Environmental Health Impacts of European Policies for Mitigation of and Adaptation to Climate Change – a Case Study for Integrated Health Assessment Using the INTARESE/HEIMTSA Methodology

USTUTT, THL, CERTH, JRC, TNO, IOM, UBath, CUEC, ENPC, RIVM, IC, NILU, ETH-Z, UM-ICIS, INERIS, met.no, MSC-East, UU,

Mega Case Study Overview

- **Aim: to demonstrate the application of the INTARESE/HEIMTSA methodology for integrated environmental health impact assessment by carrying out an assessment of environmental health impacts of high-level, cross-cutting policy issues at EU level**
- **Main Tasks:**

Issue Framing → Design → Execution → Appraisal

Issue Framing:

Main criteria for selecting policies and measures for mitigation of and adaptation to climate change:

- **reduction of CO2eq. emissions (mitigation)**
- **reduction of climate change impacts (adaptation)**
- **costs and distribution of costs (who pays how much)**

However:

Relevant side benefits or side detriments might exist, especially secondary environmental health impacts.

Examples: production and burning of biomass, renewables and nuclear instead of coal and gas for electricity production, lower air exchange rate indoors, wood stoves indoors…

These side effects should be taken into account, if relevant!

The Policy Question:

What are the (negative or positive) impacts of

a) EU mitigation options (policies and resulting measures) to reduce greenhouse gas emissions

b) EU adaptation options (policies and resulting measures) to reduce impacts of climate change

on human health worldwide?

Scoping:

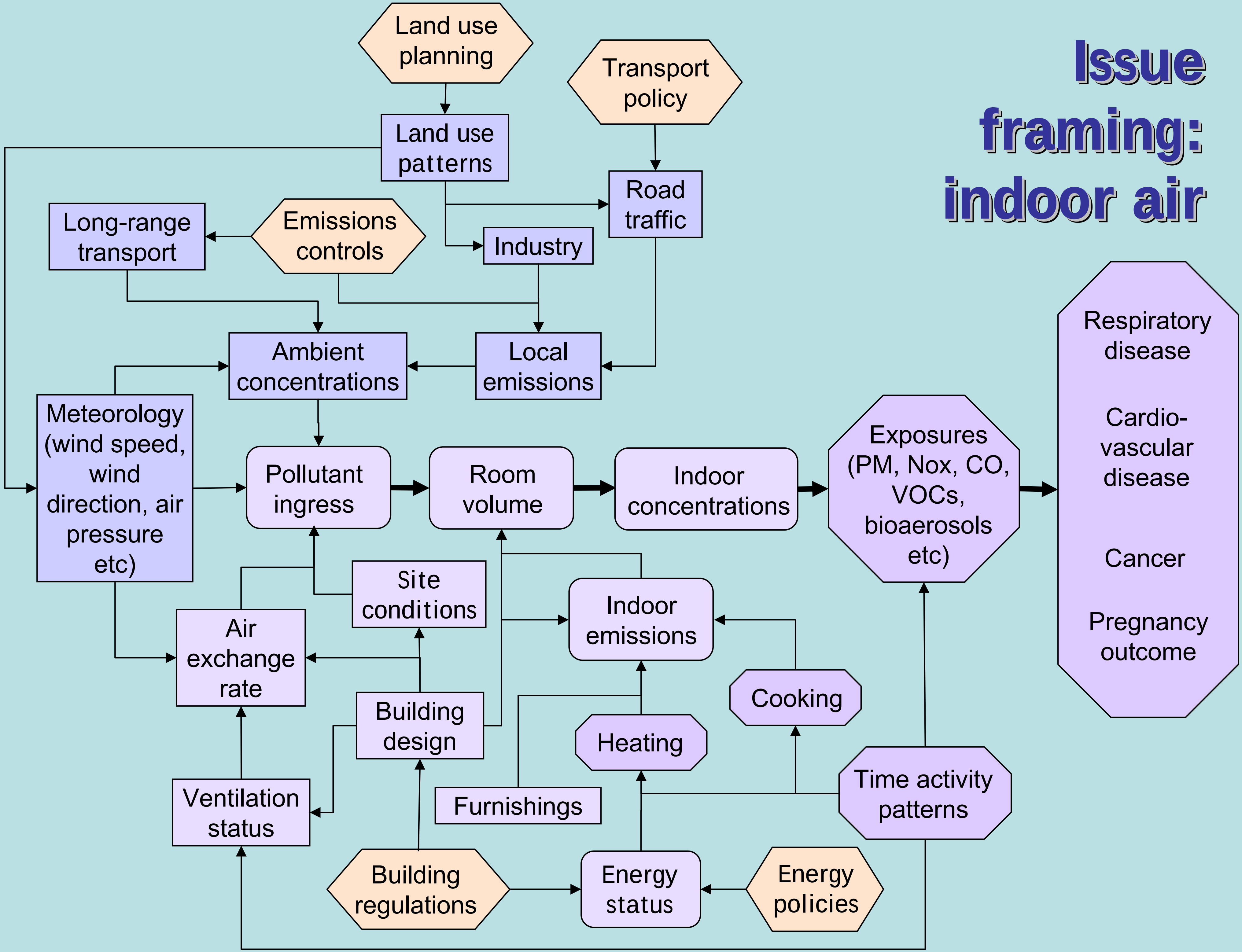
- **Methods used:**

Systematic collection of policies and measures for mitigation of greenhouse gases and adaptation to climate change; use of EU and national programs and studies

Brainstorming about the relevant health impacts occuring when implementing these options and the relevant impact pathways

Documentation of these pathways and the relation between them in causal diagrams

Issue framing: indoor air



Screening

- Estimation of the importance (order of magnitude) of health impacts from a stressor by

a) a quantitative health impact assessment with simplified methods and models and rough assumptions or

b) a qualitative expert judgment or semi-quantitative analysis of the importance of an issue

Example for Screening Results

- **Energy Policies (mDALYs / t CO_2 avoided):**
  i. **Electricity production with more wind replacing coal : - 0.4**
  ii. **Coal fired plants with CCS: -0.1**
- **Transport Policies (mDALYs / t CO_2 avoided):**
  i. **Electric cars : -0,2**
  ii. **City toll in all European metropolitan areas -0,1**

An increase of DALYs is expected for

biomass use: e.g. wood in small furnaces

better insulation of houses (increase of mould, env. tobacco smoke, radon conc.)

1 mDALY = one thousendths of a DALY; 1 DALY = 1 disability adjusted life year

Policies and Measures Included in the Climate Scenario

- Energy supply: more wind, biomass (incl. wood stoves), natural gas, solar, nuclear, CHP (combined heat and power), CCS (carbon capture and storage)
- Energy demand: more insulation, heat pumps, changed industry processes, light cars, tyres, fuel efficient engine oil, more air conditioning…
- Transport: more electric, biofuels, hybrid; enhanced public transport and bicycle use; speed limits; fuel taxes, city tolls, road pricing;
- Agriculture: production of energy crops, reduced consumption of red meat (beef) and milk products;
- City development: greener areas and albedo change

Main activity areas:

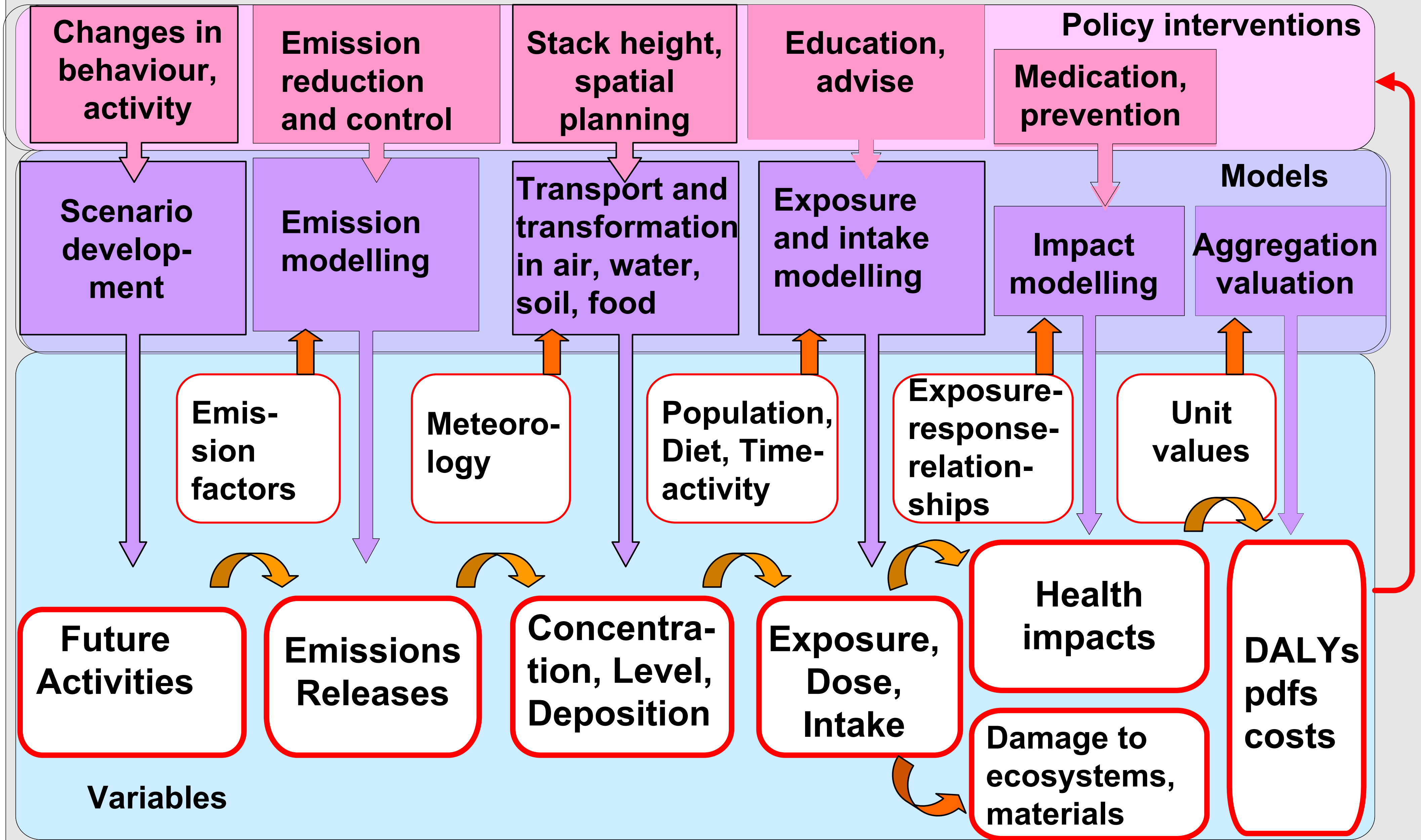
- Energy supply and demand
- Transport
- Agriculture
- Waste
- Buildings and Urban Development

