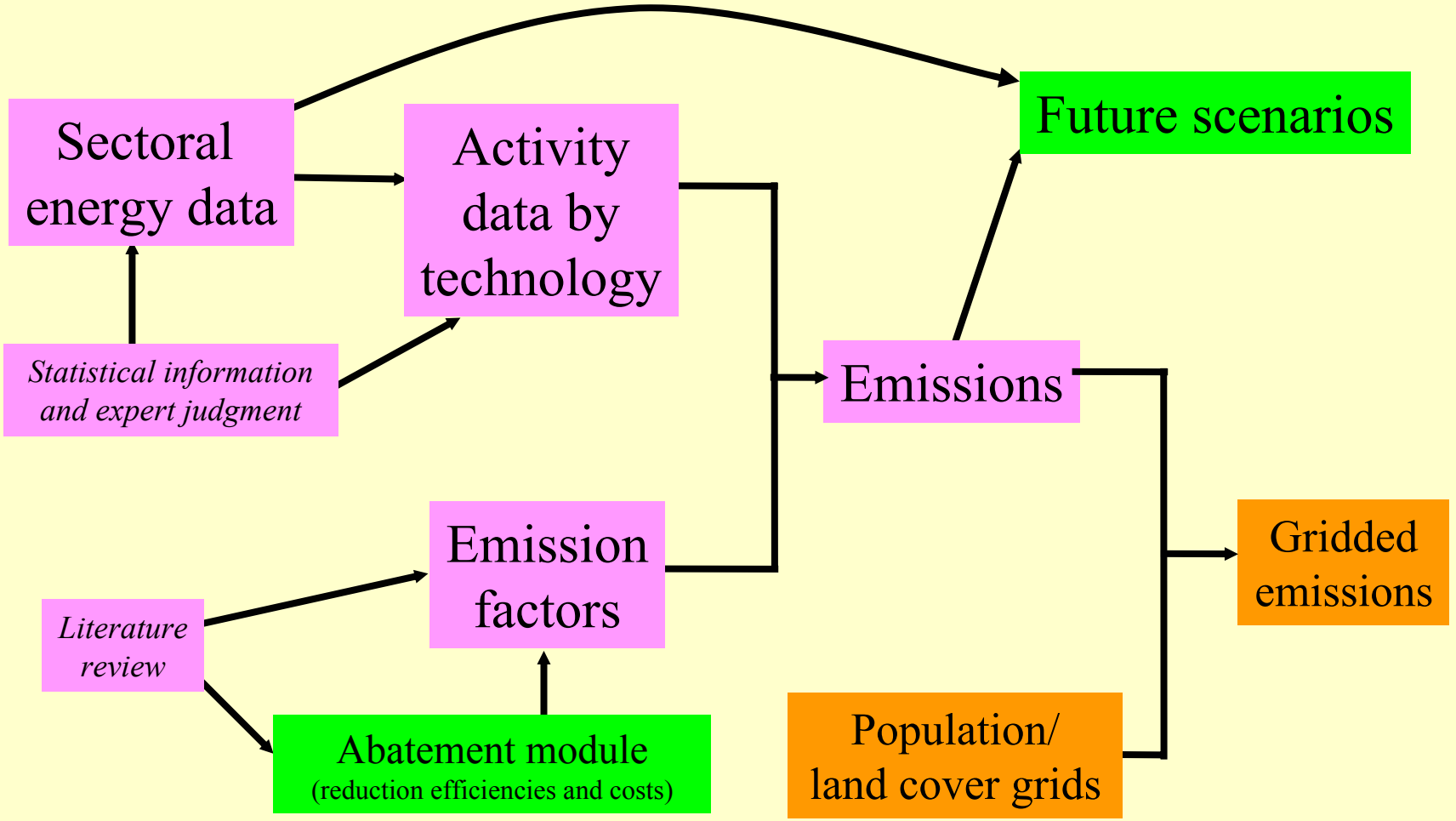
Method (1)

- **RAINS**
  - Current RAINS-PM module developed further to include BC and OC,
  - Emissions are calculated for anthropogenic sources from 1990 to 2030,
  - Activity data (intl. [IEA, OECD] and national stats and energy models),
  - Literature review of emission factors; Efs tied to regionally-specific technology and checked for consistency with the RAINS-PM database.

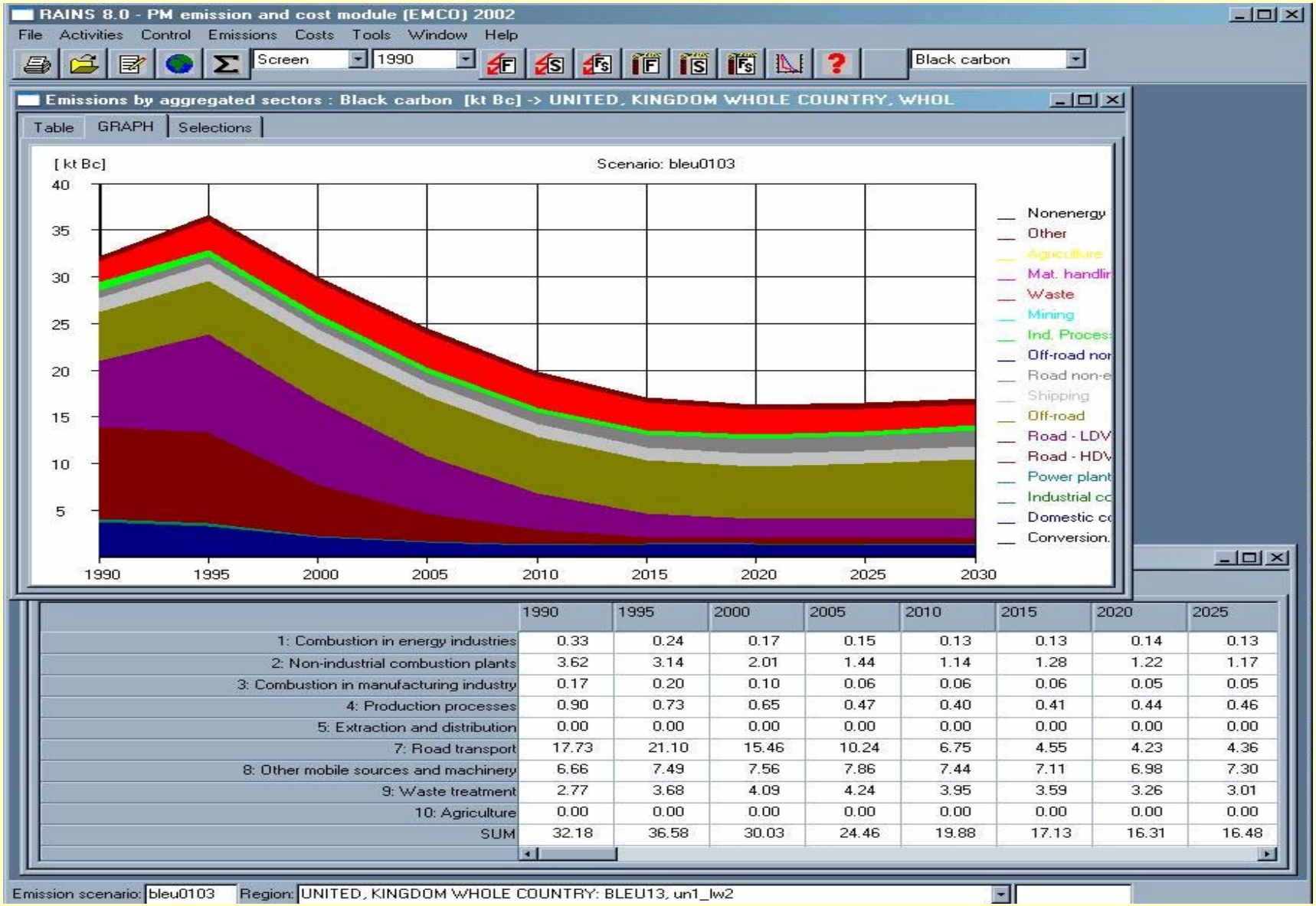
- **SPEW**
  - Emissions are calculated and spatially distributed (current database for years 1980 to 1996, results published for 1996),
  - Activity data (modified IEA),
  - Literature review of emission factors; Efs tied to regionally-specific technology,
  - Explicit uncertainty calculation.

