Universität Stuttgart
Institut für Energiewirtschaft und Rationelle Energieanwendung IER

Multi-Pollutant Multi-Effect Modelling of European Air Pollution Control Strategies - an Integrated Approach

First Results

-methodology

-comparison of baseline scenarios

-analysis of emission sectors and single pollutants

-First multi-pollutant multi-effect scenarios

(funded by DG Research 5th FP)

The MERLIN team:

- IER University of Stuttgart (Co-ordinator)
- Norwegian Meteorological Institute (met.no)
- Aristotle University of Thessaloniki, Laboratory for Heat Transfer and Environmental Engineering (AUT/LHTEE)
- University College London (UCL)
- ECOFYS Energy and Environment
- Institute for Ecology of Industrial Areas (IETU)
- Energy Research Center (ERC) of Ostrava Technical University
- National Institute of Meteorology and Hydrology (NIMH)
- University of Ploiesti (Ploiesti, Romania)

Objectives

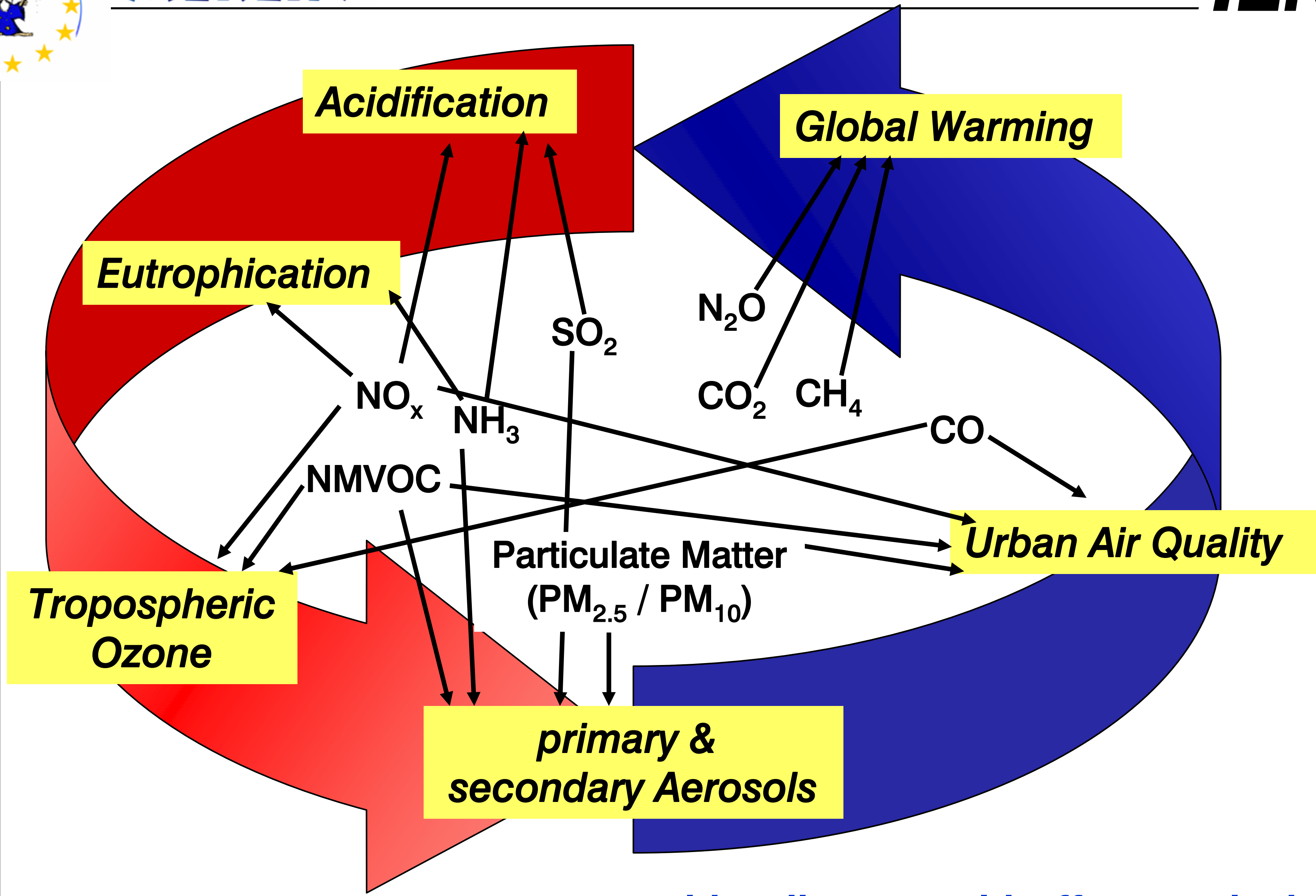
Development and application of methodologies and tools for an integrated assessment of European air pollution control strategies

Features

- **multi-pollutant, multi-effect assessment**
- **cost-effectiveness and cost-benefit analysis**
- **application of advanced optimisation methods**
- **inclusion of non-technical measures**
- **coupling with local models**
- **macroeconomic effects and distributional burdens of air pollution control**
- **inclusion of new member states**
- **differentiation between high and low stacks**

MERLIN

Universität Stuttgart
Institut für Energiewirtschaft und Rationelle Energieanwendung
IER



Multi-Pollutant Multi-Effect Analysis

Calculation example (I)

Stock

No. of vehicles:

 # [GER, PC, EURO2, gasoline, 2000]

Activities

annual mileage:

*km/vehicle*year [GER, PC, EURO2, gasoline, 2000]*

X

g/km [CO2, NOx, CO, NMVOC, PM2.5, PM10, ...]

Emission Factors

t/year [CO2, NOx, CO, NMVOC, PM2.5, PM10, ...]