Main Pressures causing env. health impacts:

PM10, PM2.5, incl. secondary PMx, ozone, noise, pesticides, PCBs, dioxins/furanes, heat;

indoor: PM2.5, PM10, ETS, radon, mould, formaldehyde

The Full Chain Approach



Step 1: Scenario development

A scenario is the description of a possible, consistent future development of a system (e.g. energy/transport/agriculture/waste system)

'Business as usual' or reference scenario:

Activities and emission factors follow trend and include agreed policies, however no climate change mitigation measures after 2012;

Some adaptation measures included;

GHG emissions and climate change according to IPCC A1B scenario

Step 1: Scenario development

450 ppm or 2° scenario:

Embedded in a worldwide emission scenario aiming at not exceeding 2° temperature increase:

Reduction of EU GHG emissions by 20% 1990-2020 and 71% 1990-2050

Climate according to IPCC B1

Constraints:

Share of renewable energy on final energy consumption > 20% 2020, > 40% 2050

At least 10% biofuels in transport fuels 2020

Minimum market shares for electric and hybrid cars

Continuation of national policies of subsidizing renewable energies (e.g. PV)

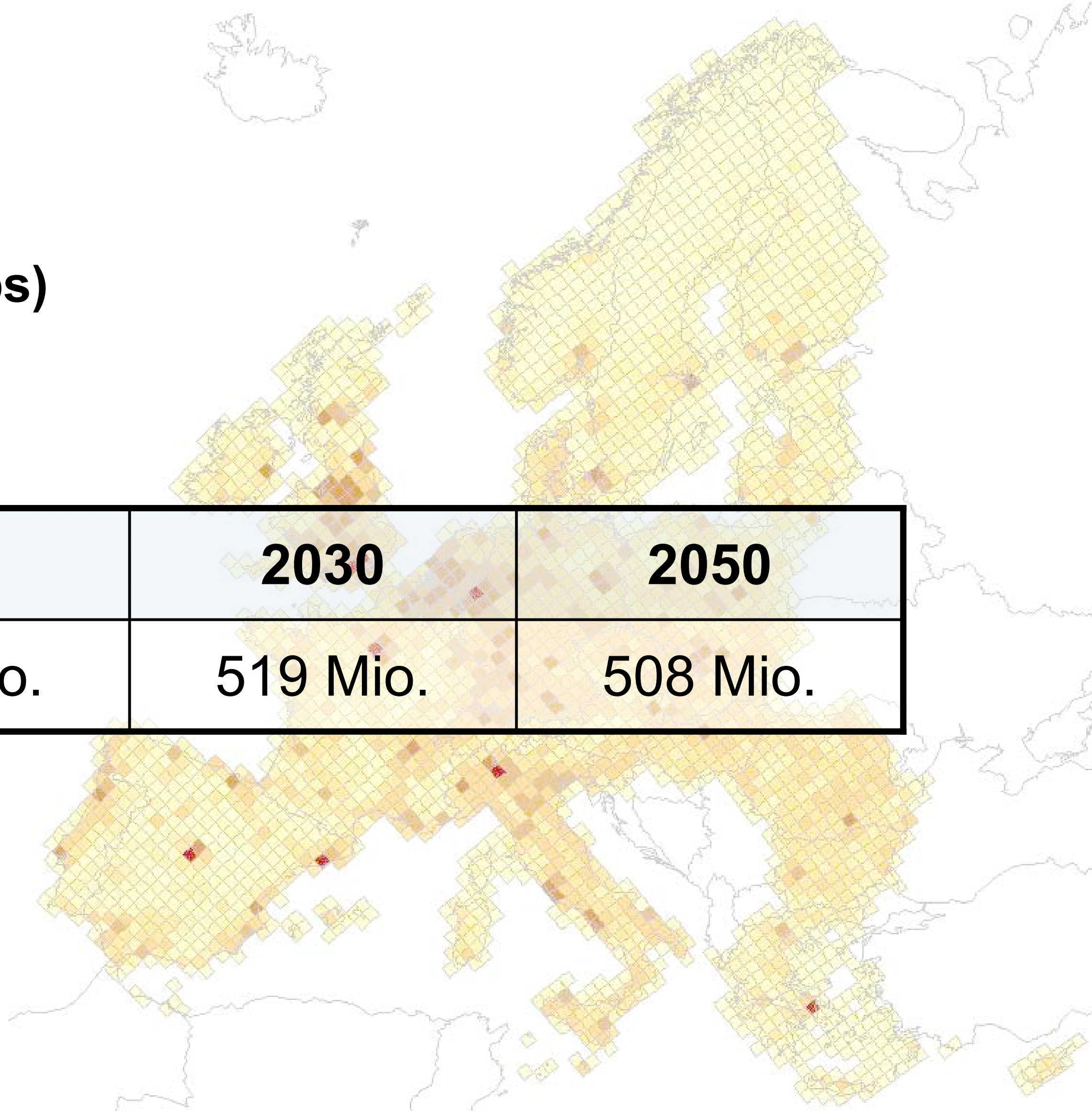
Emission trading system continues: -31.5 % 2005-2020, then -1.74 % p.a.

General assumptions

	2005	2030	2050
GDP [10^{12} $€_{2007}$]	11,7	17,8	24,4
GDP	Average annual growth 2010 - 2050: 1.7%, Regional differences among countries		
Oil price [$US\$_{2007}$/bbl]	78	100	109
Other assumptions	- additional nuclear power in countries according to current national policy		

Population data (EU 30)

Available
- **per country / EMEP grid cell,**
- **per subgroup (5 year age groups and ERF-needed groups)**
- **per CCS year**



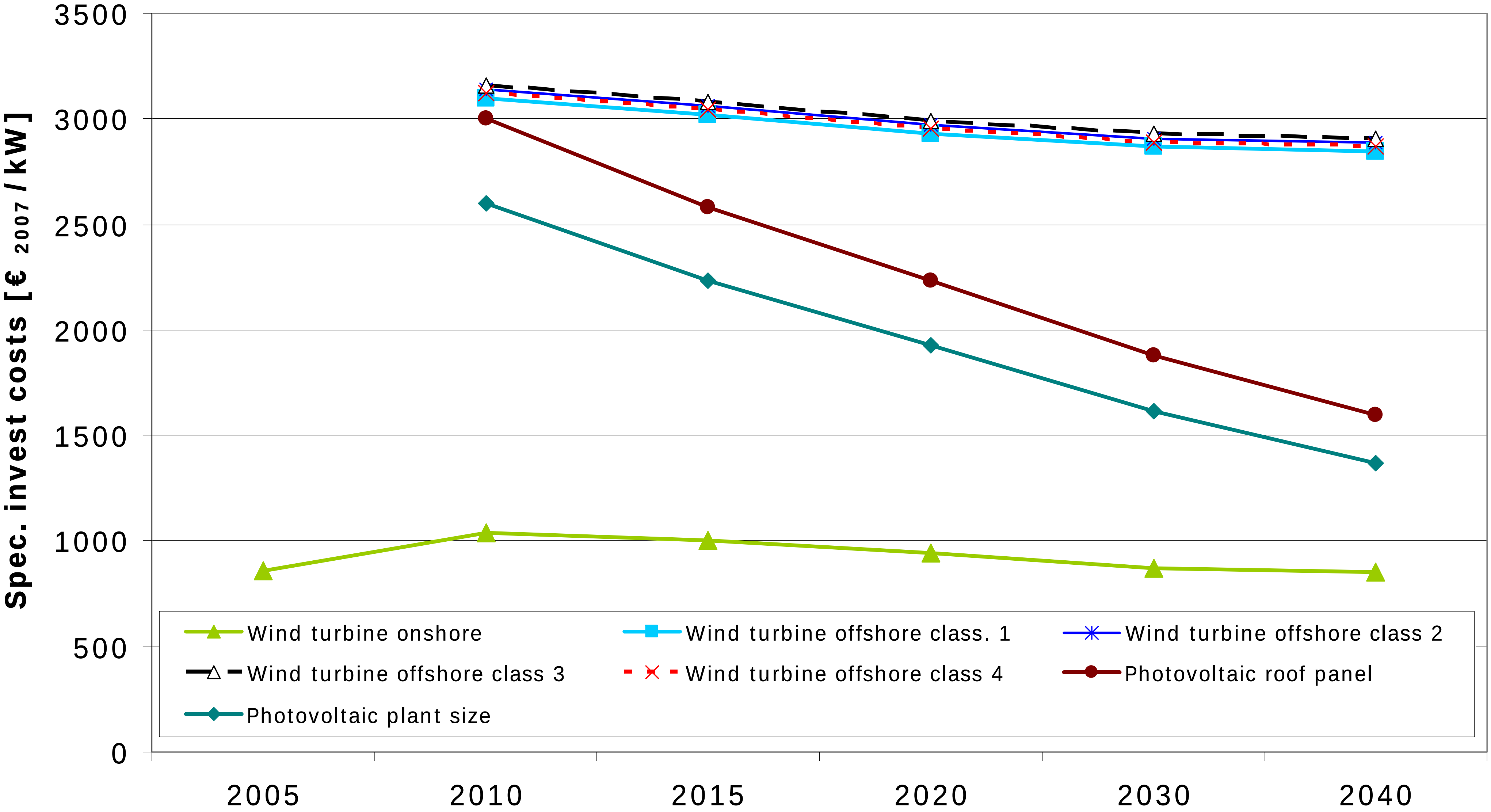
2010	2020	2030	2050
510 Mio.	518 Mio.	519 Mio.	508 Mio.