Method (2), Lots of similarities in approach

only RAINS only SPEW

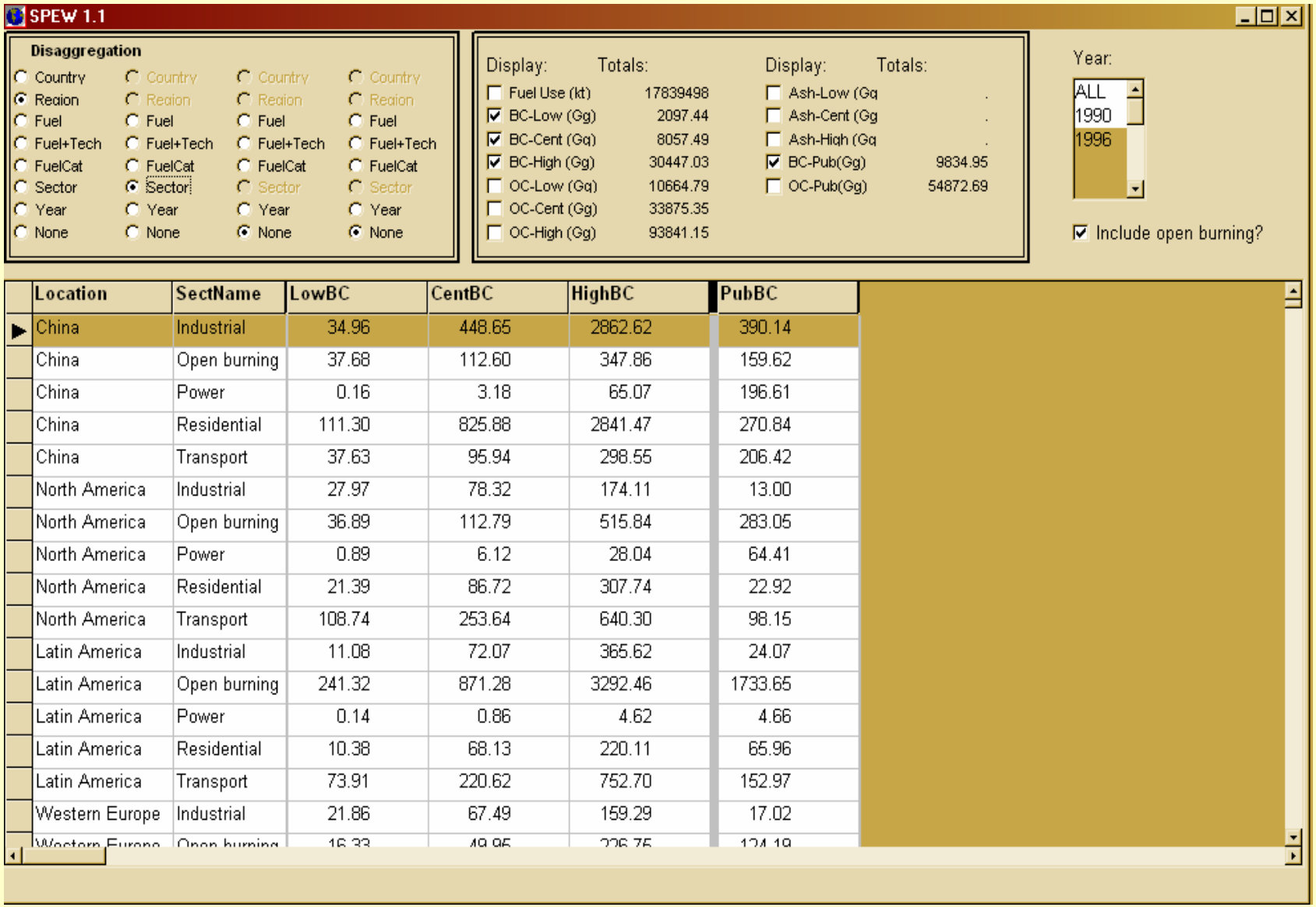


Snapshot - RAINS



	1990	1995	2000	2005	2010	2015	2020	2025
1: Combustion in energy industries	0.33	0.24	0.17	0.15	0.13	0.13	0.14	0.13
2: Non-industrial combustion plants	3.62	3.14	2.01	1.44	1.14	1.28	1.22	1.17
3: Combustion in manufacturing industry	0.17	0.20	0.10	0.06	0.06	0.06	0.05	0.05
4: Production processes	0.90	0.73	0.65	0.47	0.40	0.41	0.44	0.46
5: Extraction and distribution	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7: Road transport	17.73	21.10	15.46	10.24	6.75	4.55	4.23	4.36
8: Other mobile sources and machinery	6.66	7.49	7.56	7.86	7.44	7.11	6.98	7.30
9: Waste treatment	2.77	3.68	4.09	4.24	3.95	3.59	3.26	3.01
10: Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SUM	32.18	36.58	30.03	24.46	19.88	17.13	16.31	16.48