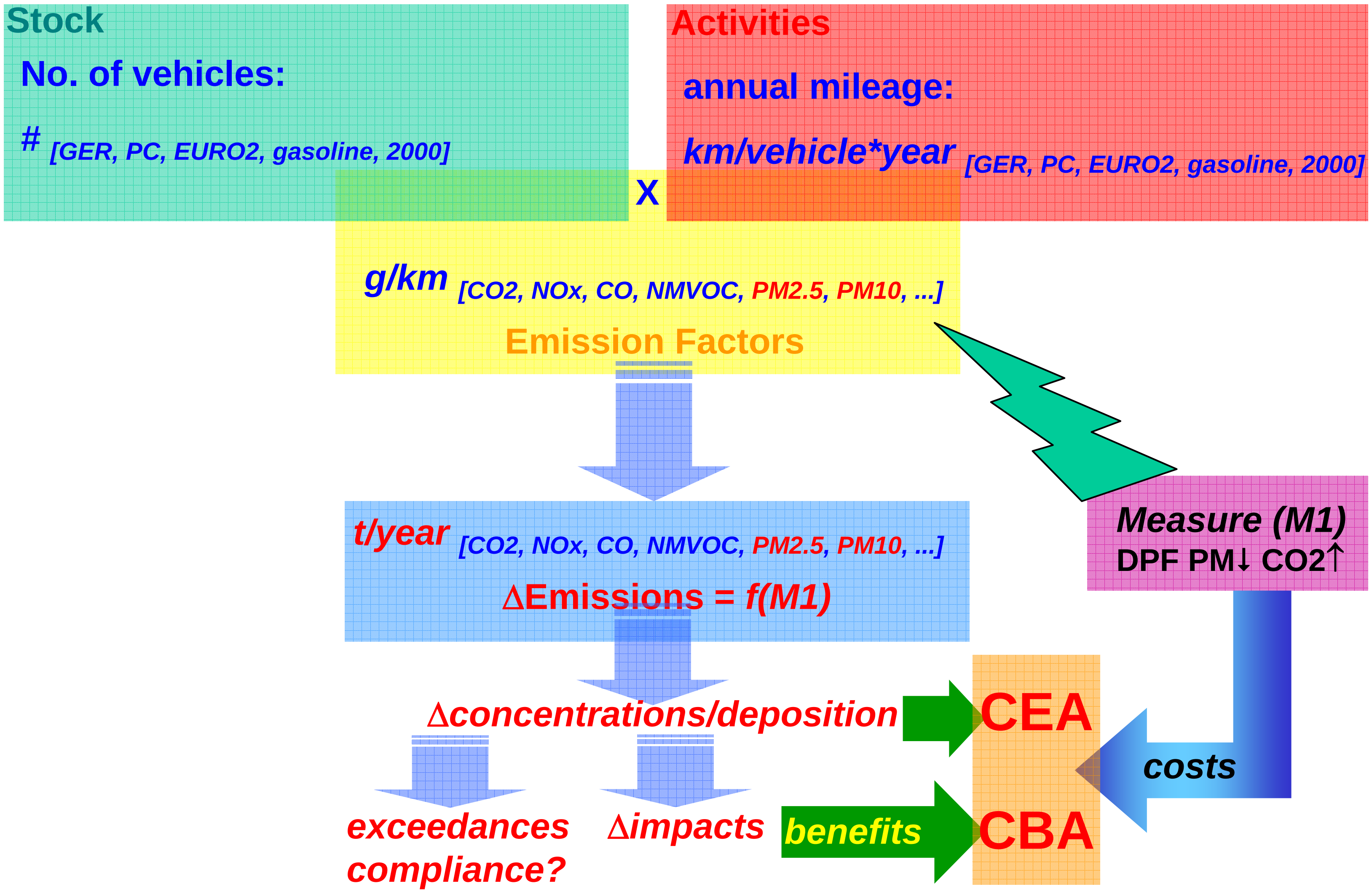
Emissions

concentrations/deposition

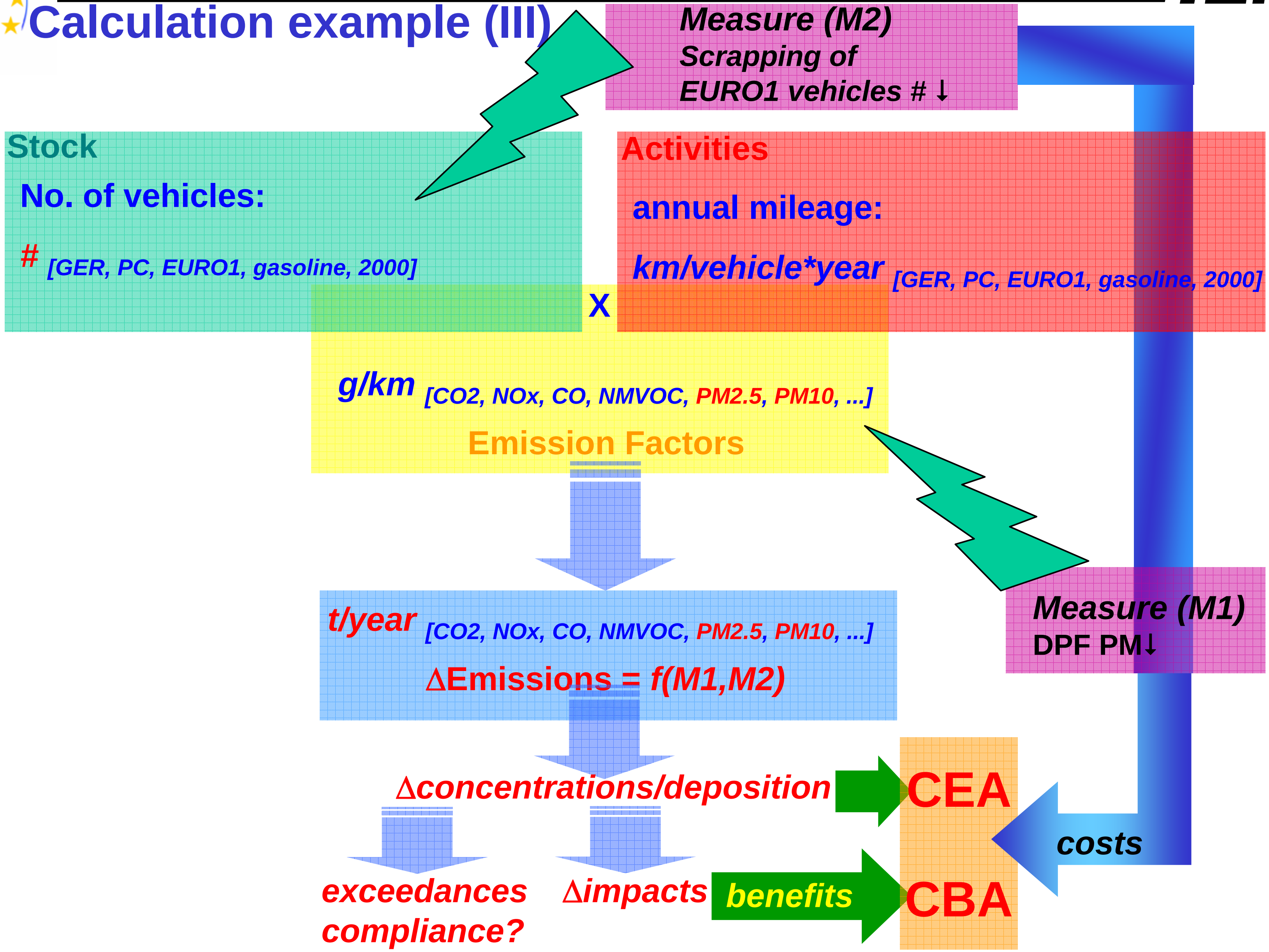
impacts

exceedances

Calculation example (II)



Calculation example (III)



Non-Technical Measures (I)

In MERLIN, non-technical measures such as:

(a) Higher motor fuel taxes

(b) Road congestion pricing

(c) Higher taxes on motor vehicle ownership

(d) Restructuring vehicle fuels taxes ***(eg the balance between diesel fuel and petrol)***

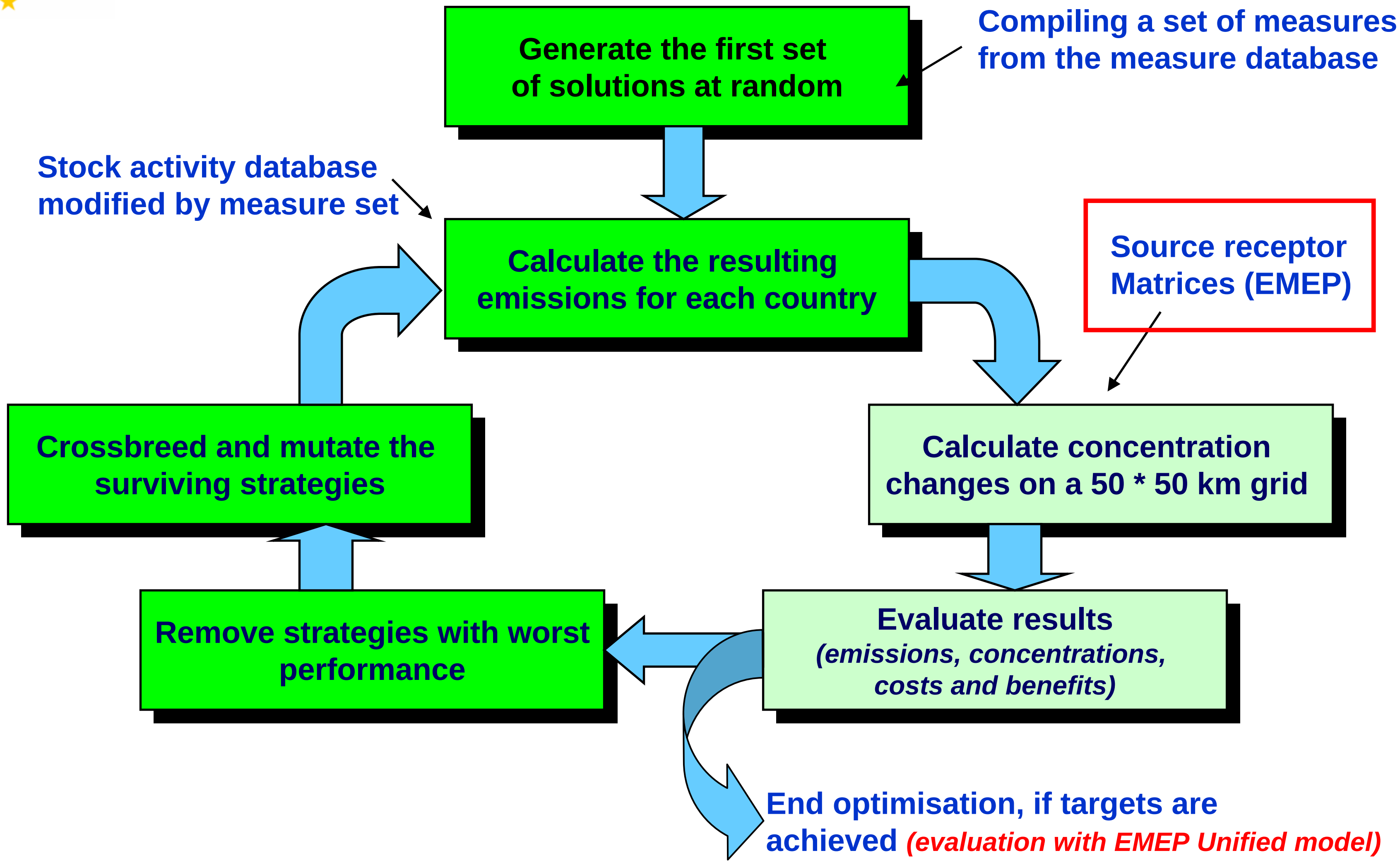
(e) Accelerated scrapping incentives

(f) Parking charges

(g) Public transport subsidy

(h) City toll

- **are evaluated, which affect activity levels by increasing relative prices.**



MERLIN Optimisation Approach (Genetic Algorithm) – the OMEGA Model

Is the global optimum reached?

- This can not be proven (for so-called ***np-hard*** problems), however it is likely, that the found solution is close to the optimum. This is achieved by:
  - Inclusion of ***special strategies*** as subsets of the starting population, to direct the search to regions of the solution space, which indicate potential for local/global optima.
  - enhancement of the ***fitness of young solutions***, i.e. leaving the mutation operator enough time to improve them locally, so they are not prematurely suppressed by older ones.
  - Use of ***diversity increasing operators***, preventing the search to ignore promising regions too early in favour of few strategies with high fitness
  - Simulation of ***SINEs*** (short interspersed elements) to provide points to the crossover operator where cutting is done with increased probability.

see e.g. Reis S , Nitter S, Friedrich R (2004) Application of Genetic Algorithms for the Optimisation of Multi-Pollutant Multi-Effect Problems. In Pahl-Wostl, C., Schmidt, S. and Jakeman, T. (eds) iEMSs 2004 International Congress: "Complexity and Integrated Resources Management". International Environmental Modelling and Software Societey, Osnabrueck, Germany, June 2004.