Number of buildings and living space of households, transport demand for EU 25

Year	Number of buildings	Number of dwellings	Living space of dwellings
2005	114.9 Mio.	197.9 Mio.	15,856 Mio. m^2
2020	147.2 Mio.	260.2 Mio.	20,502 Mio. m^2
2030	154.4 Mio.	273.6 Mio.	22,041 Mio. m^2
2050	152.0 Mio.	259.8 Mio.	22,320 Mio. m^2

		2005	2030	2050
Passenger transport	Billion pkm	5826	6742	6914
Freight transport	Billion tkm	2538	3745	4117

Invest costs of new renewable power plants in TIMES PanEU (excerpt)



Scenario generation:

- **Energy supply:**

  Minimizing energy service supply costs while observing constraints (e.g. maximum CO2 emissions): use of TIMES

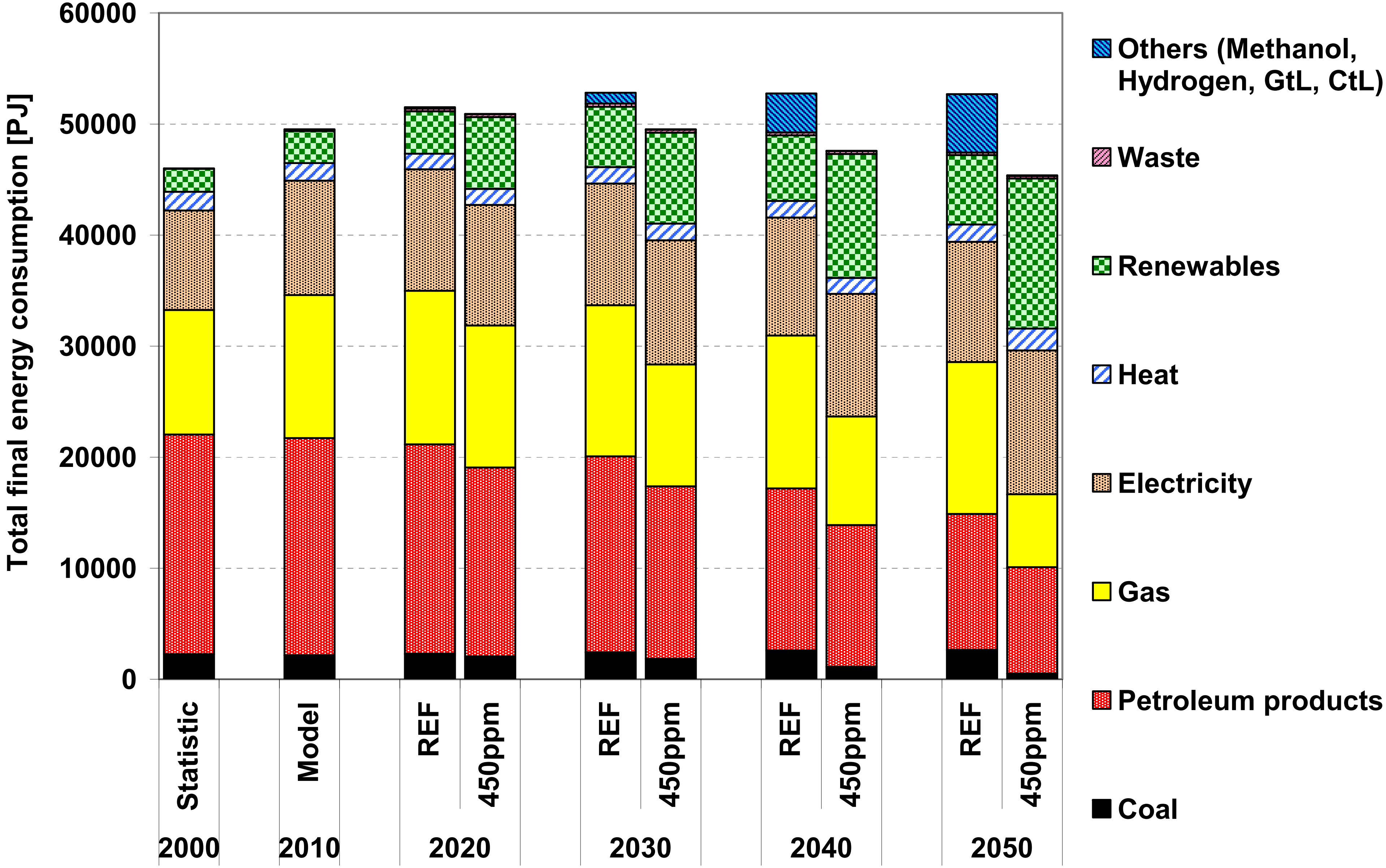
- **Transport:**

  Simulation using a stock-activity-emission factor data base, partly data from TREMOVE

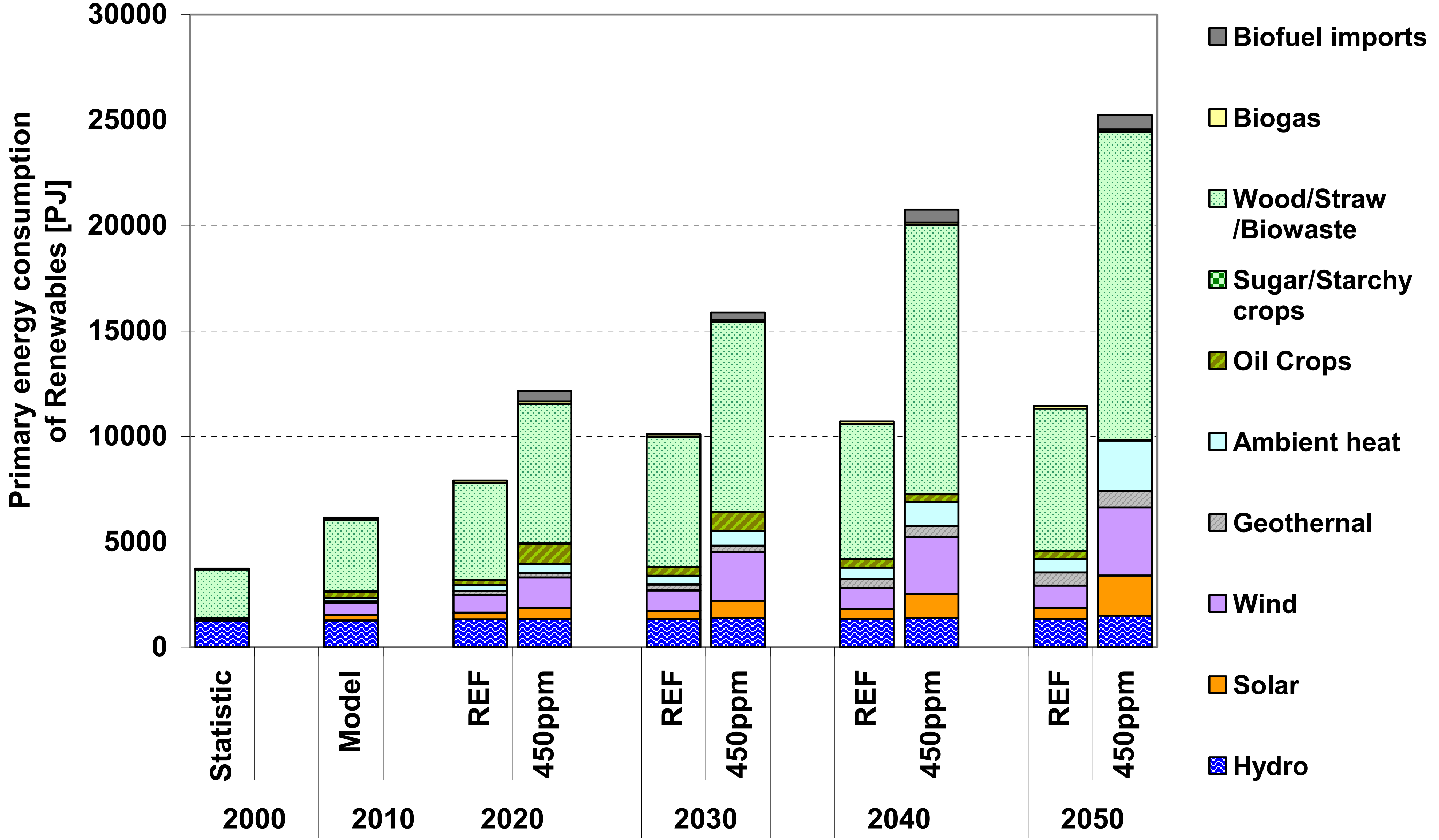
- **Agriculture:**

  use of scenarios from the IMAGE model for food production,

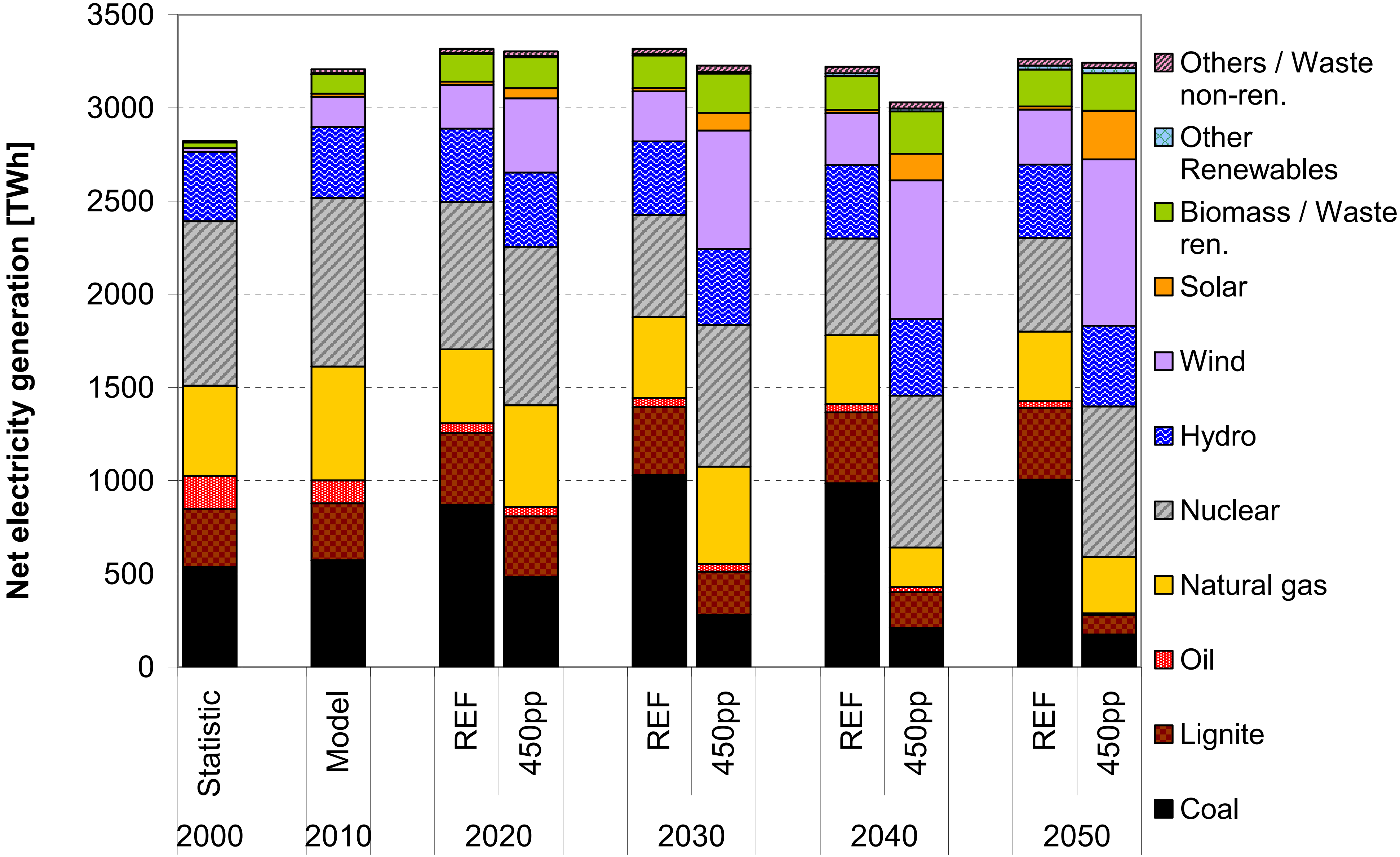
Final energy consumption by fuel (EU27)