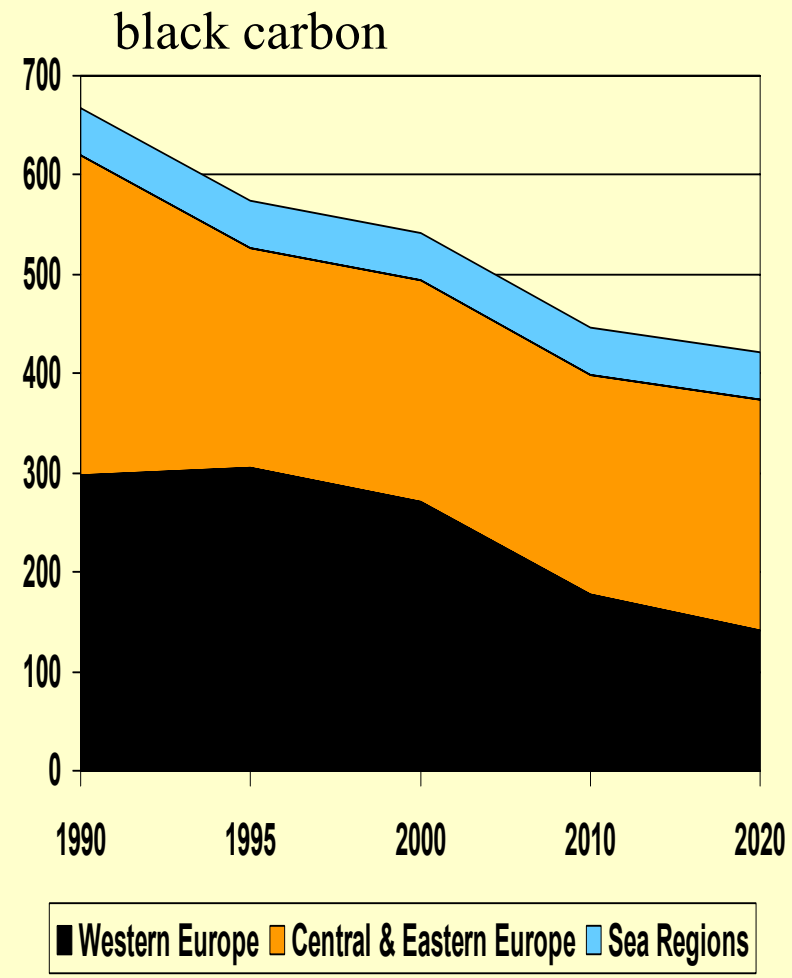
Snapshot - SPEW

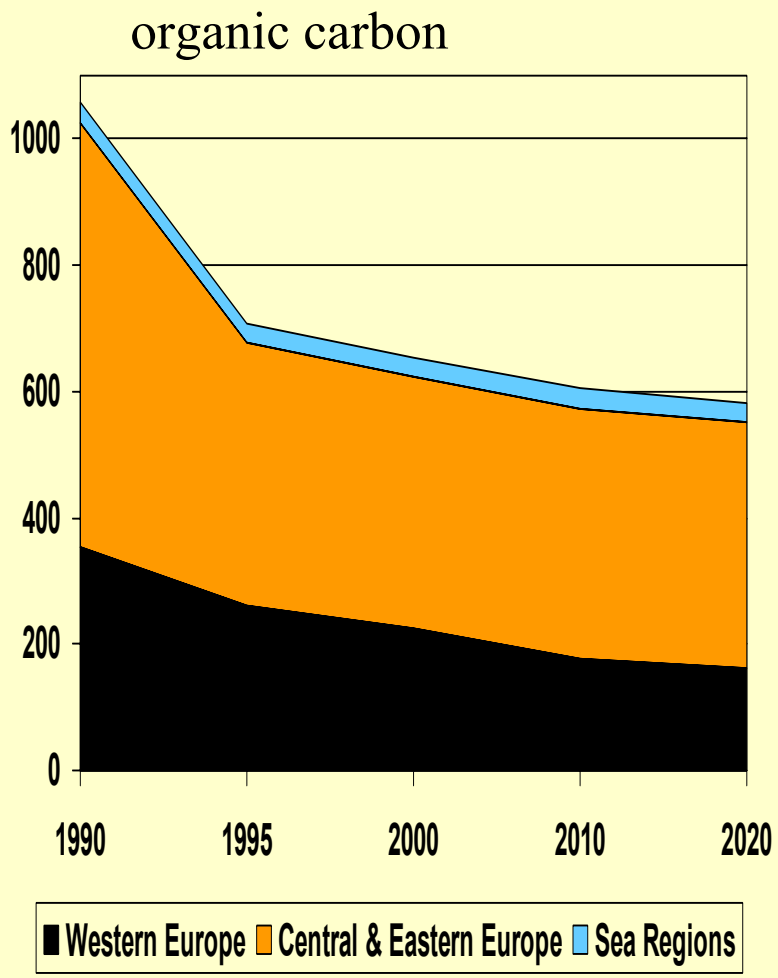


Location	SectName	LowBC	CentBC	HighBC	PubBC
China	Industrial	34.96	448.65	2862.62	390.14
China	Open burning	37.68	112.60	347.86	159.62
China	Power	0.16	3.18	65.07	196.61
China	Residential	111.30	825.88	2841.47	270.84
China	Transport	37.63	95.94	298.55	206.42
North America	Industrial	27.97	78.32	174.11	13.00
North America	Open burning	36.89	112.79	515.84	283.05
North America	Power	0.89	6.12	28.04	64.41
North America	Residential	21.39	86.72	307.74	22.92
North America	Transport	108.74	253.64	640.30	98.15
Latin America	Industrial	11.08	72.07	365.62	24.07
Latin America	Open burning	241.32	871.28	3292.46	1733.65
Latin America	Power	0.14	0.86	4.62	4.66
Latin America	Residential	10.38	68.13	220.11	65.96
Latin America	Transport	73.91	220.62	752.70	152.97
Western Europe	Industrial	21.86	67.49	159.29	17.02
Western Europe	Open burning	16.33	49.95	226.75	124.19

BC, OC emissions in Europe (by region)

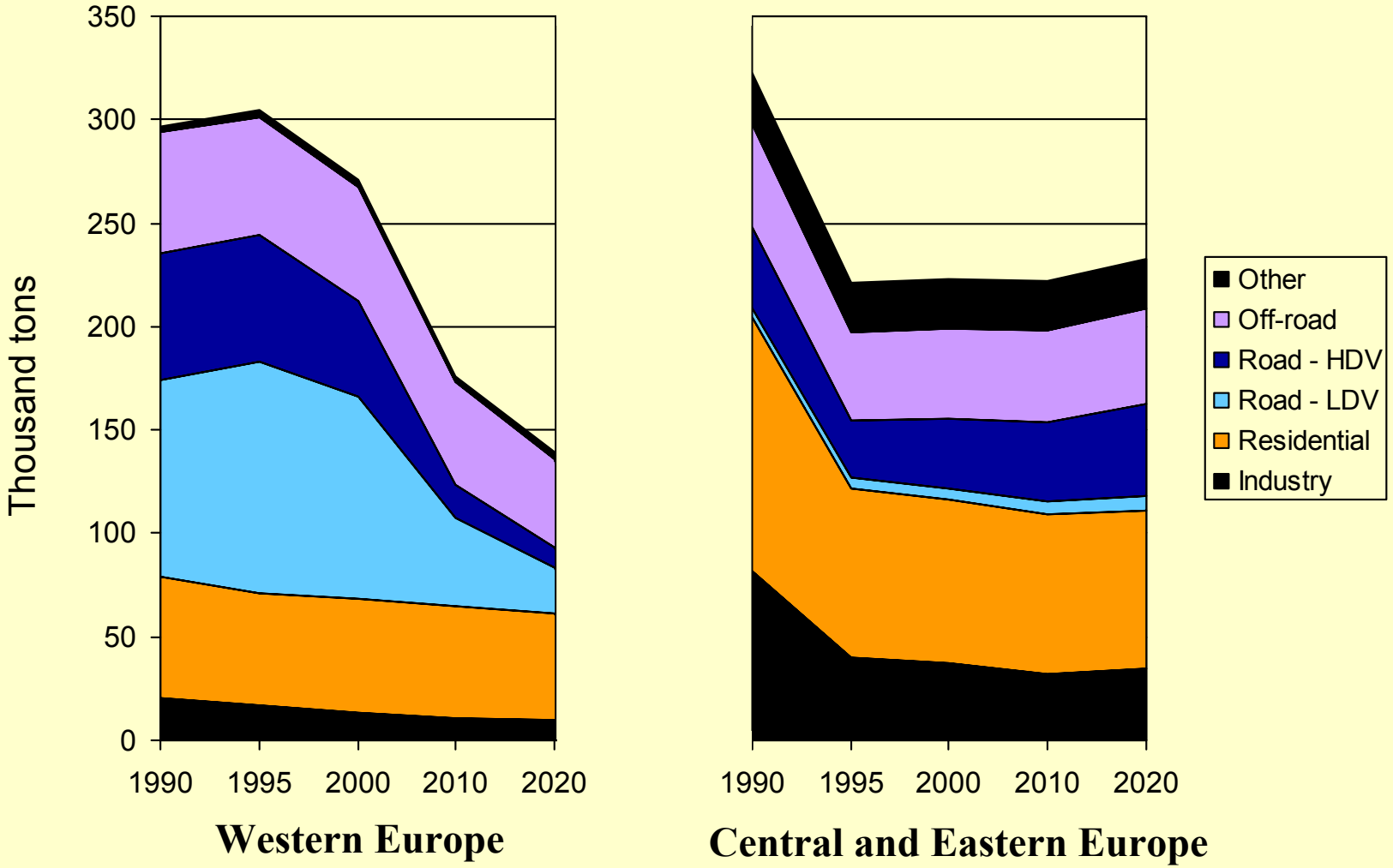
RAINS *Current Legislation Scenario [Gg]*