State of Work

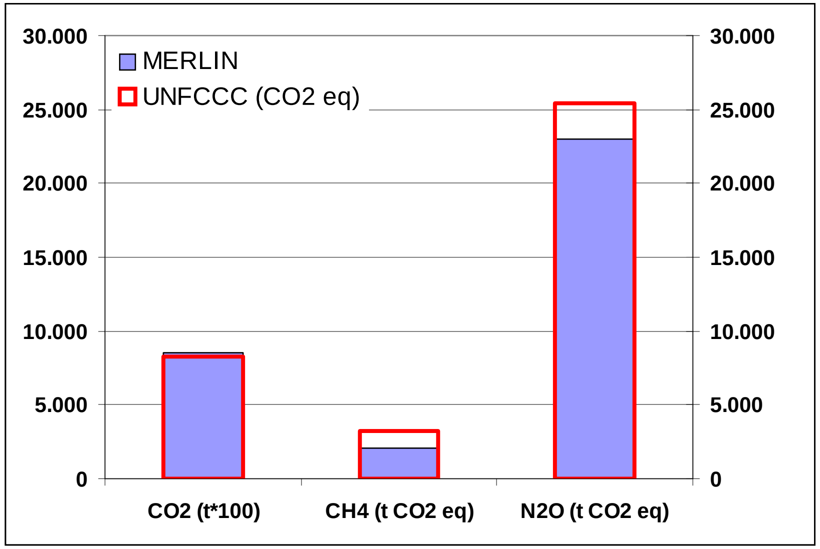
- Stock, activity data and emission factors for 2000 and the baseline scenario 2010 established and checked by comparing it with EMEP 2000 and the CAFE baseline 2010 and UNFCCC 2010 data
- About 1000 measures per country (= 25 000 measures) implemented, measure & cost data currently validated against literature and other projects, e.g. EGTEI, IIASA RAINS)
- First model scenario runs carried out for testing the full model system, including different meteorological conditions based on source-receptor relationships for 1997, 2000, and other years

MERLIN

Universität Stuttgart
Institut für Energiewirtschaft und Rationelle Energieanwendung

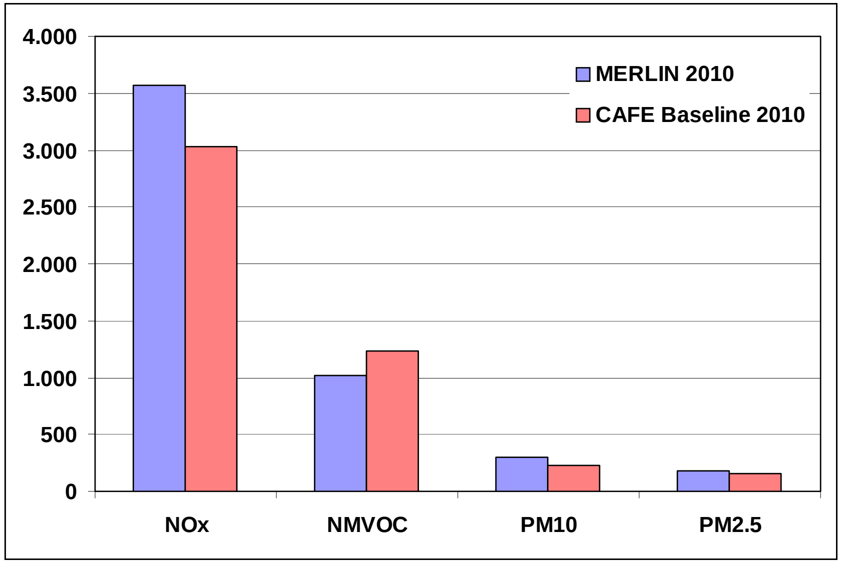
IER

Calibration/Evaluation



- Evaluation of the MERLIN transport sector for 2000, – GHG emissions vs. UNFCCC data
- R^2 over all EU Member States 0.99 for CO_2, 0.87 for CH_4 and 0.98 for N_2O

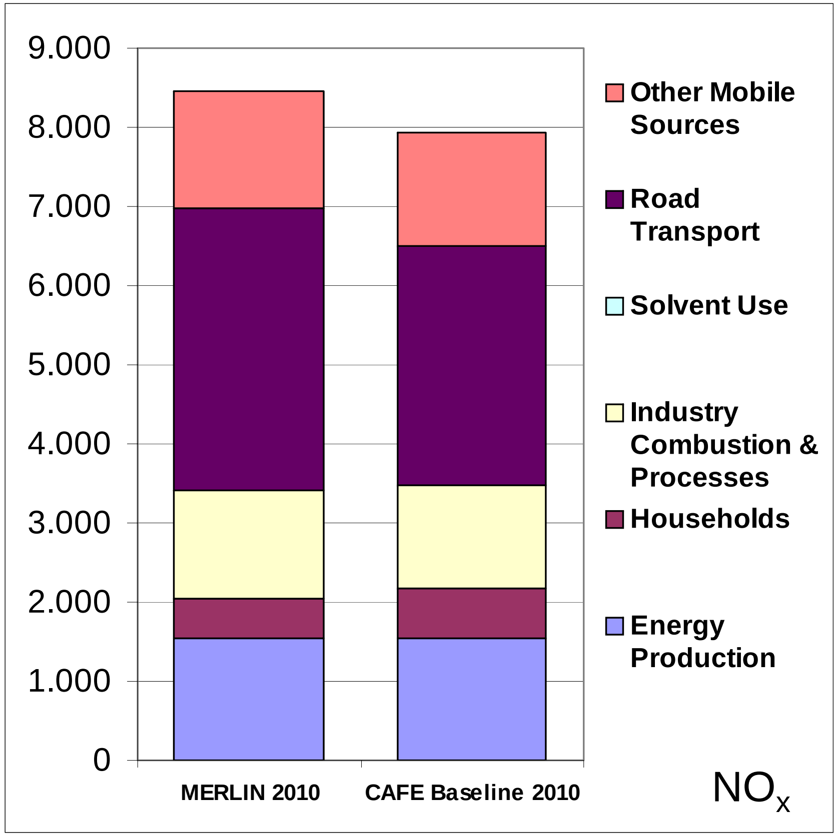
- comparison of 2010 emissions for main pollutants, MERLIN transport vs. CAFE Baseline transport sector
- R^2 over all EU Member States 0.82 for NO_x, 0.94 for NMVOC, 0.91 for PM10 and 0.90 for PM2.5
- NO_x overestimation likely due to HDV EFs update

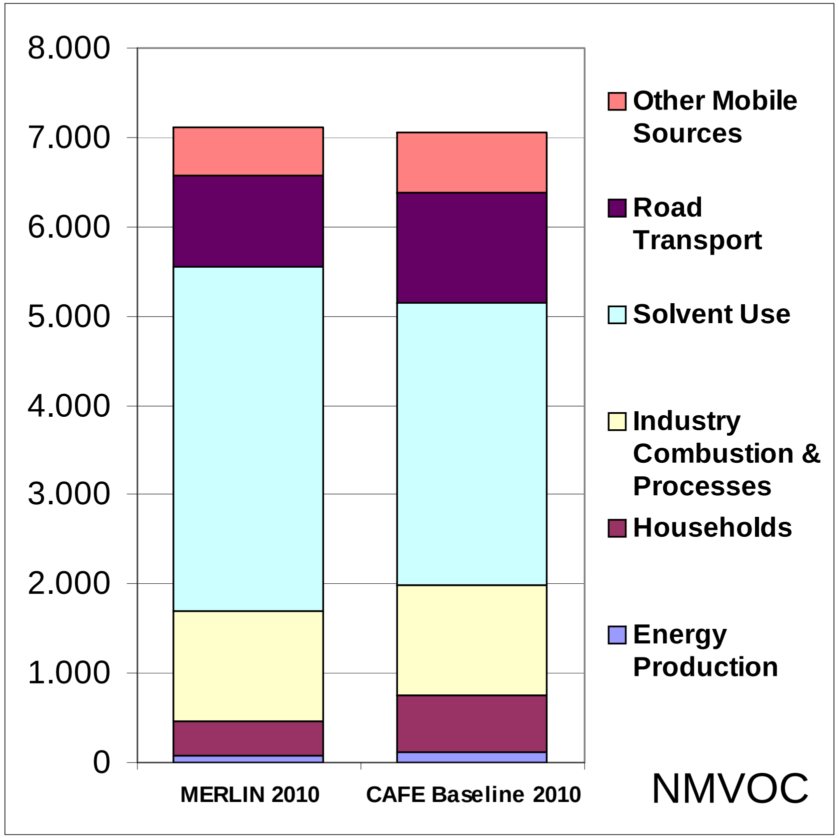


Universität Stuttgart
Institut für Energiewirtschaft und Rationelle Energieanwendung
IER