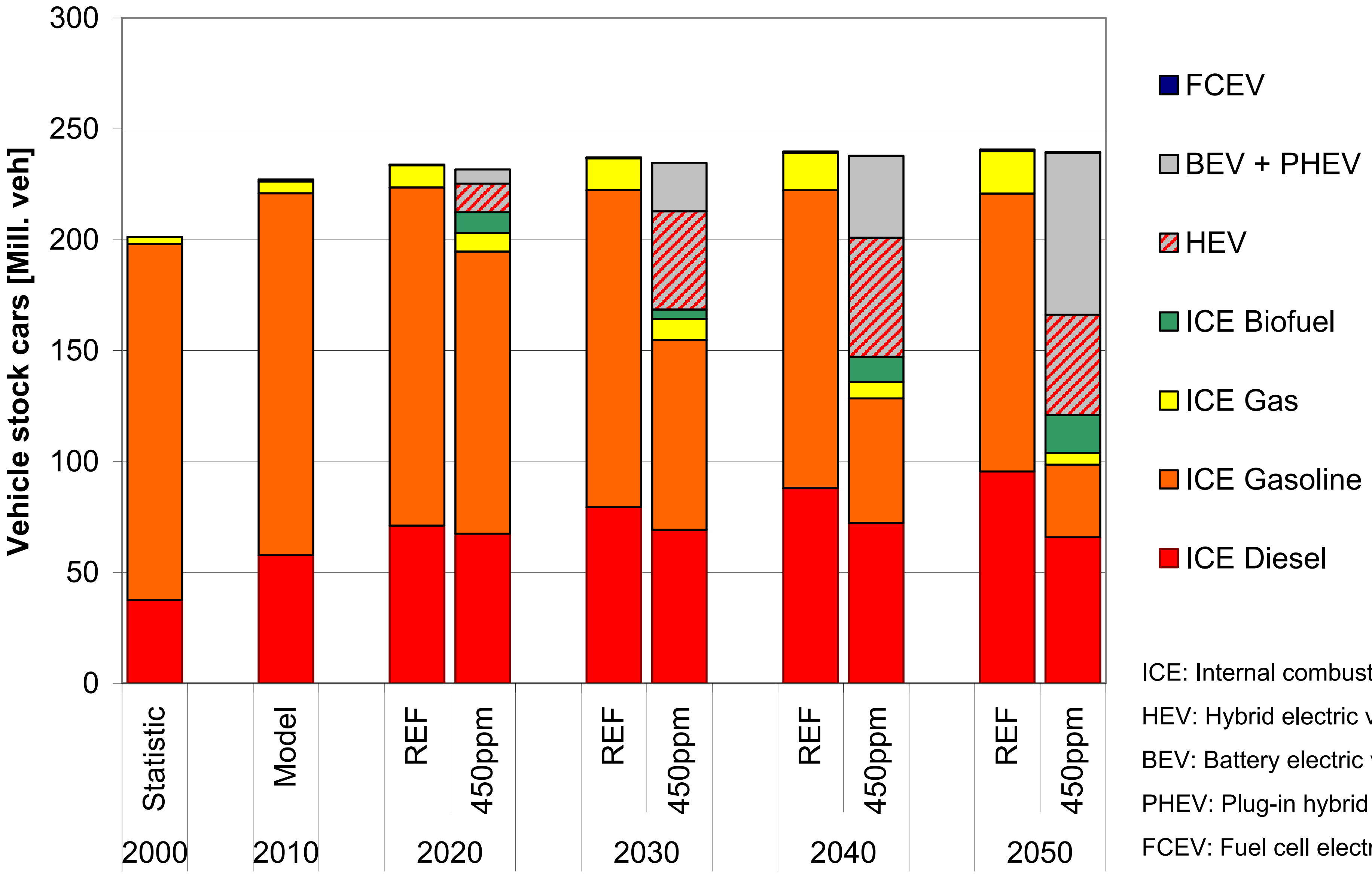
Primary energy consumption of renewable energy (EU27)



Net Electricity Generation (EU27)



Vehicle Stock of cars by technology (EU27)