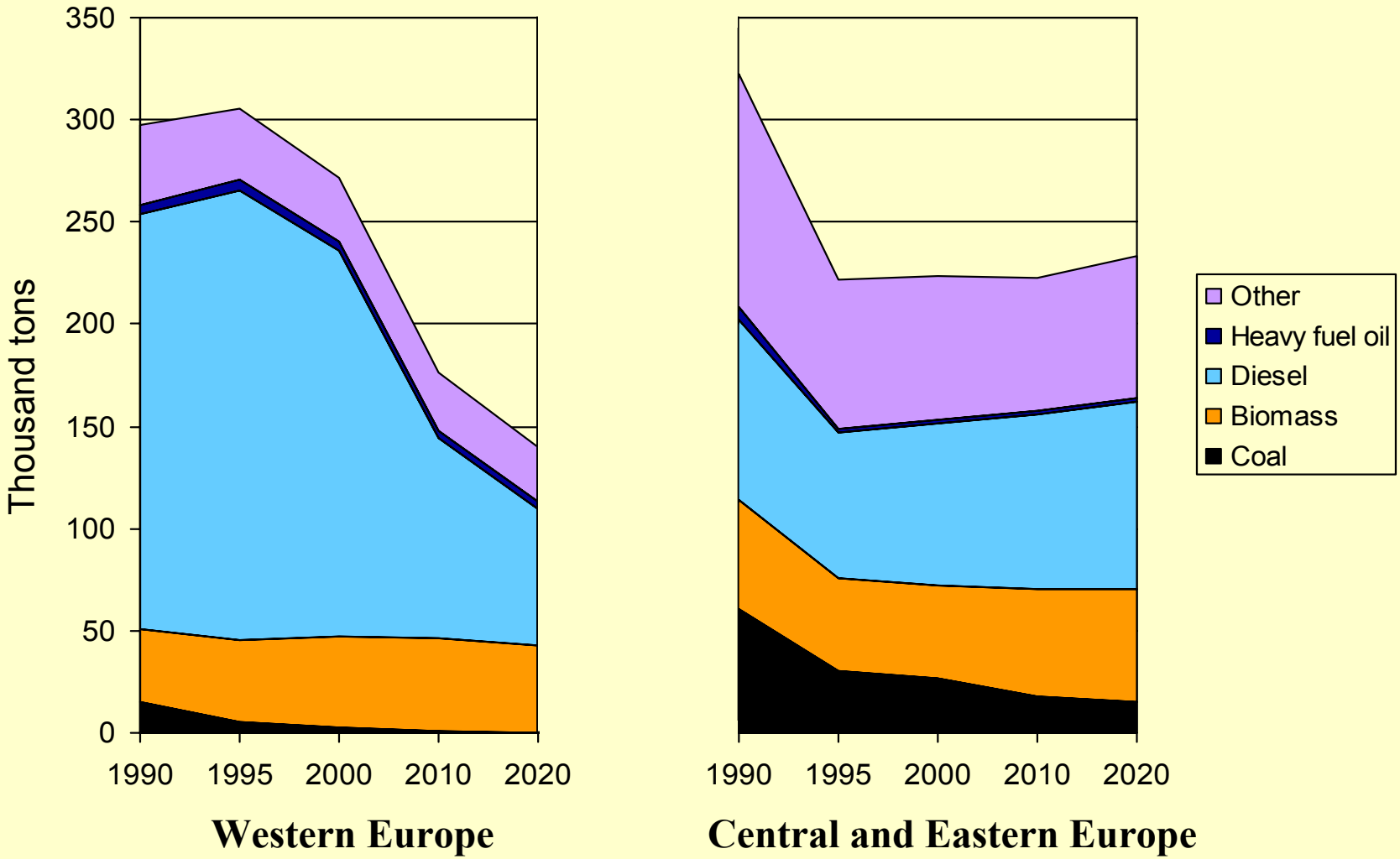
Black carbon emissions in Europe (by sector)

RAINS *Current Legislation Scenario [Gg]*



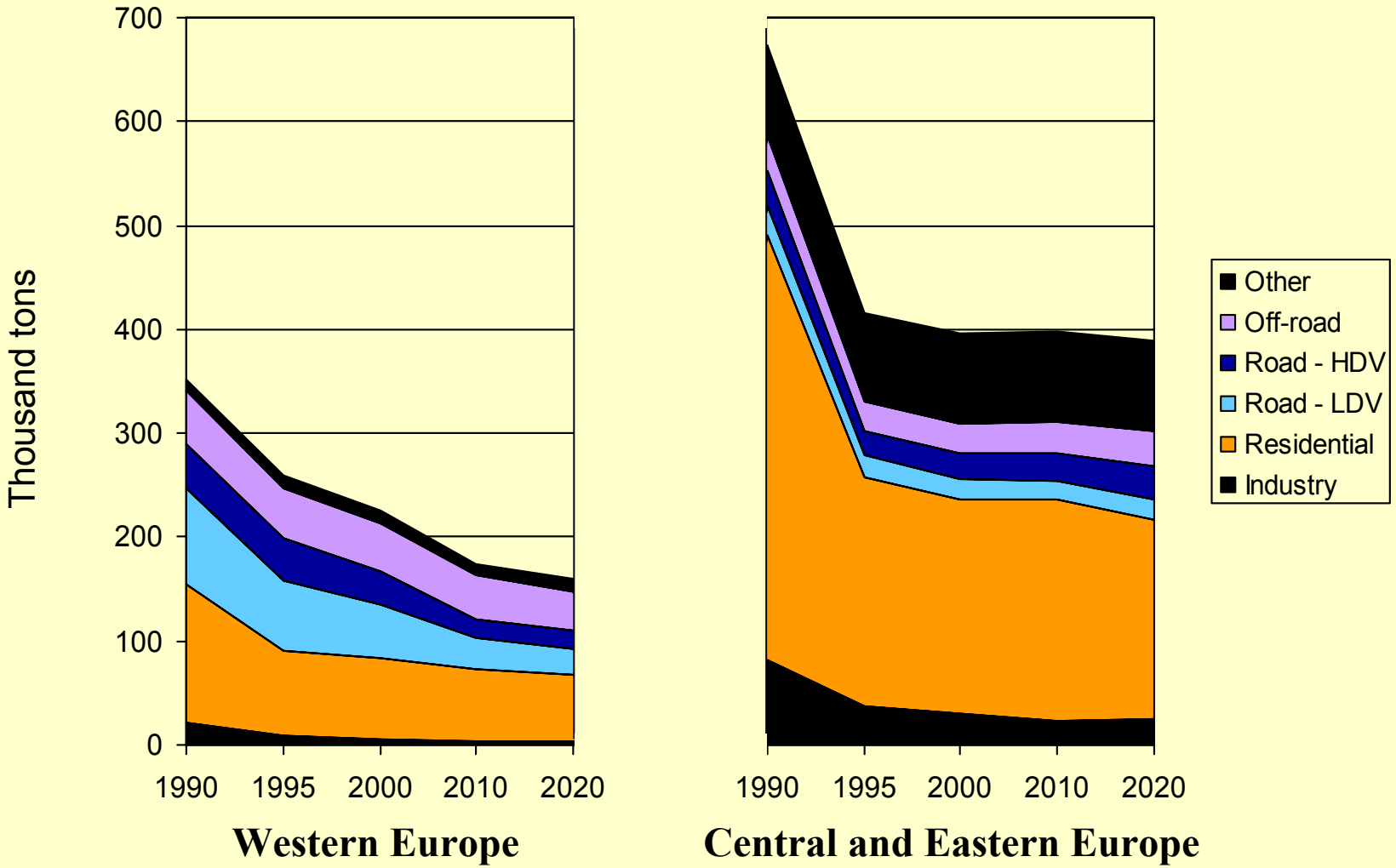
Black carbon emissions in Europe (by fuel)