MERLIN

Emission Scenarios



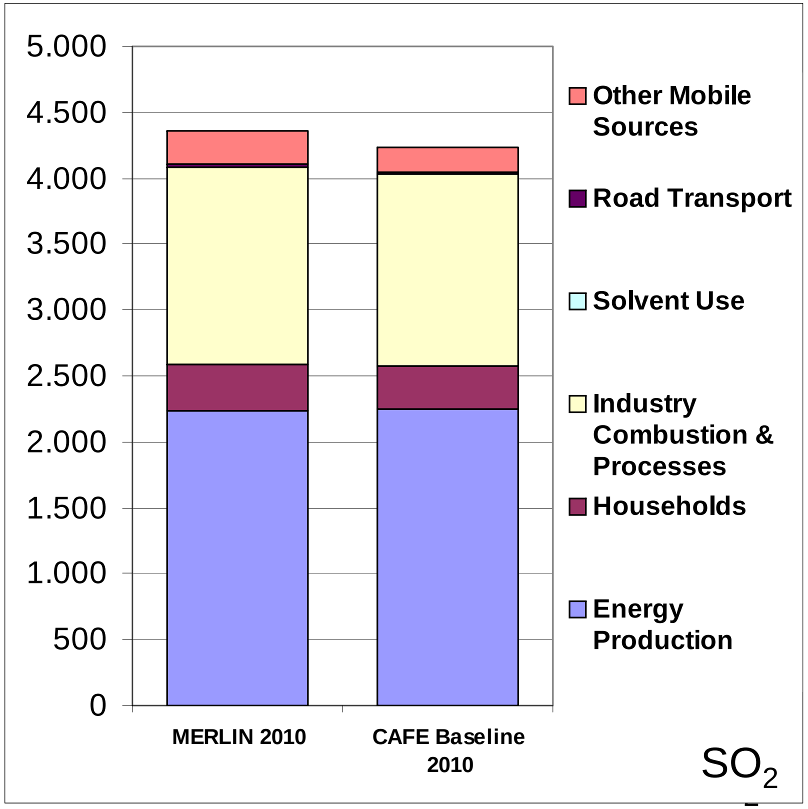


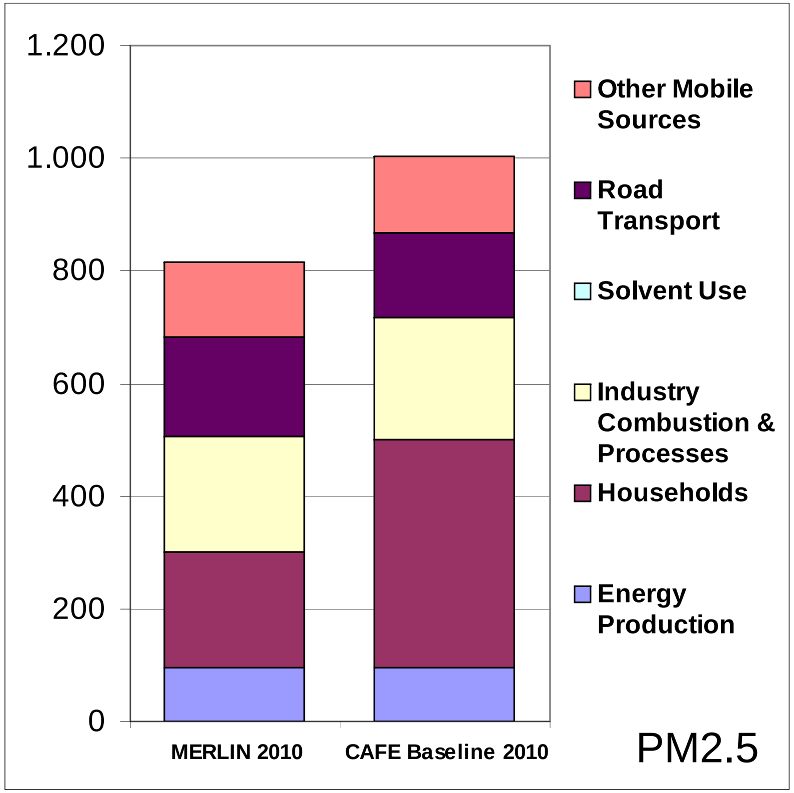
Comparison MERLIN 2010 Emissions vs CAFE Baseline (08/2004), main sectors (I)

MERLIN

Universität Stuttgart
Institut für Energiewirtschaft und Rationelle Energieanwendung
IER

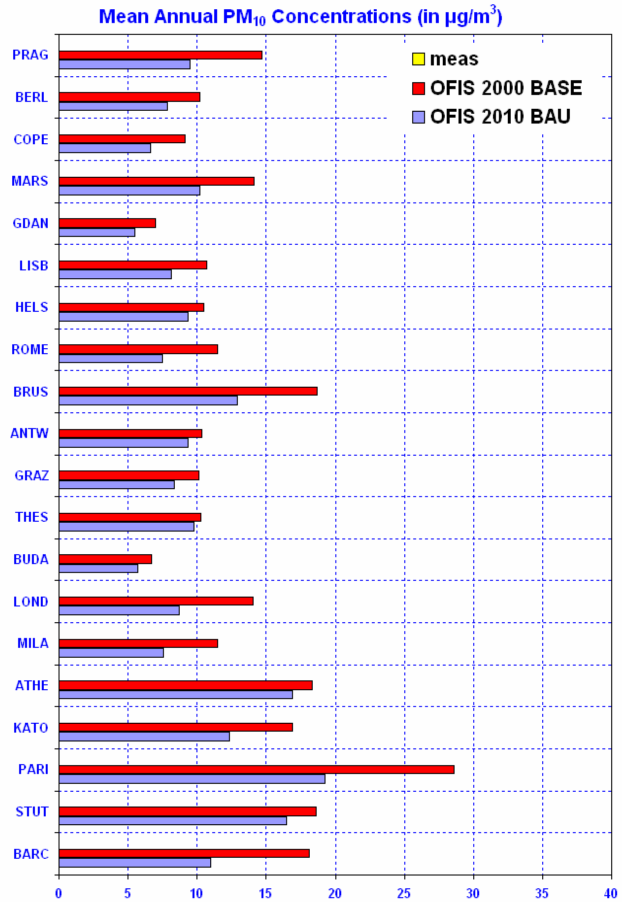
Emission Scenarios

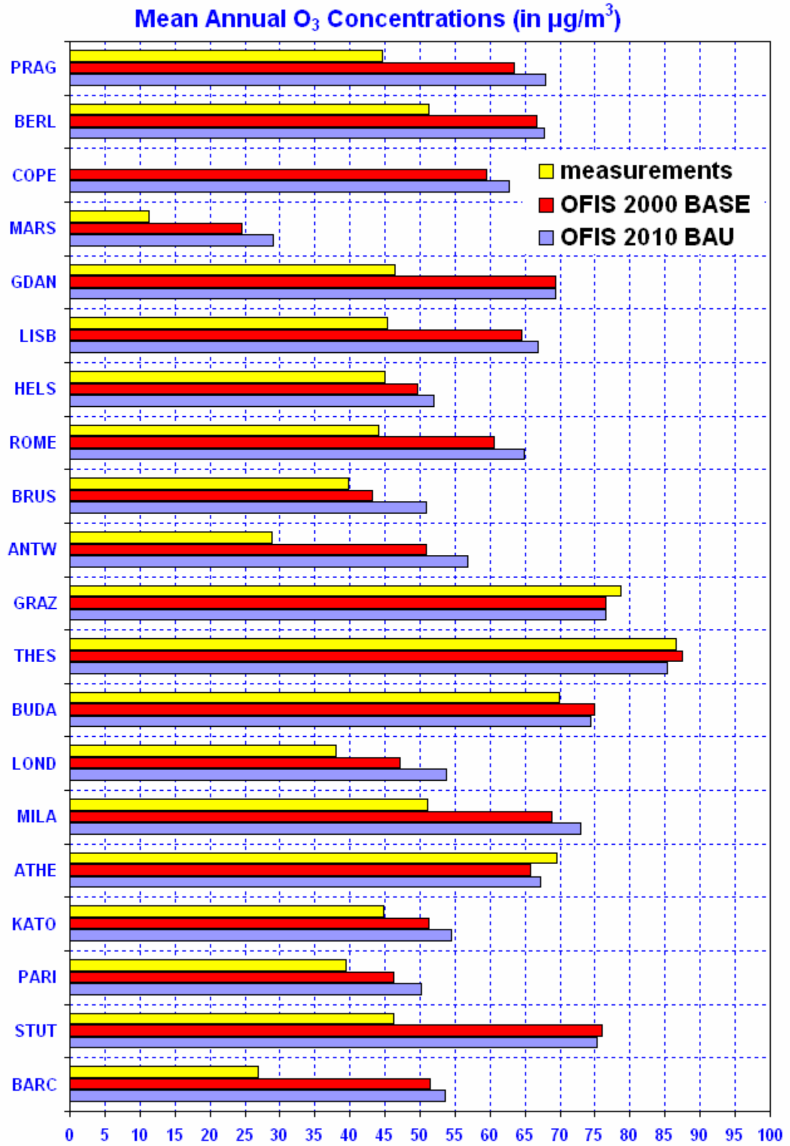




Comparison MERLIN 2010 Emissions vs CAFE Baseline (08/2004), main sectors (II)

Urban Assessment





Assessment of urban ambient air concentrations in comparison to the regional development due to emission reductions

(evaluated vs. measurements)

Impact Assessment (1): Exposure-Response-Relationships Used for Environmental Impact Assessment

Receptor	Impact	Reference	Pollutant	Factor
Adults	Chronic bronchitis *[cases per person per increase of annual mean concentration by 1 µg/m³]*	Abbey et al. 1995	PPM10[1)] Nitrates Sulfates	$4{,}9 \cdot 10^{-5}$ $2{,}5 \cdot 10^{-5}$ $4{,}9 \cdot 10^{-5}$
Entire population	Mortality due to long-term exposure *[years of life lost per person per increase of annual mean concentration by 1 µg/m³]*	Pope et al. 2002 Hurley 2004	PPM10[1)] Nitrates Sulfates	$3{,}9 \cdot 10^{-5}$ $2{,}0 \cdot 10^{-5}$ $3{,}9 \cdot 10^{-5}$