ICE: Internal combustion engine

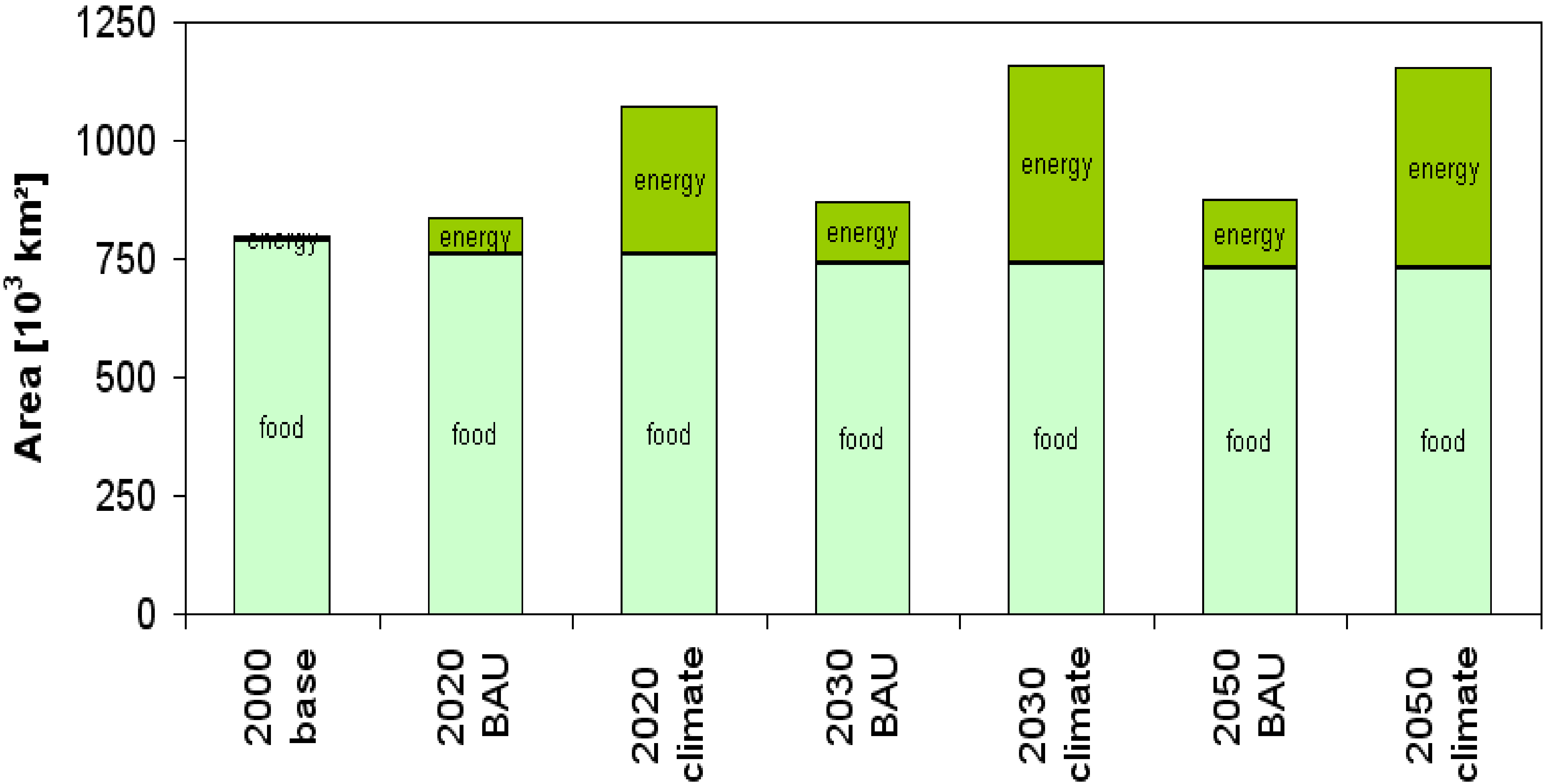
HEV: Hybrid electric vehicle

BEV: Battery electric vehicle

PHEV: Plug-in hybrid electric vehicle

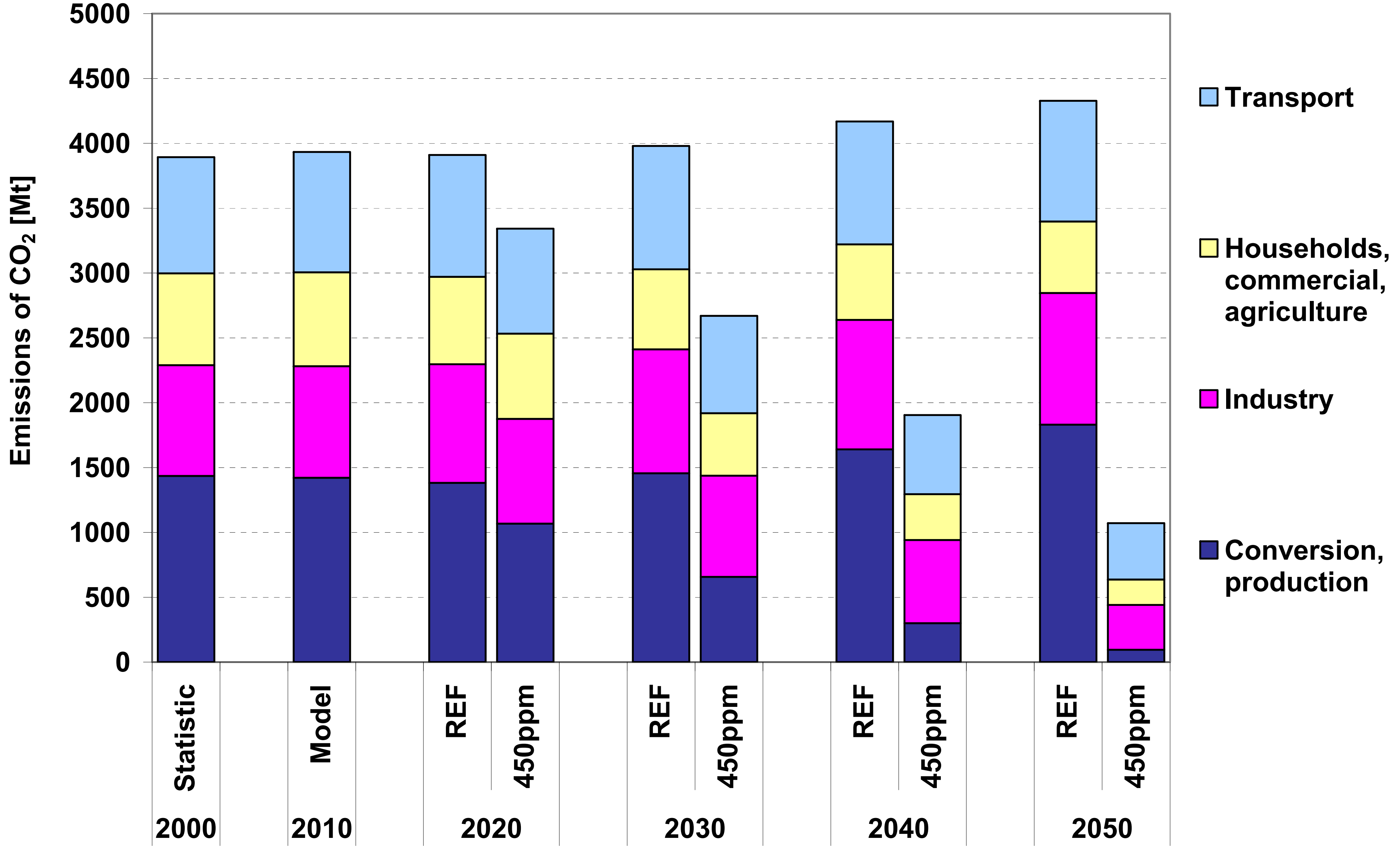
FCEV: Fuel cell electric vehicle

Total land requirement for crop production – upper bound

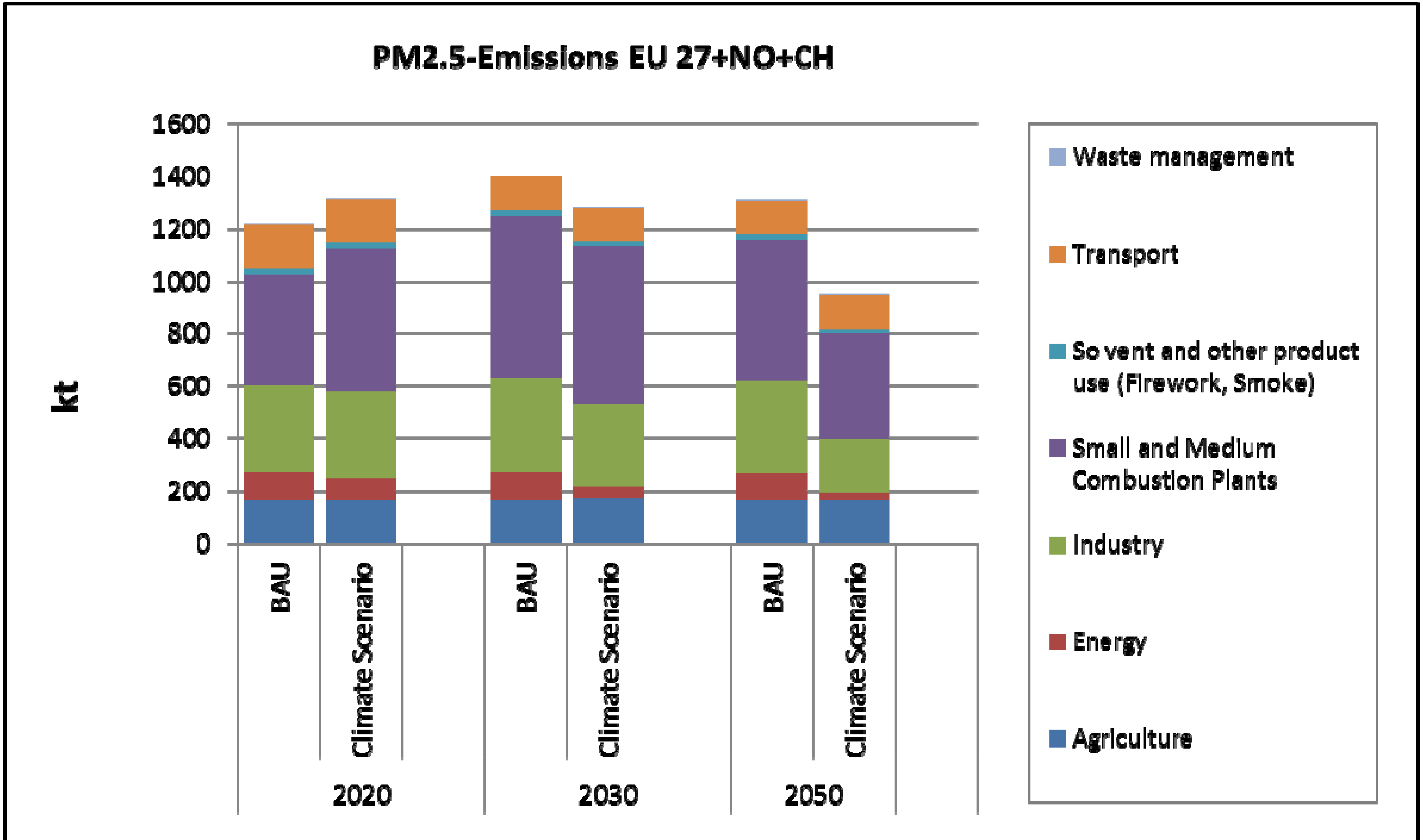


From activities to emissions

Emissions of CO_2 by sector (EU27)