RAINS *Current Legislation Scenario [Gg]*



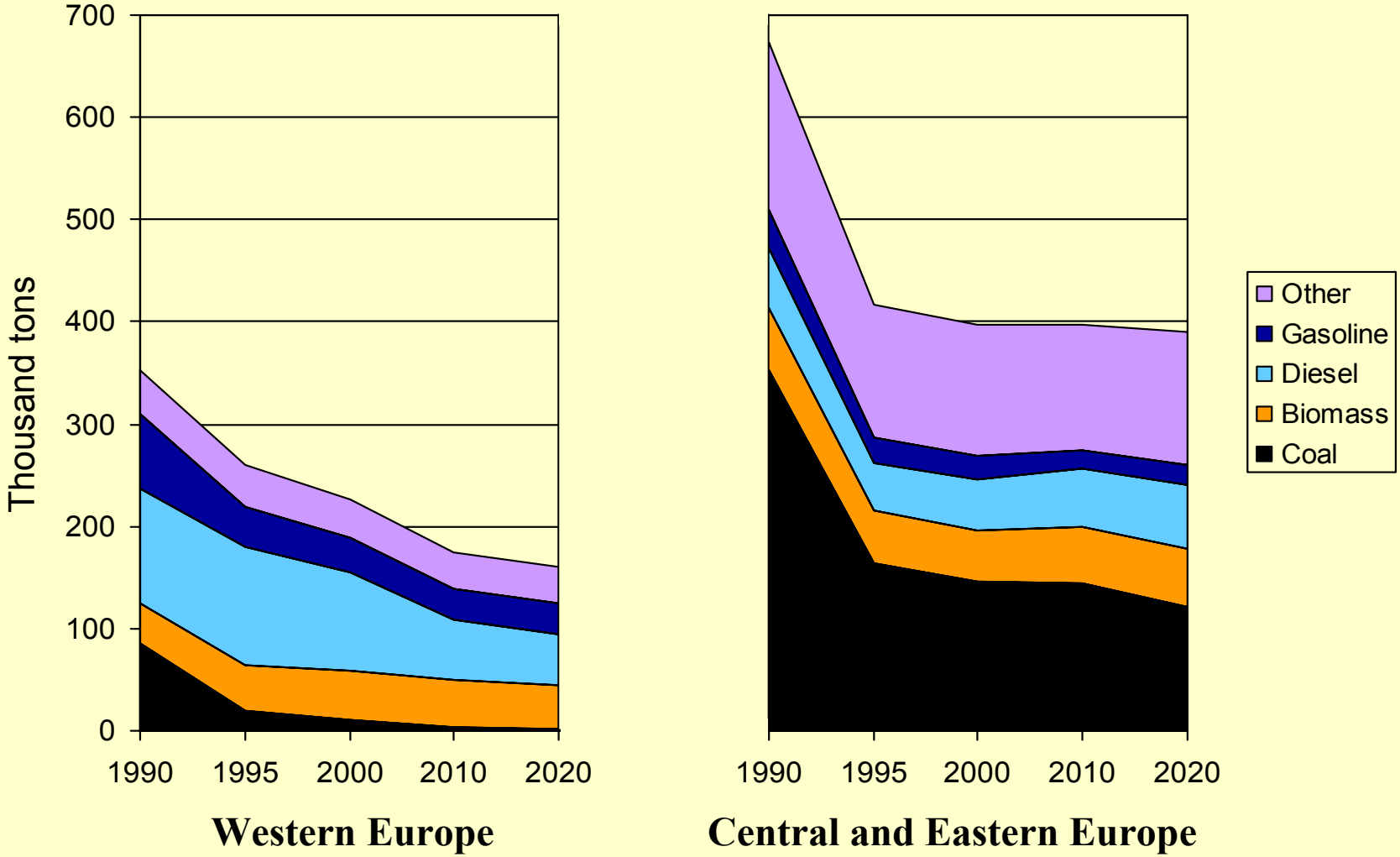
Organic carbon emissions in Europe (by sector)

RAINS *Current Legislation Scenario [Gg]*



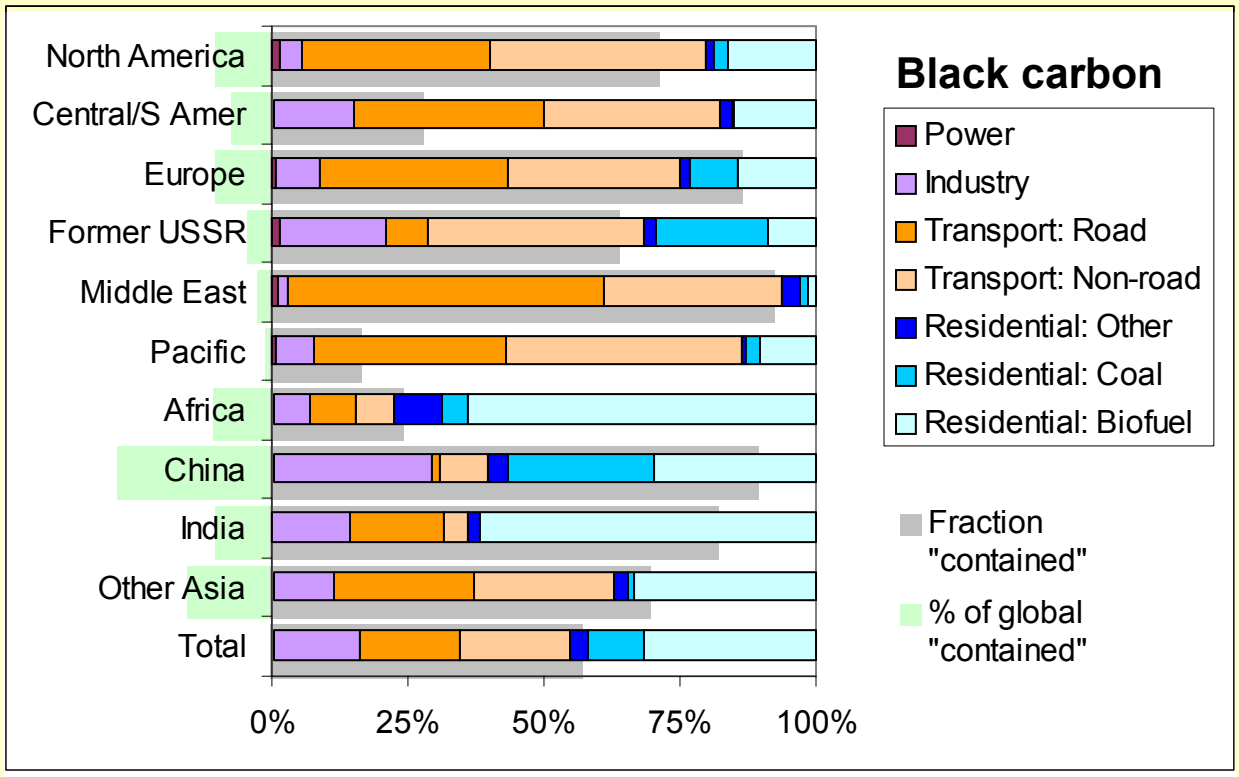
Organic carbon emissions in Europe (by fuel)