1) PPM10 : primary particles < 10 µm from anthropogenic sources

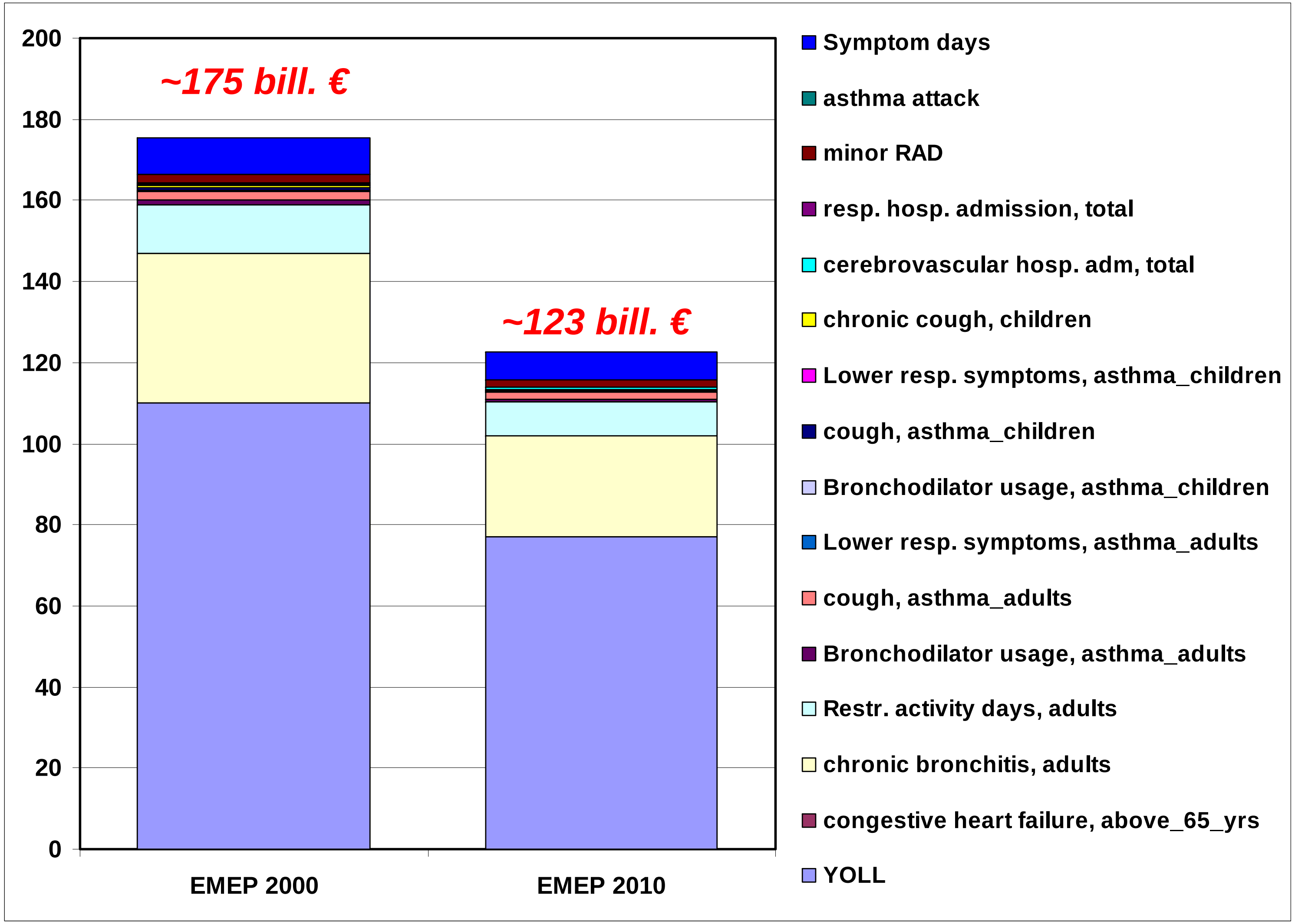
Impact Assessment (2): Human Health Effects within Europe caused by Emissions of the EU25 in 2000 *(including local damages)*

Impact	Unit	Caused by					Damage Costs [Mio €$_{2000}$]
		Sulfates	Nitrates	PM_{10}	O_3	SO_2	
Years of Life Lost (YOLL)	[1000 years]	539	741	875	16	19	110326
Congestive heart failure older 65	[1000 cases]	4	5	6	0	0	47
Chronic bronchitis, adults	[1000 cases]	54	74	88	0	0	36672
Restr. activity days, adults	[1000 days]	27330	37570	44399	0	0	12023
Bronchodilator usage, adults	[1000 cases]	6301	8662	10236	0	0	1008
Cough, asthmatics, adults	[1000 days]	12970	17820	21063	0	0	2333
Lower resp. symptoms, adults	[1000 days]	2344	3222	3807	0	0	75
Bronchodilator usage, children	[1000 cases]	750	1030	1217	0	0	120
Cough, asthmatics, children	[1000 days]	2581	3548	4193	0	0	465
Lower resp. symptoms, children	[1000 days]	995	1368	1616	0	0	32
Chronic cough, children	[1000 epis.]	572	786	929	0	0	549
Cerebrovascular hosp. Adm.	[1000 cases]	7	10	11	0	0	466
Respiratory hosp. Admission	[1000 cases]	3	4	5	13	7	136
Minor restr. activity days, adults	[1000 days]	0	0	0	20030	0	2203
Asthma attack, asthmatics	[1000 days]	0	0	0	548	0	25
Symptom days	[1000 days]	0	0	0	120400	0	9030
Total		**-**	**-**	**-**	**-**	**-**	**175509**

Impact Assessment (3): Human Health Effects within Europe caused by Emissions of the EU25 in 2010 *(including local damages)*

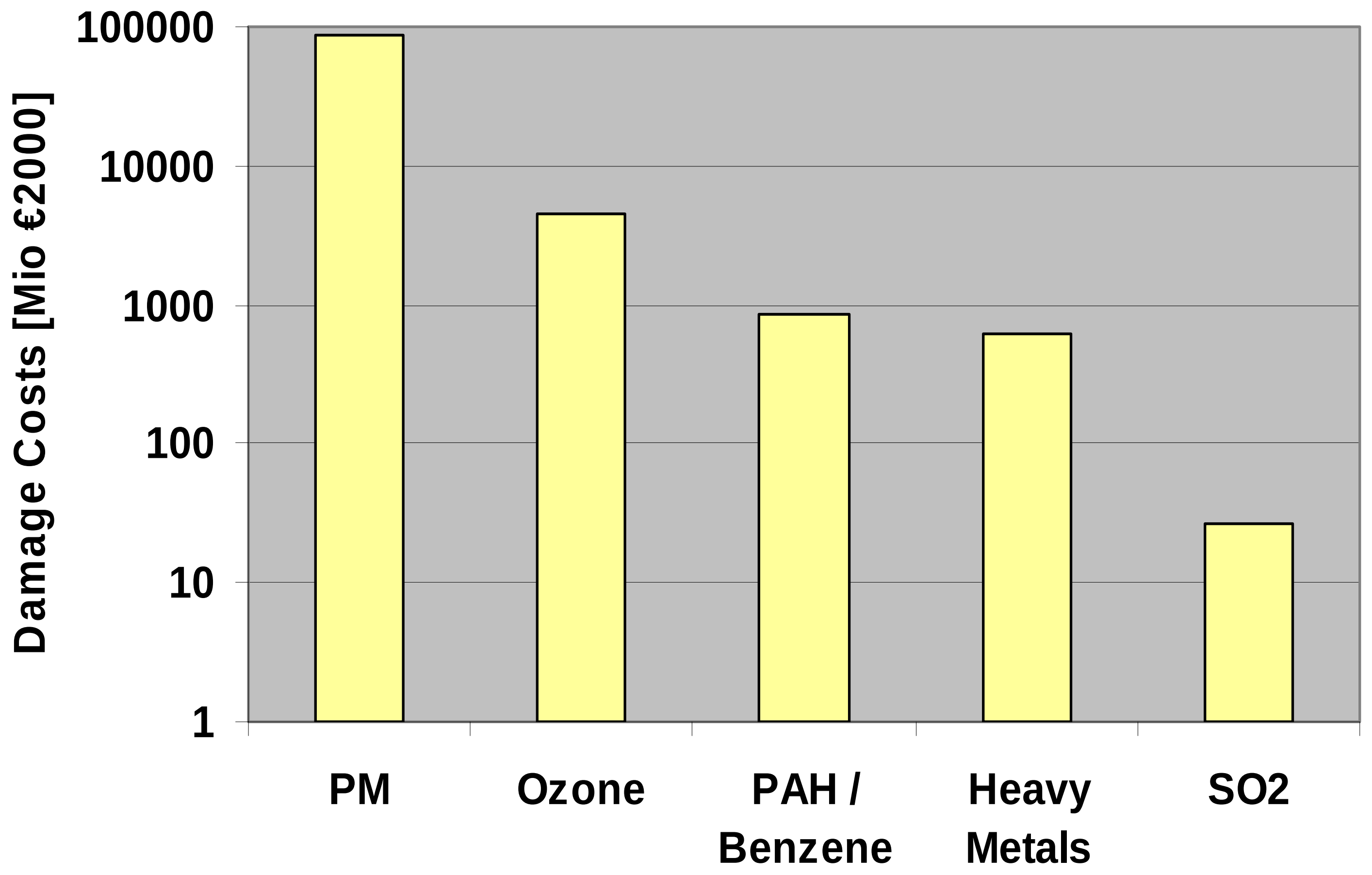
Impact	Unit	Caused by					Damage Costs [Mio $€_{2000}$]
		Sulfates	Nitrates	PM_{10}	O_3	SO_2	
Years of Life Lost (YOLL)	[1000 years]	321	579	593	13	14	76640
Congestive heart failure older 65	[1000 cases]	2	4	4	0	0	32
Chronic bronchitis, adults	[1000 cases]	32	58	60	0	0	25404
Restr. activity days, adults	[1000 days]	16260	29360	30096	0	0	8329
Bronchodilator usage, adults	[1000 cases]	3750	6768	6938	0	0	698
Cough, asthmatics, adults	[1000 days]	7715	13930	14278	0	0	1617
Lower resp. symptoms, adults	[1000 days]	1395	2518	2581	0	0	52
Bronchodilator usage, children	[1000 cases]	446	805	825	0	0	83
Cough, asthmatics, children	[1000 days]	1536	2772	2842	0	0	322
Lower resp. symptoms, children	[1000 days]	592	1069	1096	0	0	22
Chronic cough, children	[1000 epis.]	340	614	630	0	0	380
Cerebrovascular hosp. Adm.	[1000 cases]	4	7	8	0	0	323
Respiratory hosp. Admission	[1000 cases]	2	3	3	10	5	101
Minor restr. activity days, adults	[1000 days]	0	0	0	15700	0	1727
Asthma attack, asthmatics	[1000 days]	0	0	0	429	0	19
Symptom days	[1000 days]	0	0	0	94370	0	7078
Total		-	-	-	-	-	**122827**