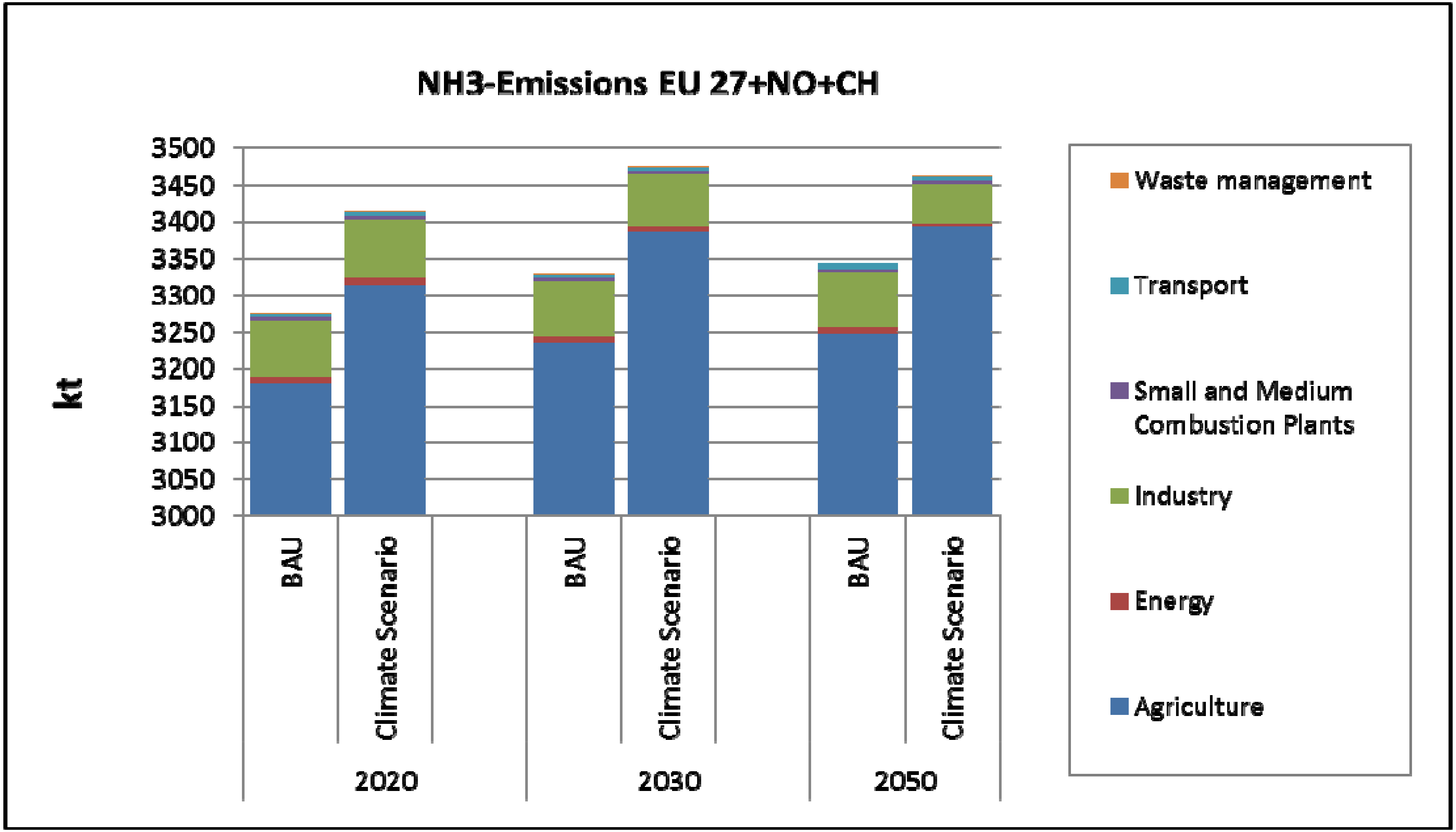


PM2.5-Emissions by Source Category for EU 29

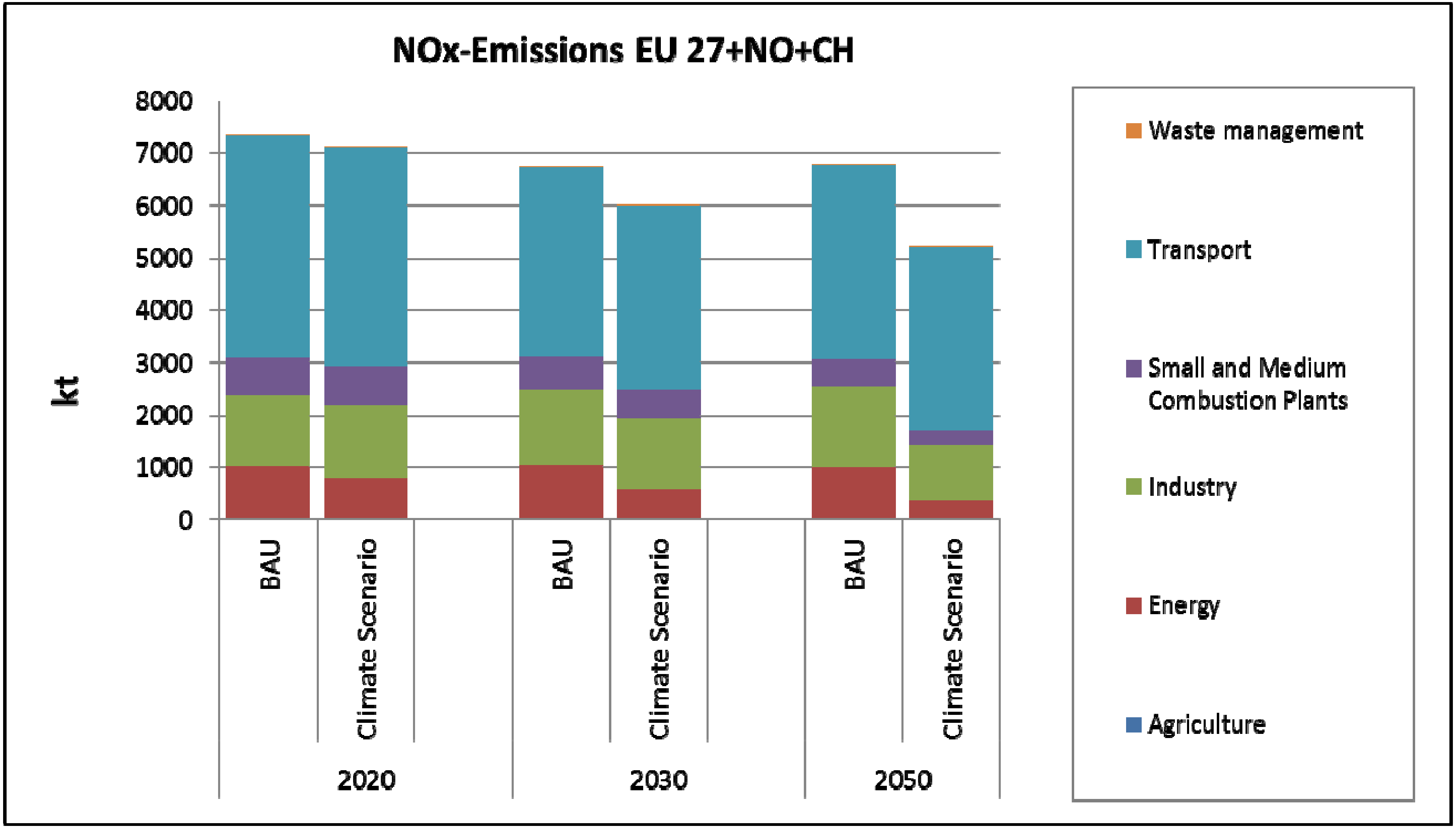


Results of Case Study

NH3-Emissions by Source Category for EU 29

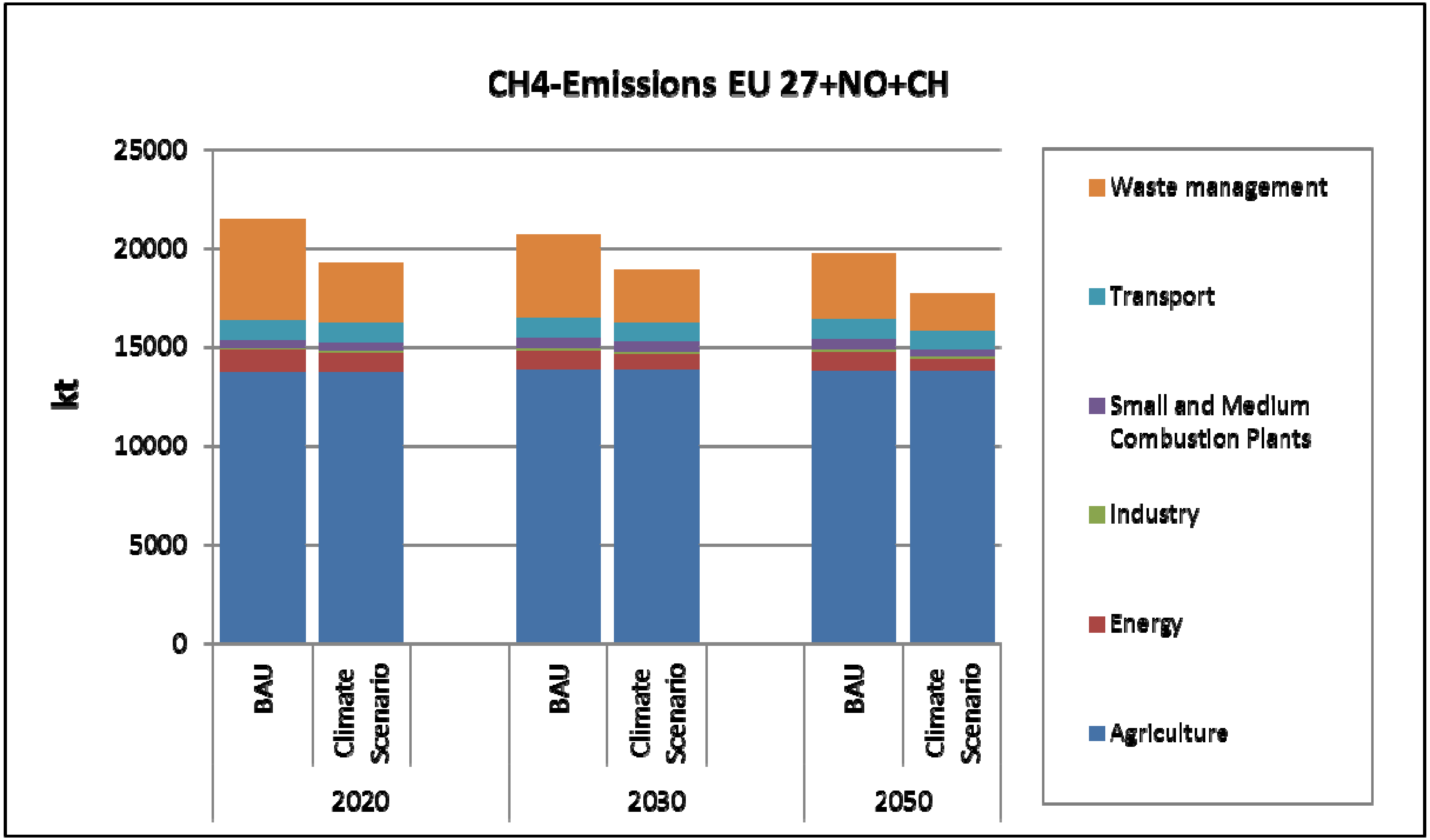


NOx-Emissions by Source Category for EU 29



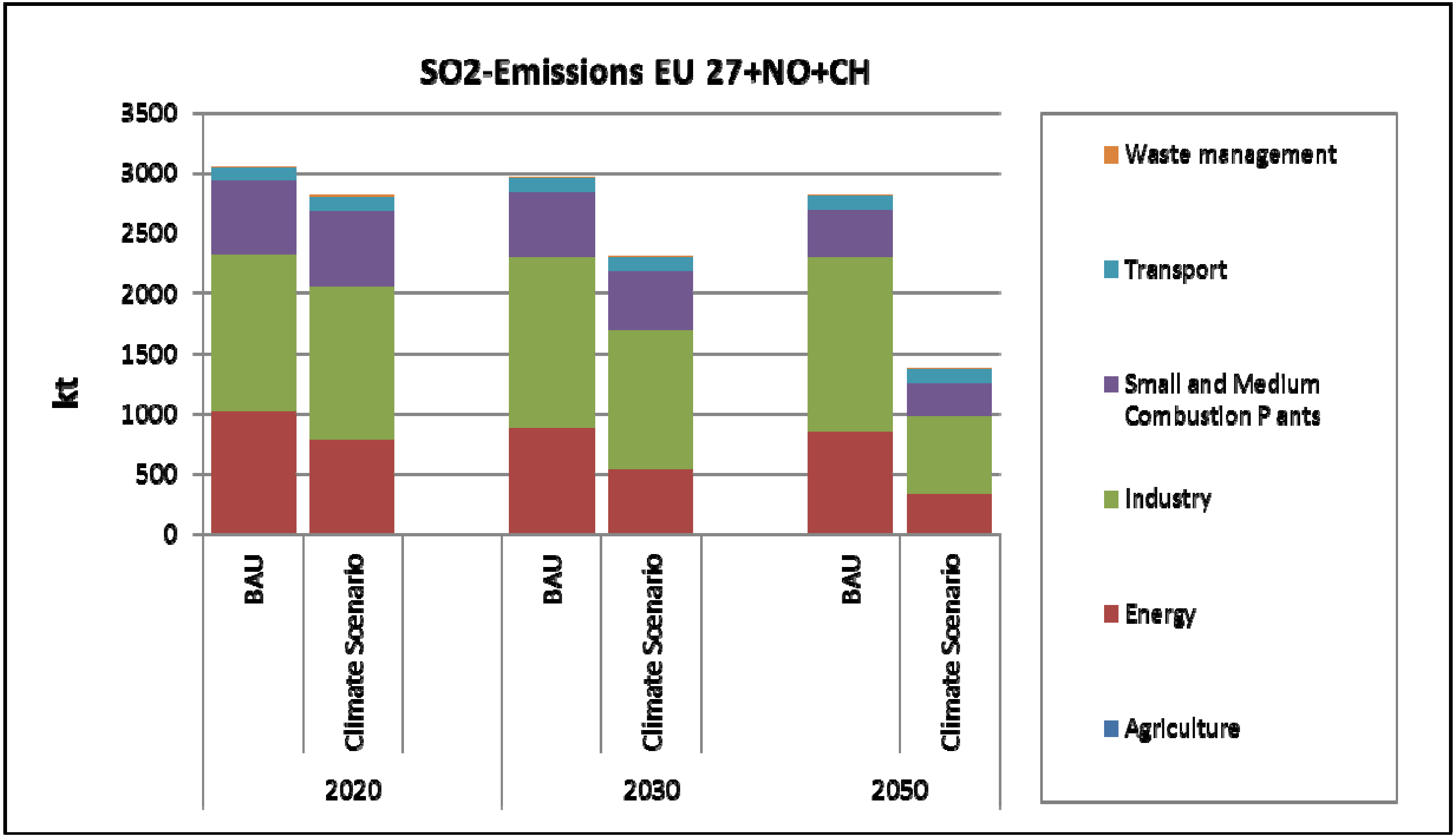
Results of Case Study

CH4-Emissions by Source Category for EU 29

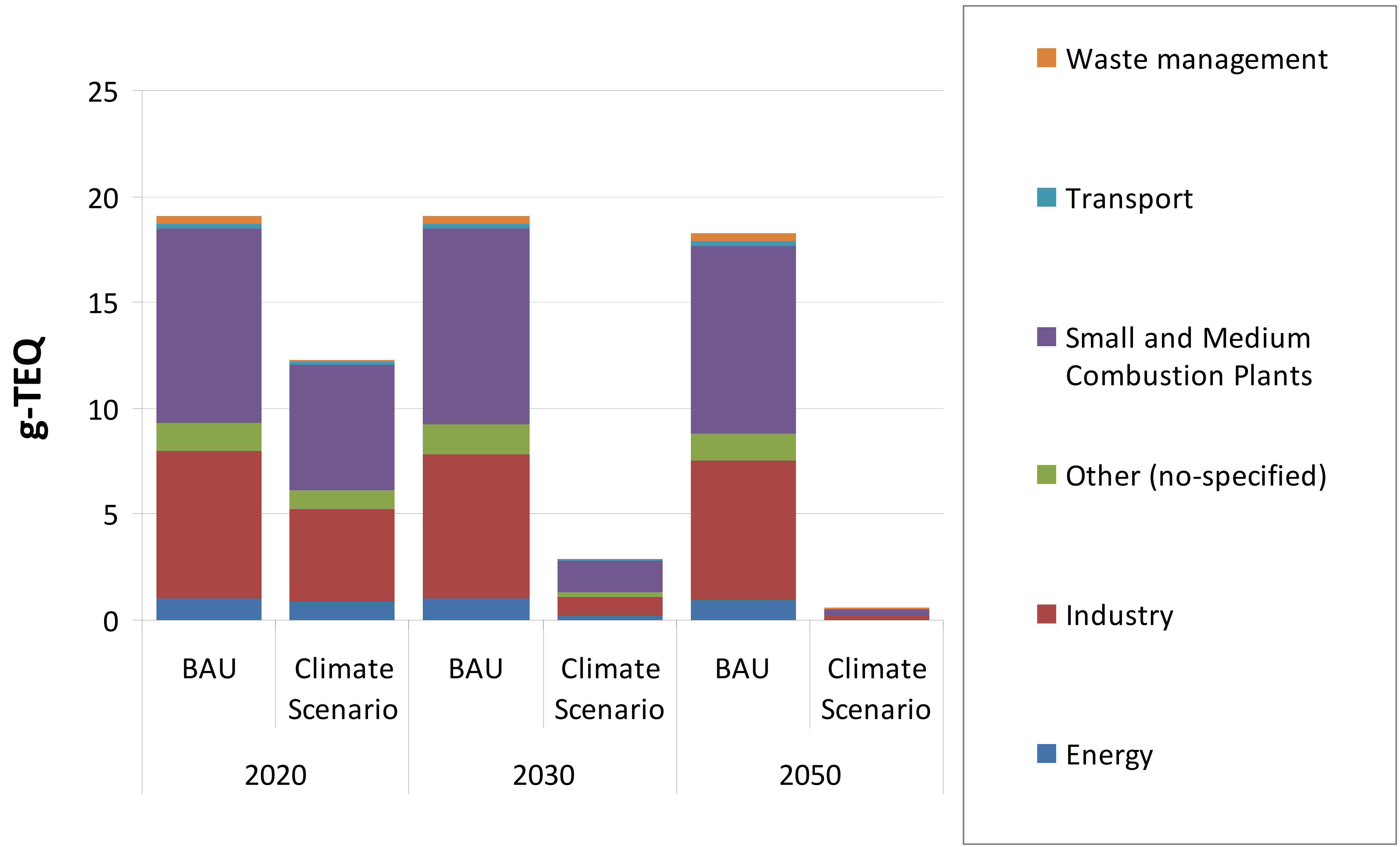


EU 29: EU27+Switzerland and Norway

SO2-Emissions by Source Category for EU 29



Dioxin Emissions in EU27+NO+CH