RAINS *Current Legislation Scenario [Gg]*



Global emissions of black carbon in 1996

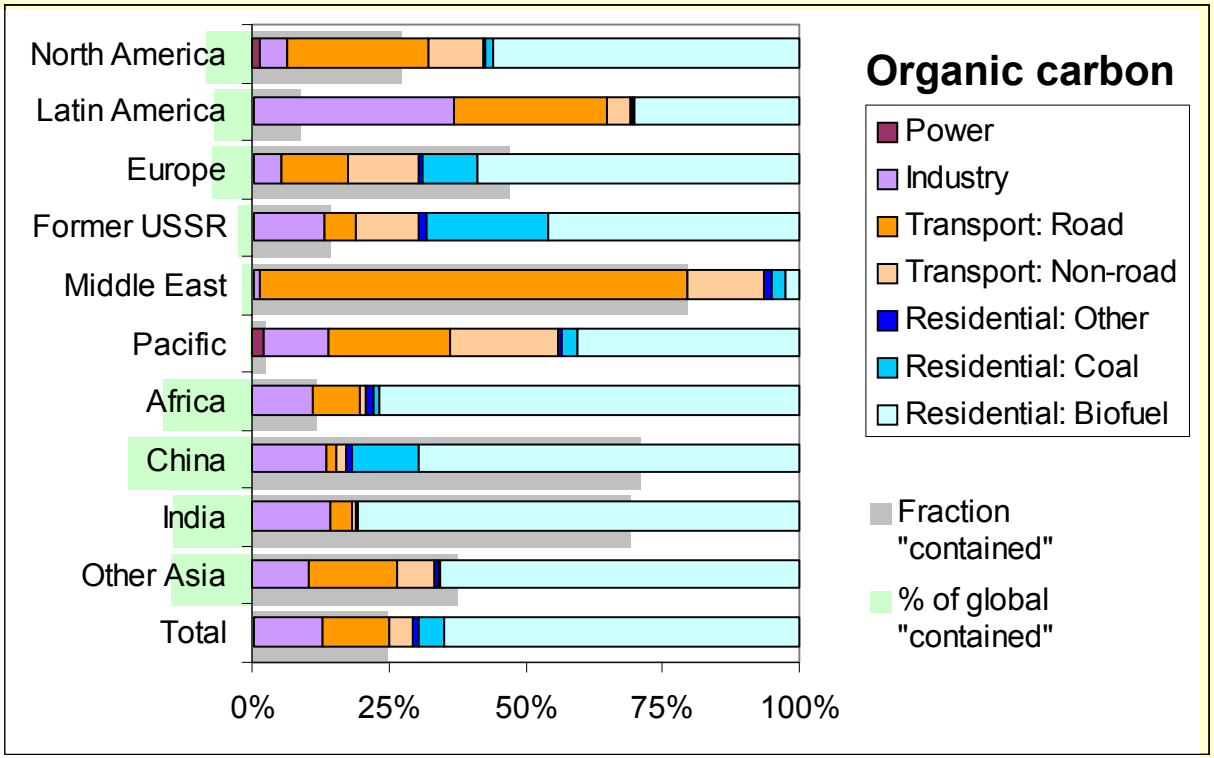
SPEW Central scenario



Region	[Gg]
North America	538
Latin America	1192
Europe	553
Former USSR	291
Middle East	108
Pacific	199
Africa	1966
China	1487
India	577
Other Asia	1029
Total	**7937**

Global emissions of organic carbon in 1996

SPEW Central scenario

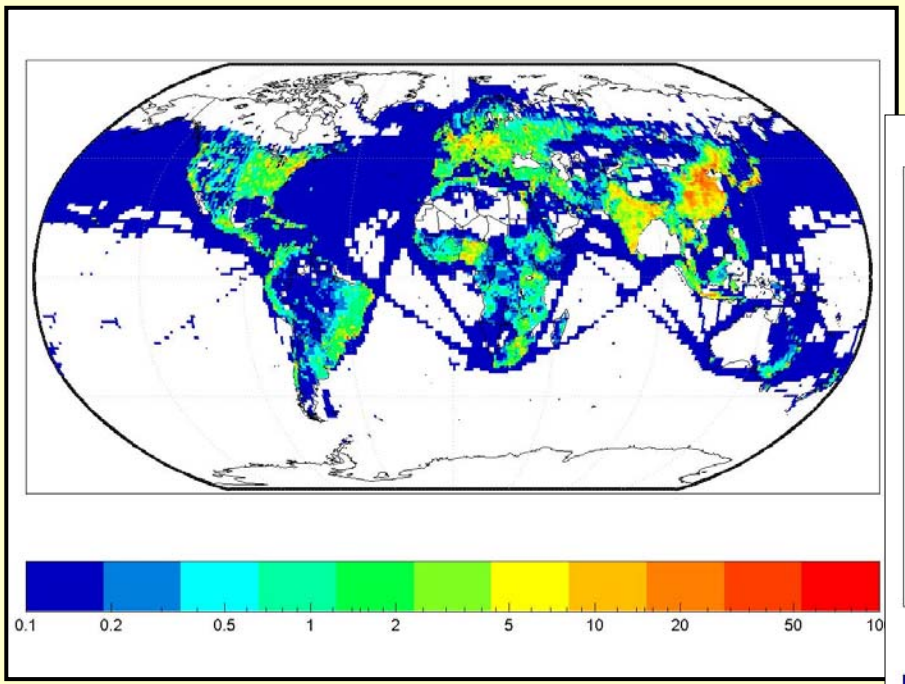


Region	[Gg]
North America	2055
Latin America	6896
Europe	1386
Former USSR	1458
Middle East	204
Pacific	1154
Africa	12022
China	2817
India	1866
Other Asia	3462
Total	***33321***

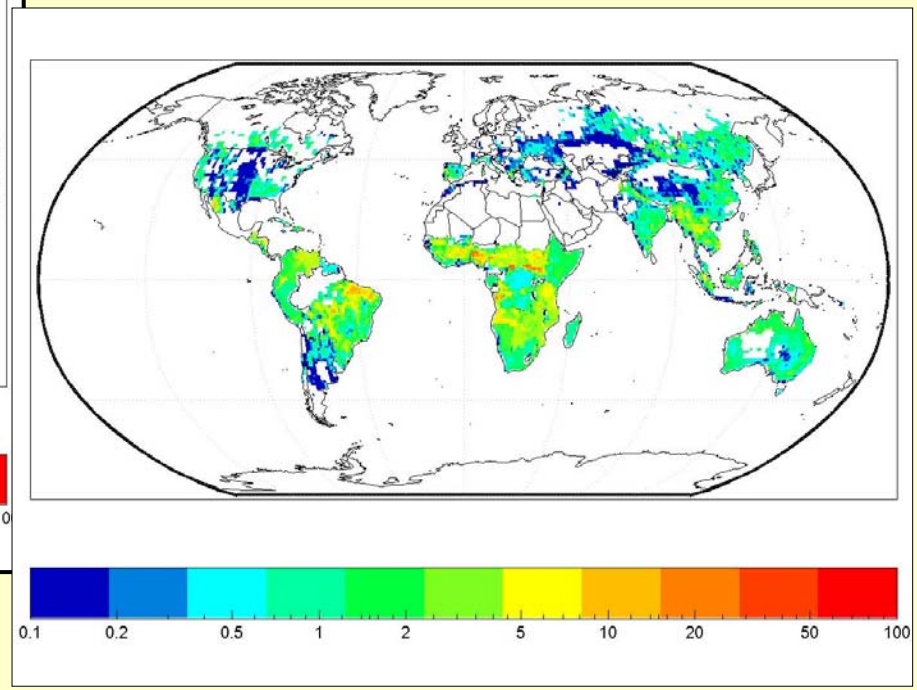
Global distribution of BC and OC emissions in 1996