Change of damage costs from EMEP 2000 to EMEP 2010: approx. -53 bill. €



Impact Assessment (4) :Assessment of Health Impacts due to Emissions in EU 25– for 2000 and 2010 baseline *(estimates, including local damages)*

Impact Assessment (5): Health Damage Costs from Air Pollution in the EU-15 2000



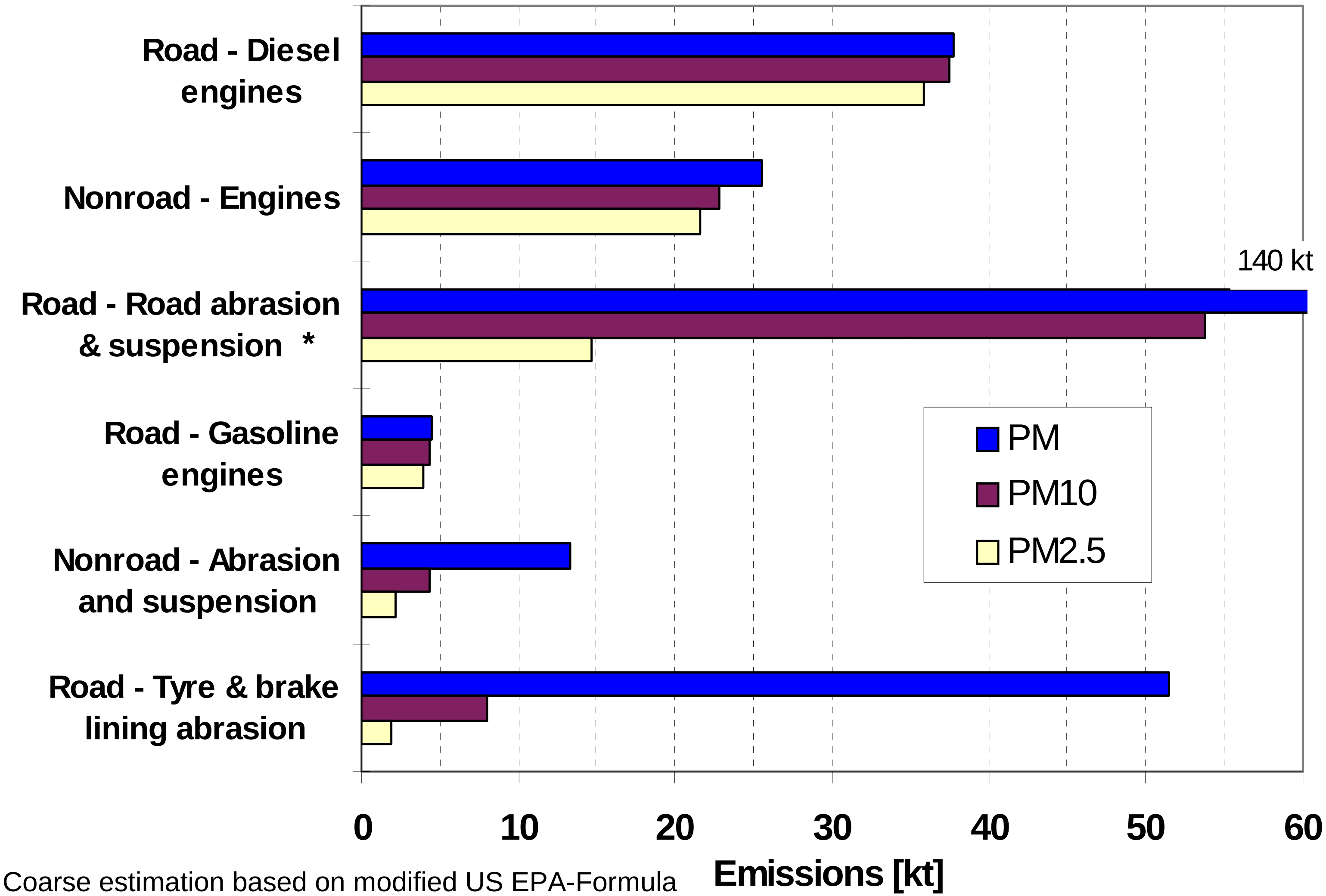
For more information:

http://www.ExternE.info

For own rough estimations of damage costs due to (not to large) changes of emissions of air pollutants you may use the internet-based tool

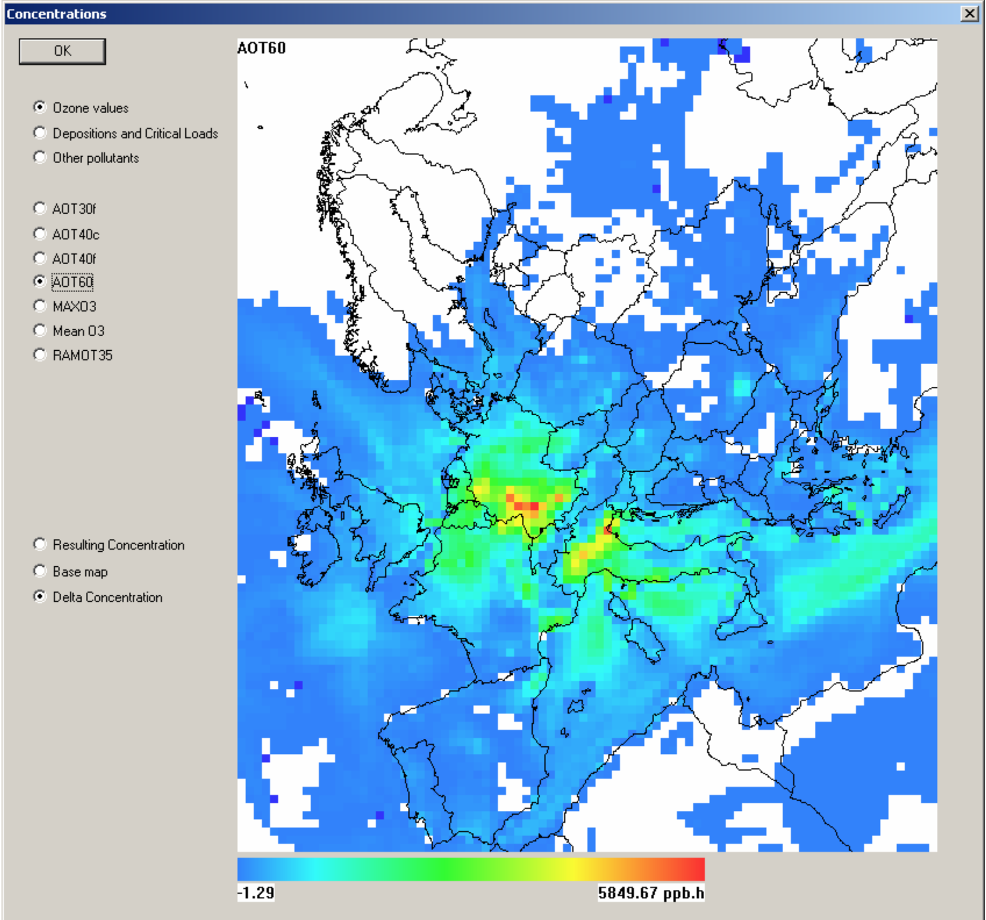
ECOSENSELE

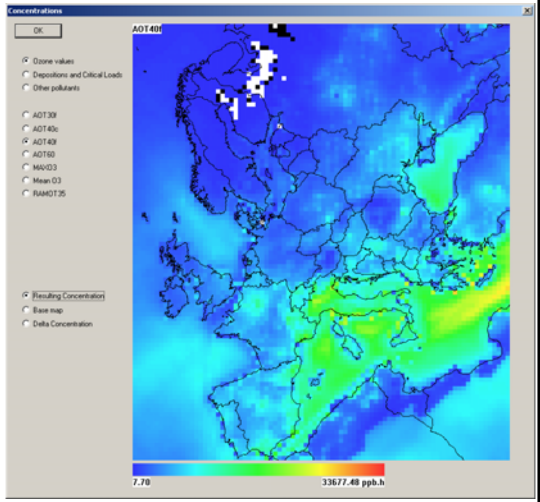
Particulate Matter Emissions from Transport in Germany 2000