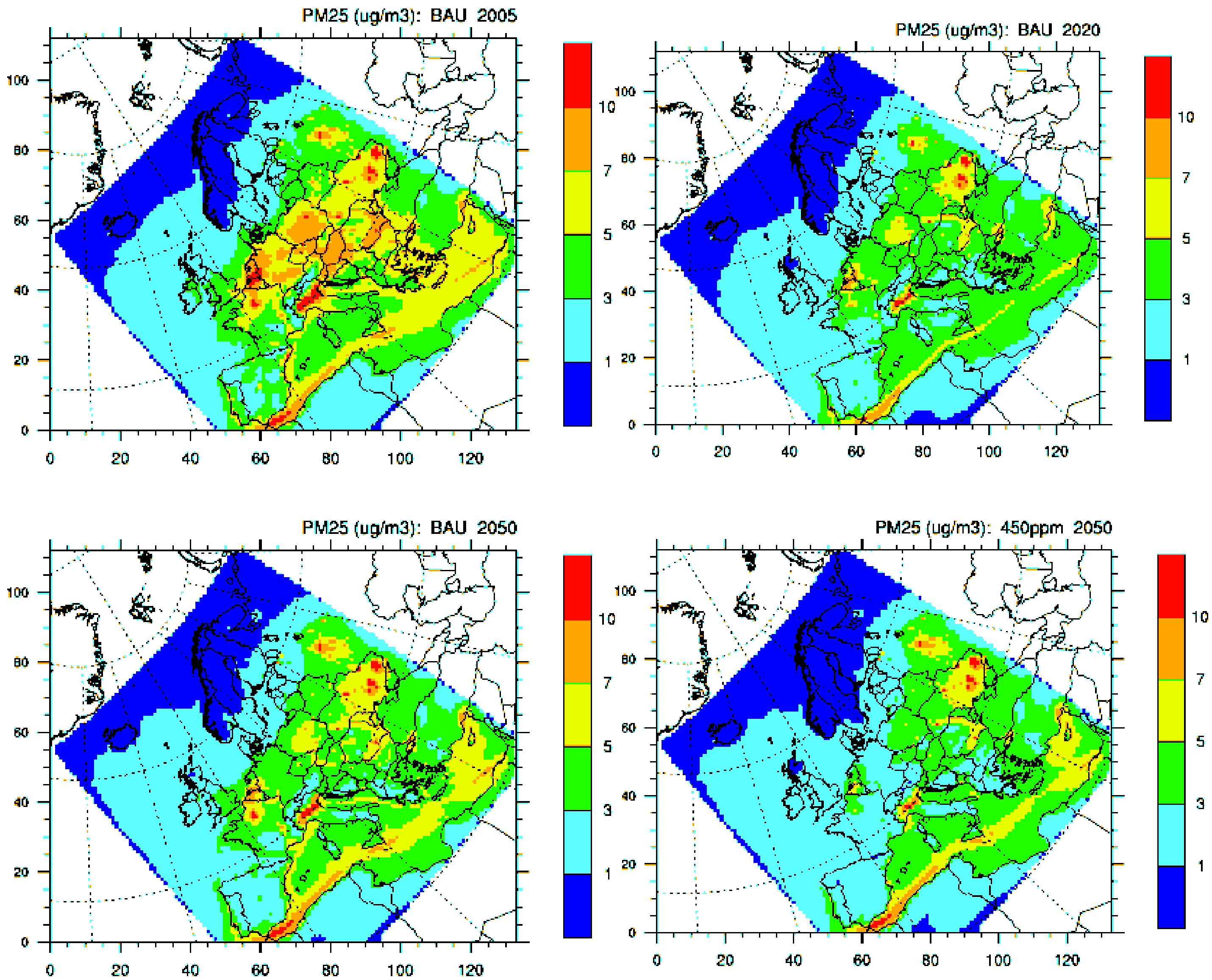


From emissions to concentrations/levels/intake/exposures

Used models:

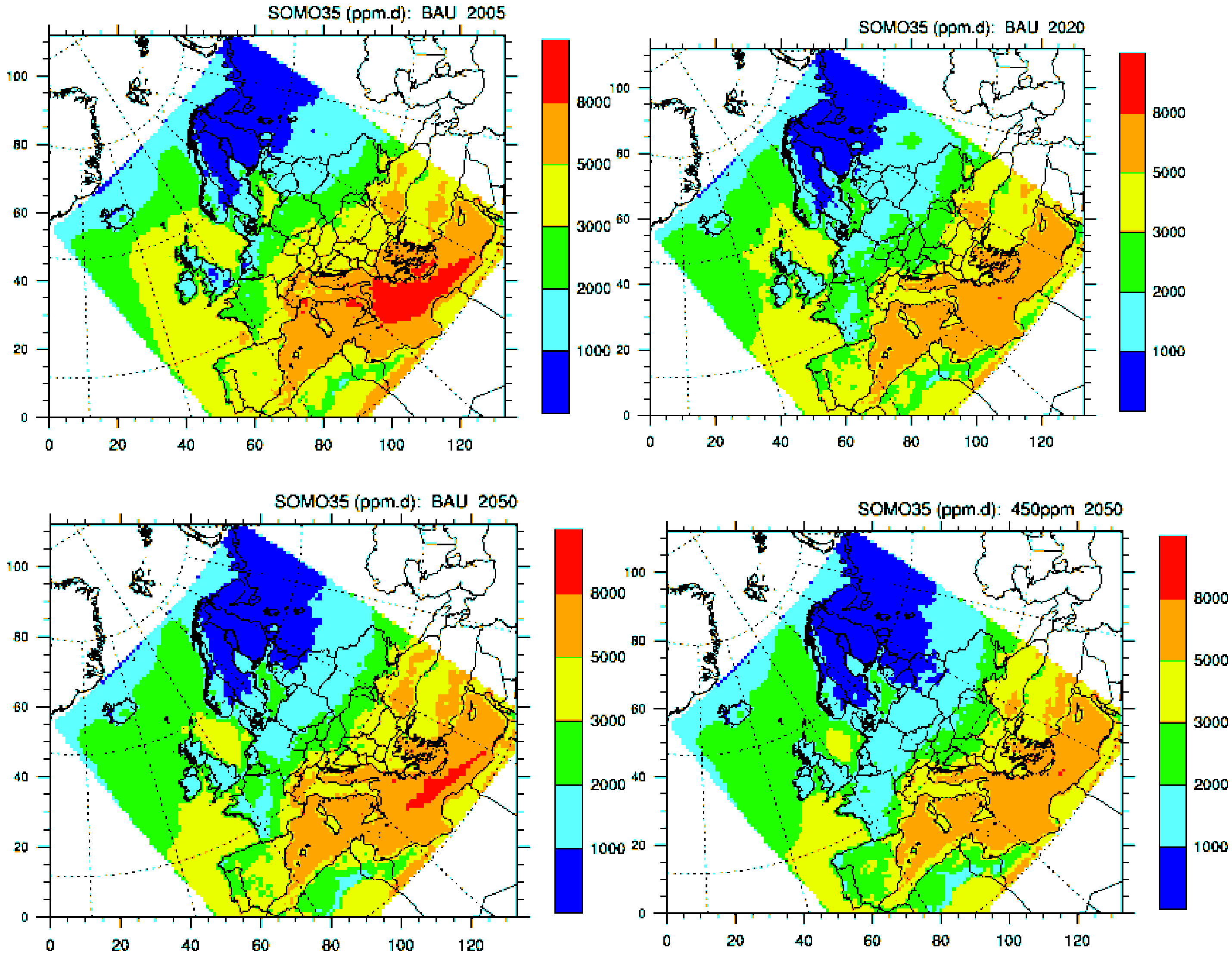
- Outdoor air: EMEP, Polyphemus, Chimere, ECOSENSE (parametrized), MSC-EAST (POPs, fertilizers)
- New tool for assessing local impacts of pesticide application
- Urban increment: new ‚urban increment estimation tool'
- Multimedia to food: new multimedia models dynamiCROP (pesticides), PANGEA (POP)
- Noise: new noise upscaling model
- Indoor: Steady state mass balance model with homogenous mixing
- Exposure: new LAMA model