SPEW (Bond *et* al., submitted to JGR)

black carbon



organic carbon



units: ng/m²/sec

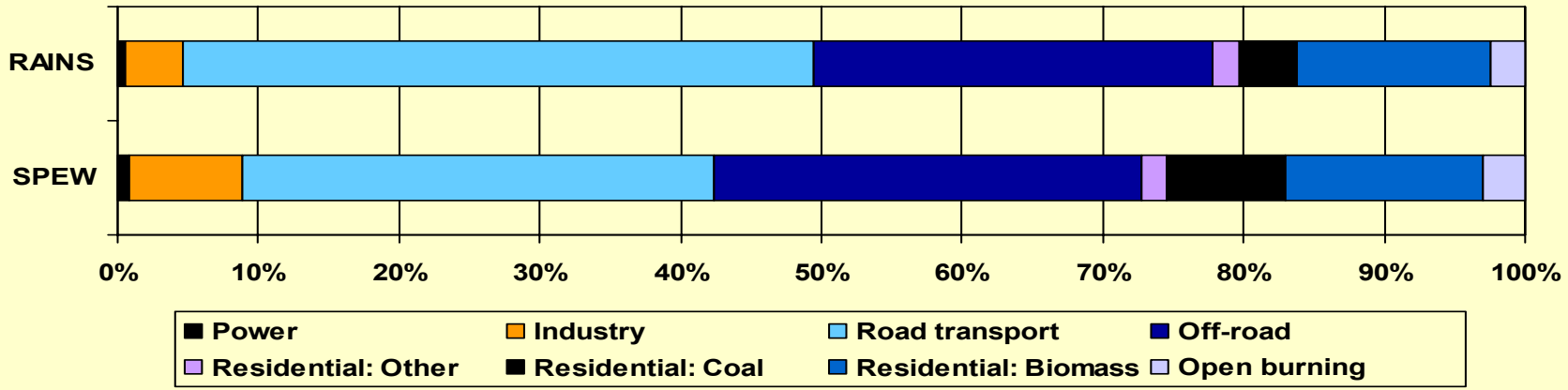
Comparison of BC and OC estimates for Europe [Gg/year]

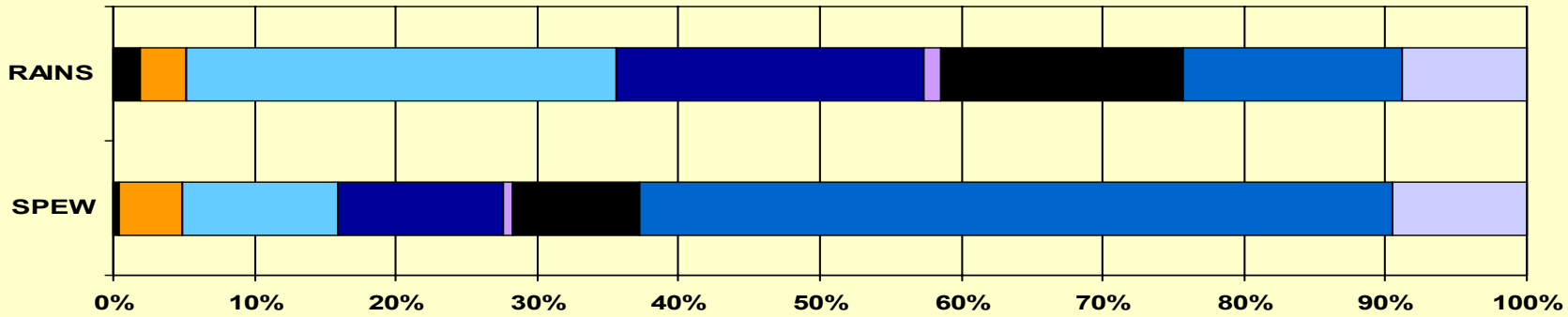
Source	*Year*	*Black carbon*	*Organic carbon*
Cooke *et al.*, 1999	1996	1355	3246
SPEW (Bond *et al.,* submitted)	1996	553 (395-1117)	1386 (707-3039)
RAINS *(*Kupiainen and Klimont*, in preparation)*	1995	427	433
Derwent *et al.,* 2001	1995-98	482-511±140	n.a.

- Recent work indicates that BC/OC emissions might be significantly smaller than previously believed,
- Large differences, but… not always the same sources are included and geographic coverage of "Europe" varies.

Adjusted RAINS and SPEW estimates for Europe

black carbon – RAINS: 415 Gg, SPEW: 509 Gg





organic carbon – RAINS: 409 Gg, SPEW: 758 Gg

Uncertainty - Outline

- **Emission factors - Carbonaceous aerosol emission profile depend on combustion conditions,**
  - governed by time-temperature history of the fuel
  - what factors have an effect and how significant is the effect (fuel, operation, stove design, engine technology, etc.)?
  - measurement method – are the methods comparable?

- **Large sets of measurements needed to get a coherent picture**

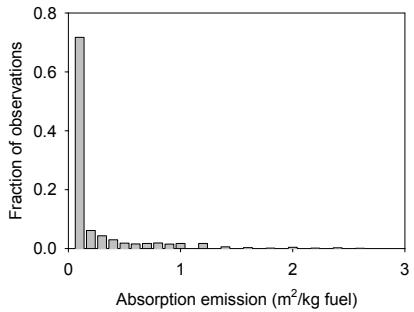
- **Also other sources of uncertainties than emission factors**

Uncertainty (1)

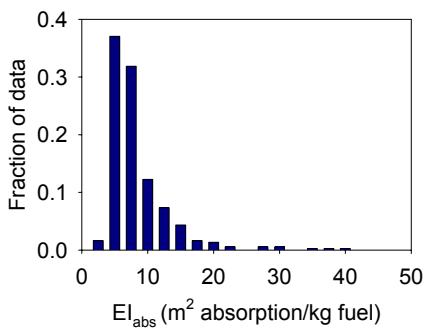
How do we know that emission factors are representative?

Single events:
~50% of absorption emitted during 6% of the observed time (oil boiler, Germany)

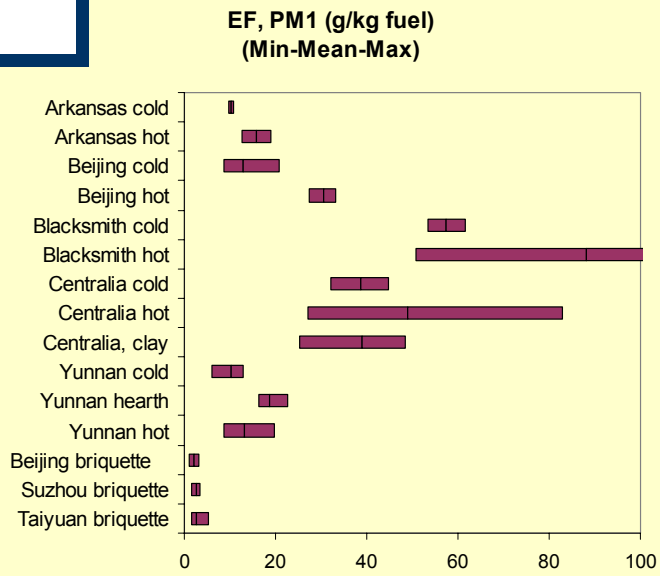
Industrial oil boiler



what about sampling bias?