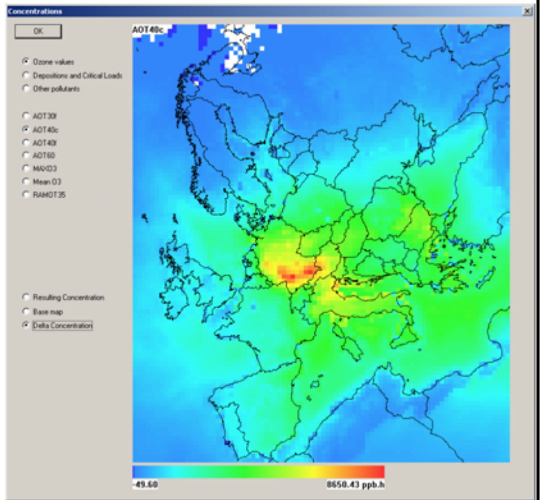
* Coarse estimation based on modified US EPA-Formula

Model results (1) : Ozone maps for a health-related strategy aiming at compliance with 0 ppb.h exceedance of AOT60





ΔAOT40f



ΔAOT40c

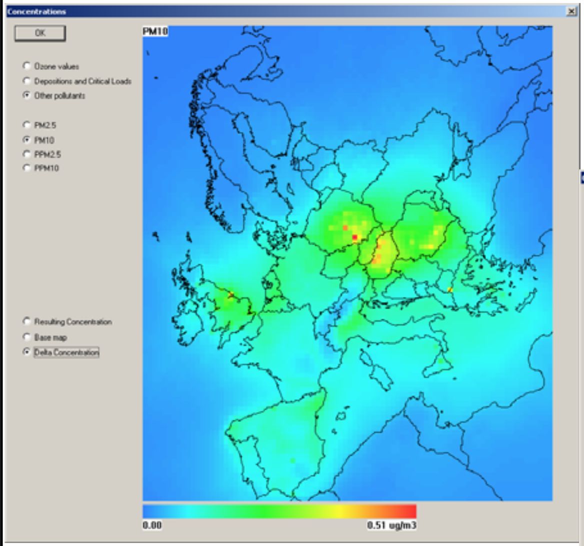
ΔAOT60 for a health-oriented Ozone scenario

Exceedance of AOT 60:

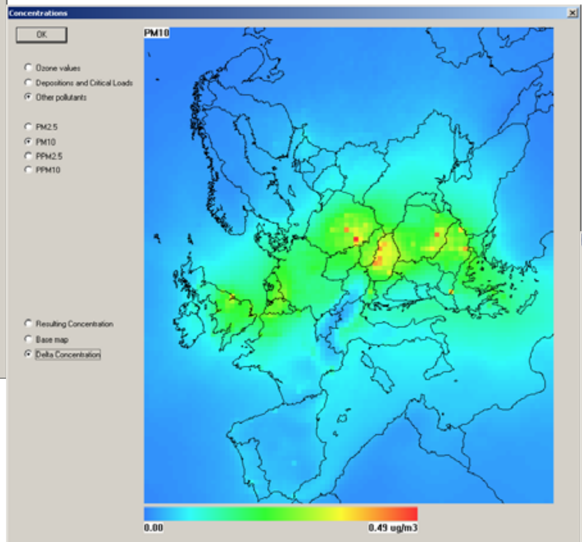
base case 2010: 64 %, health impact scenario: 25% of grid cells

Total costs: 92 billion €, emission reduction 2.97 Mt of NO_x, 2.51 Mt NMVOC

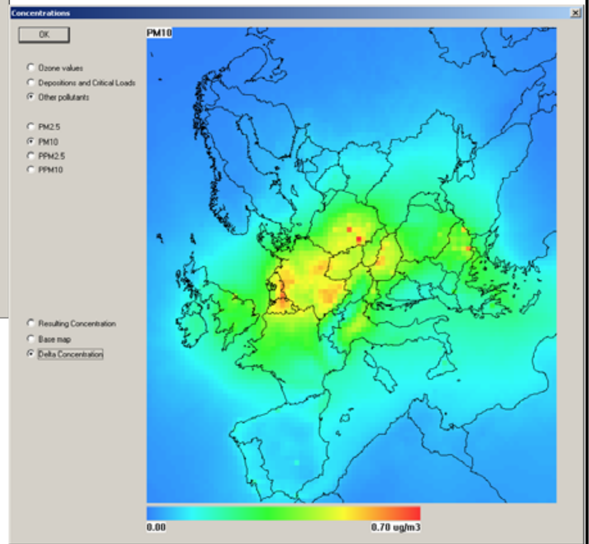
Model results (2) : changes in PM10 concentrations related to different emission reductions of primary particle (PPM10) emissions in the EU25



-20%



-30%



-40%

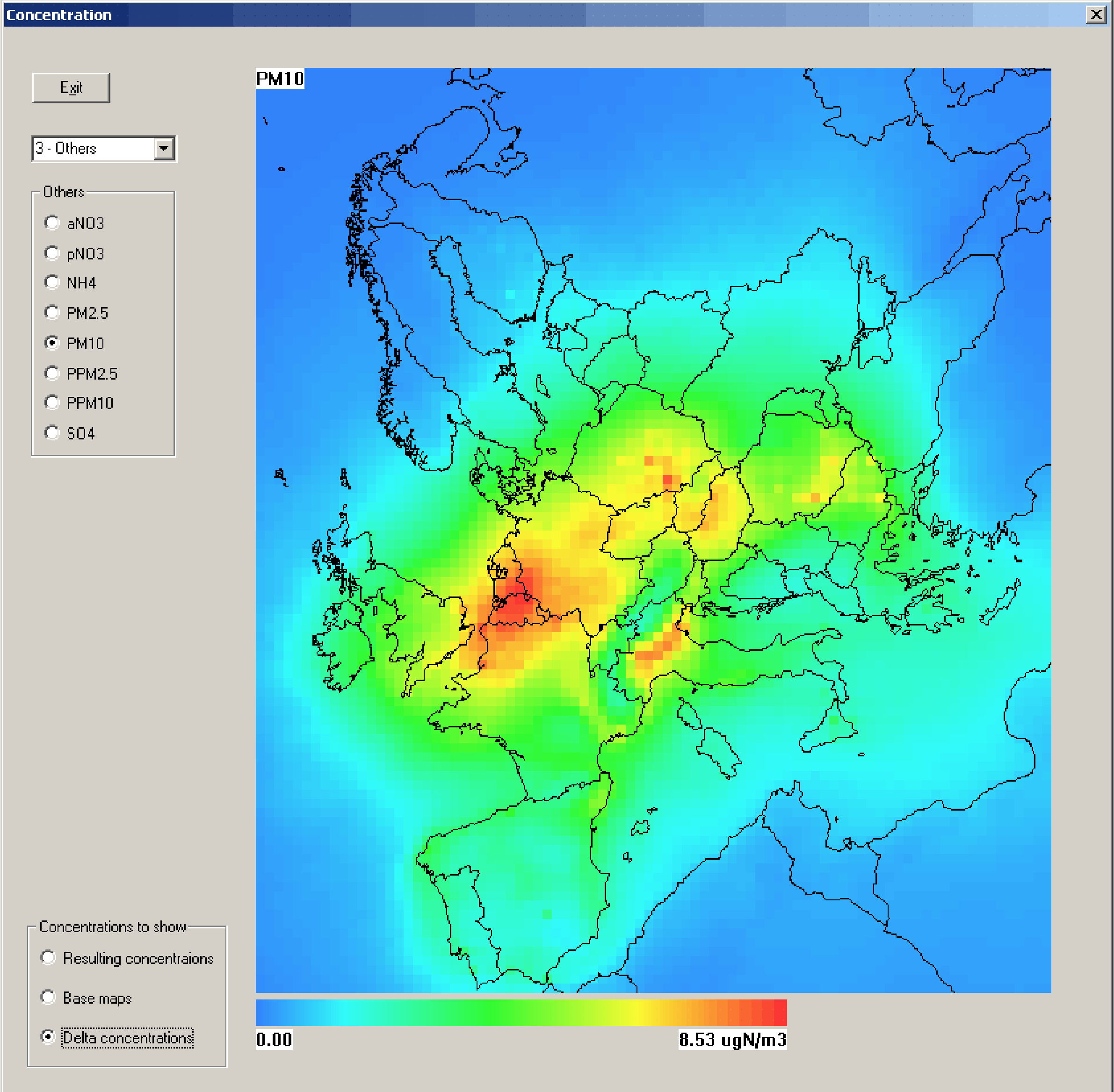
Different emission targets for PM10 have been set to analyse the algorithms selection of abatement measures; depending on measure selection, spatial patterns and height of emission varies significantly. Forthcoming model runs will analyse specific sector influence on emission reductions using sector-specific source-receptor matrices taking into account emission heights and their influence on concentration changes.