Single units:
0.2% of trucks emit 10% of the absorption (Seattle highway)



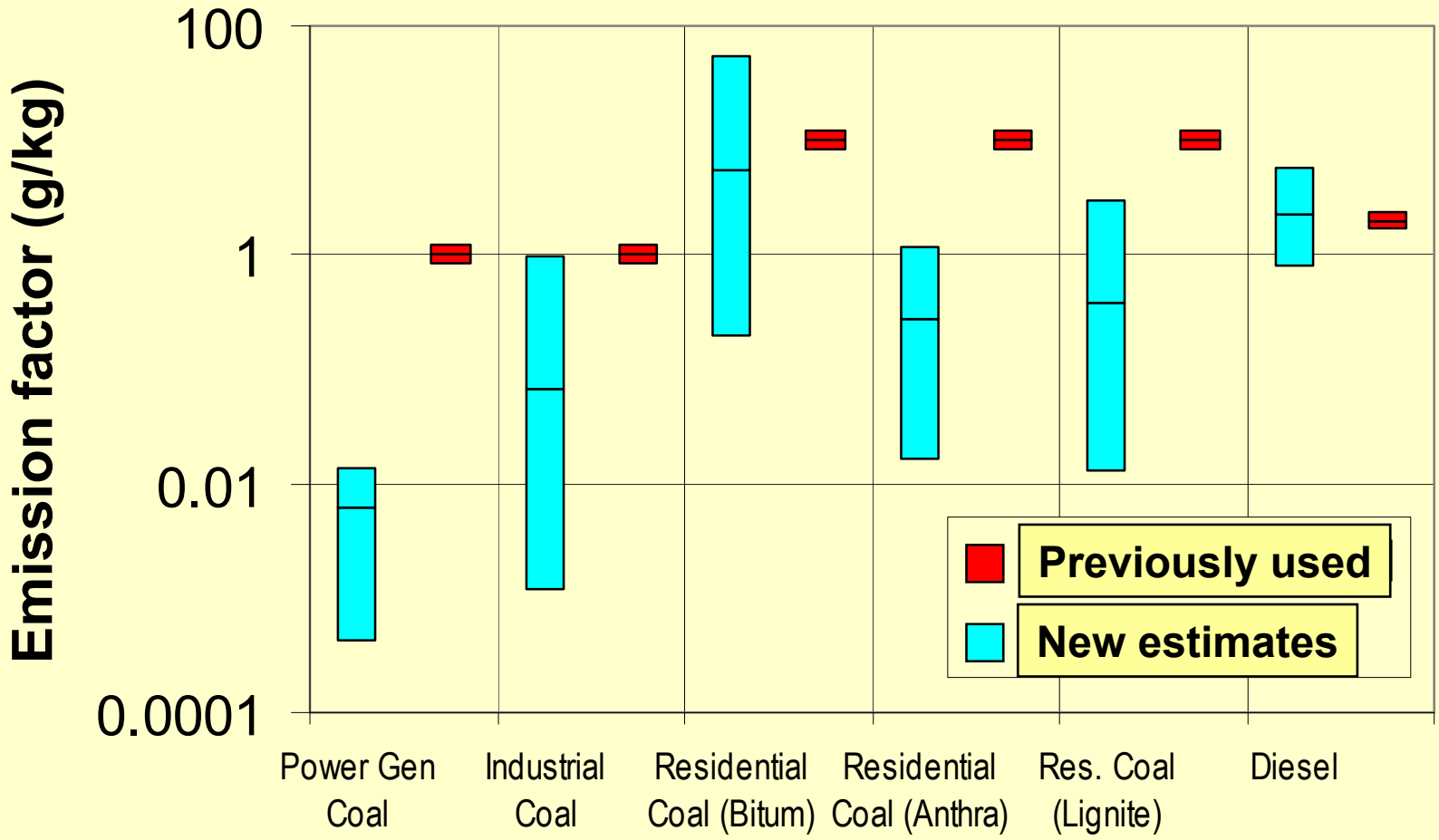
Uncertainty (2)

Are the measurements comparable?

- **The measurement methods vary, do they measure the same thing?**
  - optical (BC or LAC) → absorption
  - thermal (EC/OC) → thermal evolution of carbonaceous species
  - thermal with an optical correction (EC/OC) → thermal evolution of carbonaceous species
  - solvent extraction (OC) → soluble organic species
- **Examples:**
  - carbon black: integrating sphere (optical) overestimated by 21% vs. a thermal method (Hitzenberg et al., 1999. Atm.Env. 33, 2823-)
  - ambient samples: integrating sphere (optical) agreed within 5% vs. a thermal optical method (Hitzenberg et al., 1999)
  - diesel exhaust: different thermal evolution protocols of the thermal optical method agree within TC ±5% and EC ±20% (Chow et al., 2001. Aerosol Sci. Tech. 34, 23-)

Uncertainty (3) Re-assessment of BC emission factors

(Streets *et al.*, *Atmospheric Environment*, 35, 4281, 2001)



There is a need for emission measurements!

BC/OC source	*Remarks*
Road traffic, exhaust	*Several studies, mainly US*
Off road and machinery, exhaust	*Few studies or no data at all*
Domestic combustion, wood	*Few studies, mainly US*
Domestic combustion, coal	*Few studies, some very old*
Domestic combustion, oil	*Few old studies*
Power plants & industry, solid fuels	*Several studies, however, of abated emissions*
Power plants & industry, oil & gas	*Few old studies*
Industrial processes	*Few studies*
Dust (traffic, agriculture, etc.)	*Few studies*

Uncertainty (4)

Important contributors

Apart from emission factors…

- **Activity data, e.g., biomass in residential sector, off-road transport, open burning;**
- **Detailed split of coal and biomass consumption in residential sector, i.e., fireplaces, stoves, boilers, etc.;**
- **Poor information *(read NO information)* on how efficient are currently applied 'PM' control technologies in removing carbonaceous particles,**
- **Interpretation and use of reported measurement data.**

TOP4 contributors to variance (SPEW)

- Global BC emissions (”contained” sources)
  - cokemaking (China)
  - wood/residential (activity, emission factors)
  - coal/industrial (emission factors, high emitters)
  - diesel/on-road (emission factors, high emitters)

- Global OC emissions (”contained” sources)
  - wood/residential (activity, emission factors)
  - gasoline/transport (two-stroke engines)
  - agr.waste/residential
  - wood/industrial

Summary of results for black carbon

- Recent estimates agree reasonably well and suggest that emissions are significantly lower (about 60%) than previous work,
- For most regions more than 70% of emissions from “contained” sources,
- Combustion of diesel fuel (transport) dominates (about 50-80 %) emissions in the industrialized regions,
- More than 50 % of emissions in developing world originate from combustion of coal and biomass in residential sector,
- In 1990 and 2000, Western Europe contributed more than 50 % of BC in Europe, (excluding shipping).
- European emissions are calculated to decline in the future - primarily due to measures in Western Europe,
- Additional climate “measures” (more diesel and biofuels) could lead to higher BC emissions.

Summary of results for organic carbon

- Recent estimates significantly lower (about 60%) than previous work,
- Large discrepancies between studies, especially for residential combustion,
- In most regions, majority of emissions originate from open burning,
- Combustion of fuel in residential sector responsible typically for more than 50 % of emissions (primarily biomass),
- Emissions from transport are typically the second most important source,
- In Europe, majority of emissions originates from Central and Eastern European countries (solid fossil fuels in residential sector),
- European emissions are calculated to decline only slightly in the future.

Conclusions

- **Methodology for assessment of regional and global BC/OC emissions developed, but a thorough verification** *(and comparison between the models)* **of assumptions used in calculations needed.**
- **Emissions from transport and residential combustion dominate "contained" emissions.**
- **Emissions from open burning are typically more important for OC than BC.**
- **Large uncertainties of estimates.**
- **More work needed in order to reduce uncertainties and fill in the gaps.**
- **Awaiting feedback from atmospheric modelers…**

Primary references

- Bond, T.C., Streets, D.G., Yarber, K.F., Nelson, S.M., Woo, J-H., Klimont, Z., **A Technology-Based Global Inventory of Black Carbon and Organic Carbon Emissions from Combustion.** *Submitted to Journal of Geophysical Research*.

- Kupiainen, K. and Klimont, Z., **The Primary Emissions of Submicron and Carbonaceous Particles in Europe and Potential for their Control.** IIASA interim report, i*n preparation*.