MERLIN

Universität Stuttgart
Institut für Energiewirtschaft und Rationelle Energieanwendung
IER

Model results (3): PM10

ΔPM10 concentrations (1997 meteo) for a reduction of ~38% of road transport PM10 emissions in the EU25 countries



Model results (4): PM10

AIR POLLUTION - RESULTS HUMAN HEALTH [bill. €]:

Case	Damaging substance	Mortality		Morbidity		Total (Rounded)
		Inside EU-25	Outside EU-25	Inside EU-25	Outside EU-25	
-25% PM10	health benefits -PM10	3,4	0,3	1,6	0,1	5,4
	abatement costs					3,0
-40% PM10	health benefits - PM10	12,2	0,9	5,9	0,4	19,5
	abatement costs					20,1
-50% PM10	health benefits - PM10	19,7	1,5	9,6	0,7	31,5
	abatement costs					49,4

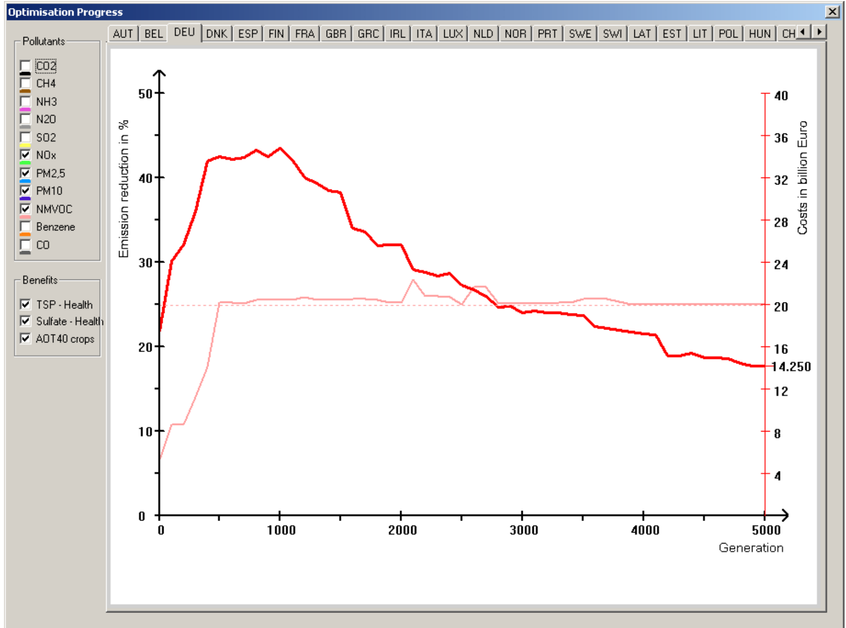
Comparison of benefits (as reduced damage costs) and abatement costs

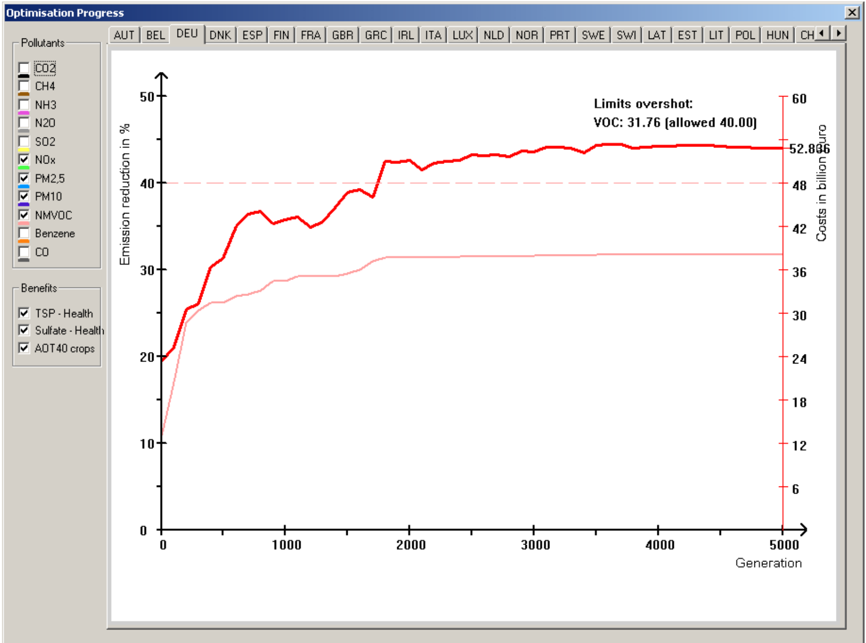
- **sector:** road transport
- **target:** road transport PM10 reduction by 25%, 40% and 50% below 2010 BAU
- ***main measures:***
  - *FAP (with Siliconcarbid-Filter)*
  - *DPX Catalyzed Particulate Filter*
  - *Catalysed Diesel Particulate Filter + fuel born catalyst*
  - *CRT (Continuously Regenerating Technology) on PC, LDV and HDV diesel*

MERLIN

Model results (5): Case study NMVOC from Solvent Use

- **CEA for a 40% (below) and 25% (right) reduction of NMVOC emissions from Solvent Use, optimisation result for Germany (emission reduction in the EU25)**
- **40% reduction cannot be achieved on top of 2010 BAU in Germany, 25% possible**





- **MFR for Germany ~31.8% reduction, overall costs ~52 bill. € for EU25 (i.e. all EU countries!)**

Model results (6): Case study NMVOC from Solvent Use

• **List of abatement measures identified in the 25% reduction case for Germany:**

ref-solv-1	no primary measure, incinerator on drying oven
ref-solv-5	high solid topcoat, very high solid surfacer, HVLP-application for primer and surfacer, improved pneumatic aoolication for top coats, no secondary measure
ref-solv-6	application of 100 % water-based coatings, no secondary measure
ref-solv-7	application of 100 % water-based coatings, no secondary measure
ref-solv-9	medium solvent coating systems with airless,electrostatic,roller coating,curtain coating,dipping, no secondary measure
ref-solv-11	no primary measure and retrofit of open circuit machine with activated carbon adsorption or condensation unit
ref-solv-13	production of 90 % vulcanised rubber, 10 % thermoplastic rubber, use of 10% solvent-based adhesives, coatings, inks, and cleaning systems (60-wt% solvent content), 90 % non solvent-based adhesives, coatings, inks and cleaning systems (10 wt-% solvent cont
ref-solv-16	production mix: 80 % low solvent based coatings (10 wt.-% average solvent content), 10 % high solvent-based coatings (40 wt.-% solvent content), 10 % other paints, no secondary measure
ref-solv-17	Production mix: 10 % high solvent-based glues (65% wt.-%solvent content), 90 % low solvent-based glues (5 wt.-% solvent content), no secondary measure
ref-solv-19	high solvent inks (60-wt-% solvent content), catalytic or thermal incineration
ref-solv-20	Radiation-curing inks (solvent free) and reduced consumption of isopropanol for impregnation and vegetable oil-based cleaning agents, no secondary measure
ref-solv-21	water-based inks (10wt-% solvent content), no secondary measure
ref-solv-22	UV-curing inks (solvent-free), no secondary measure
ref-solv-23	Process optimisation(better control of deviations from normal operating conditions, avoiding of start ups and shut downs, ...) and Schumacher type desolventiser-toaster-dryer-cooler, no secondary measure
ref-solv-25	15 % conventional high-solvent adhesives (60 wt-% solvent content), 55 % water based adhesives (2 wt-% solvent content), 30 % solvent free adhesives, no secondary measure
ref-solv-26	55 % water based adhesives (2 wt-% solvent content), 45 % solvent free adhesives, no secondary measure
ref-solv-27	70 % water-based preservatives (1 wt-% solvent content), 20 % solvent based preservatives (90 wt-% solvent content), 10 % creosote preservatives (20 wt-% solvent content), plus improved application technique (double vacuum impregnation system) and enclos
ref-solv-28	Use 100 % water-based products (10 wt-% solvent content), no secondary measure
ref-solv-33	substitution of aerosols with compressed gases (e.g. CO2, N2O, N2, etc.), application of pump mechanism and application of alternative products ("not-in-kind-alternatives") (e.g. Roll-on-products, cream, powder, soaps etc.)

Efficient air pollution control measures in health protection scenarios (I)

Energy and Industry

Optimisation and improvement of bag houses
Optimisation and improvement of electrostatic precipitators
multicyclons
Substition of coal and heavy fuel oil with natural gas

Selective Catalytic Reduction, where not yet implemented
Improved primary measures (LowNox + over fire air)
Wet scrubbing, where not yet used (secondary aerosol red.)
Leak detection and repair programs (Refineries, fugitive)

Households

Substitution of coal and wood with light fuel oil and gas
State of the art stoves
Energy saving (if CO2 reduction is included in target)

Efficient air pollution control measures in health protection scenarios (II)

Transport

-Particulate filters in existing and new off-road vehicles (construction machinery, tractors,..)
-Retrofitting particulate filters for diesel engines
-Particulate filters with new diesel engines
-CSCR (Compact Selective Catalytic Reduction) in HDV
-Switch to CNG (compressed natural gas) engines
-City toll in large cities

-Reduction of break and tyre wear (?),
-Reduction of road abrasion (??)

-Reduction of specific fuel consumption resp. CO_2-emission and /or higher taxes proportional to emissions (and noise)

Efficient air pollution control measures in health protection scenarios (III)

Solvent Use
-Substitution of solvents in sprays
Emission reduction in
-Offset printing (less isopropanol, high boiling point cleaners)
-Degreasing processes
-Paint application in mechanical engineering branch
-Production of solvent based goods
-Paint application – wood (carpenter)

Agriculture (reduction of secondary aerosols)
-Cover of manure storage
-Improved slurry application technique (slurry injection, band spreading)

Next steps:

Short term *(within MERLIN)*:

- continue validation of data on measures and costs
- continue testing of the model
- carry out a larger number of scenario runs with diferent targets
- sensitivity analysis
- estimation of macroeconomic impacts

Long term *(within further running research projects)*:

- further measures,
- hemispheric transport,
- water and soil model (multimedia),
- heavy metals,
- improved nesting with urban models
- assessment of biodiversity change and land use change

Further long term aims: exposure modelling, inclusion of indoor pollution, POP‘s