Concentration fields – Unified EMEP model



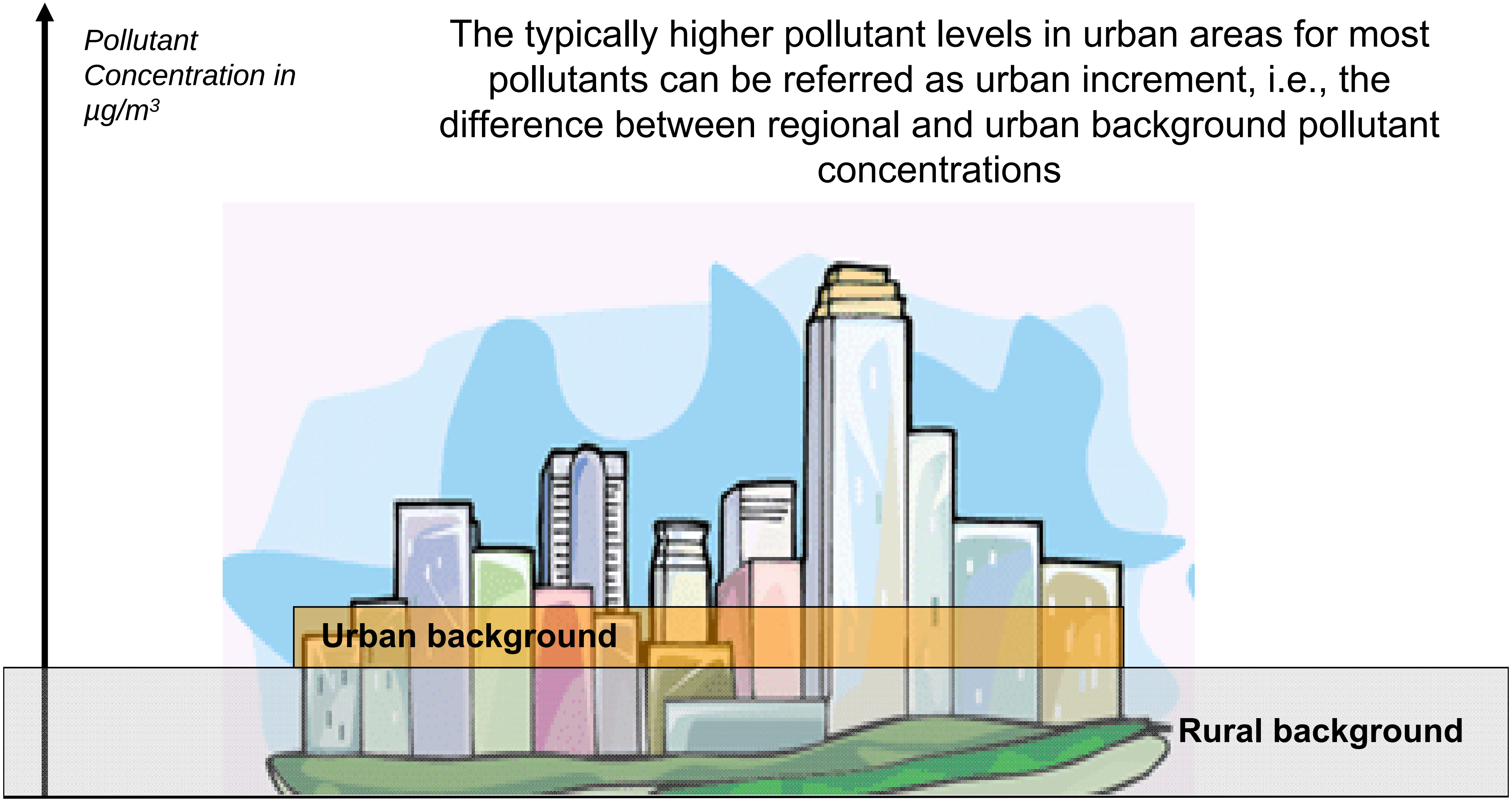
Calculated concentrations of $PM_{2.5}$ in 2005, 2020 and 2050 for BAU scenario, and in 2050 for climate policy scenario

Concentration fields – Unified EMEP model



Calculated concentrations of SOMO35 in 2005, 2020 and 2050 for BAU scenario, and in 2050 for climate policy scenario

The typically higher pollutant levels in urban areas for most pollutants can be referred as urban increment, i.e., the difference between regional and urban background pollutant concentrations



Urban increment (PM2.5)

developed by Torras Ortiz (2010), USTUTT

$$C_{i\ urban} = \varpi_i + \phi_i \frac{E_{iUE}}{A_{UE} \cdot u_{avg}} + \gamma\, C_{i\ rural}$$

where

C_i urban = Urban increment of pollutant i.

E_{iUE} = Total emission of pollutant i within the urban entity in tons.

A_{UE} = Urban entity area in km^2.

u_{avg} = Urban entity average wind speed in m/s.

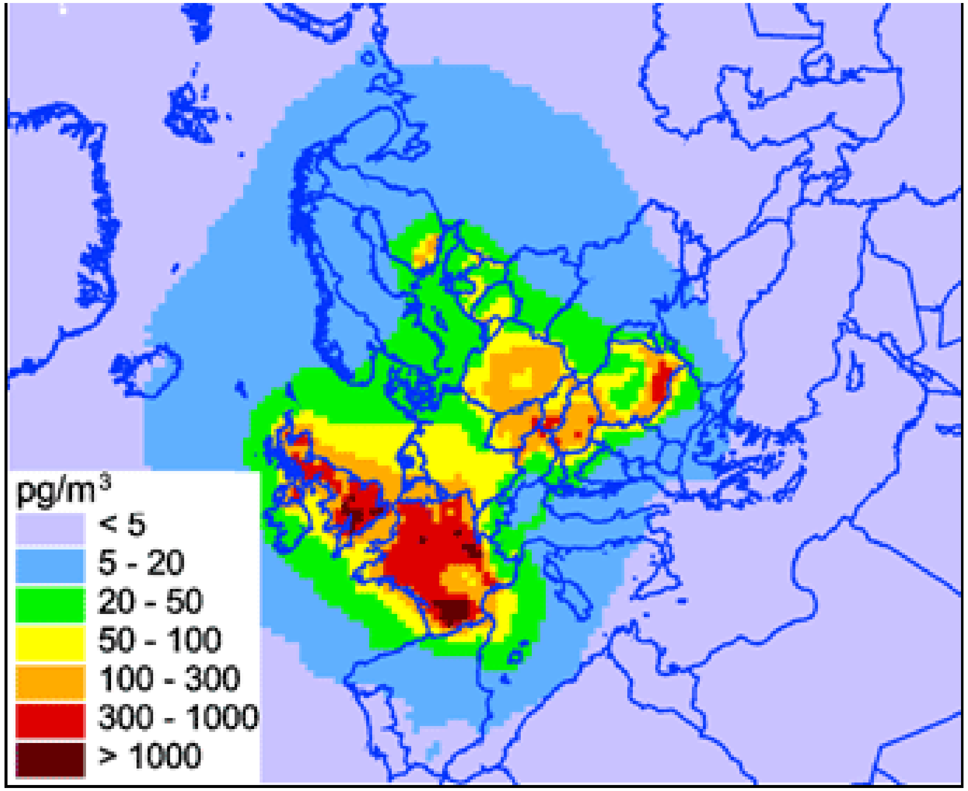
$C_{i\ rural}$ = Rural background concentration of pollutant i in $\mu g/m^3$

ω_i, φ_i, and γ_i = Multiple-regression parameters for pollutant i.

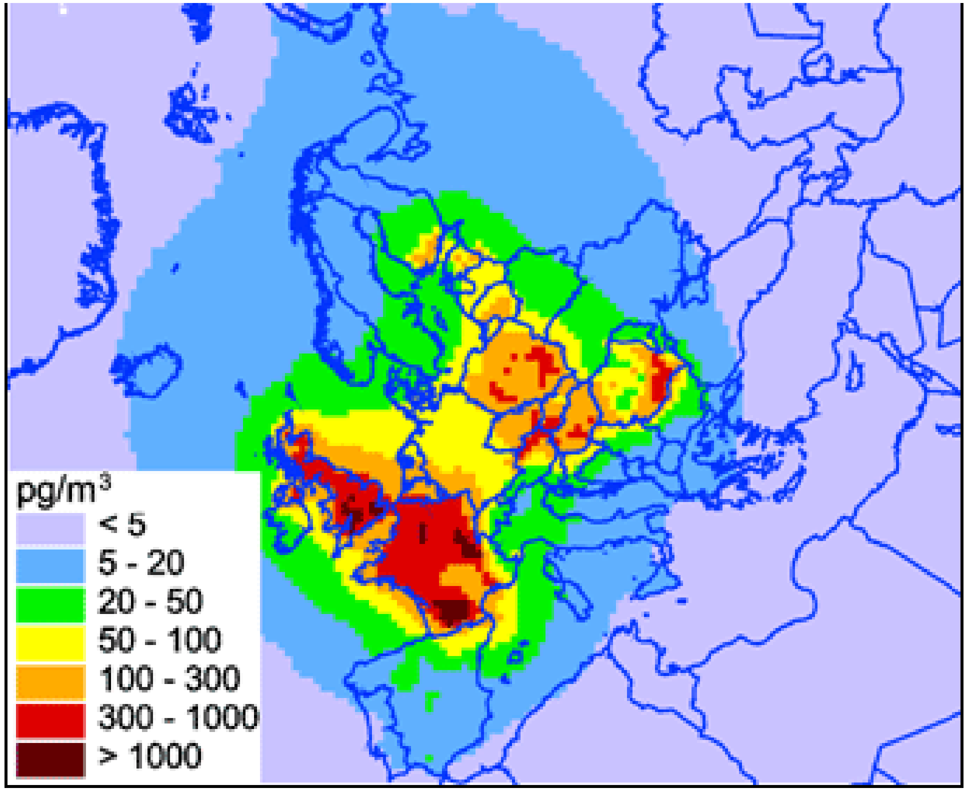
Torras Ortiz, S. (2010). "A hybrid dispersion modelling approach for quantifying and assessing air quality in Germany with focus on urban background and kerbside concentrations," submitted Doctoral Thesis, University of Stuttgart, Stuttgart.

Pesticide Atmospheric Modeling

Air concentration, trifluralin



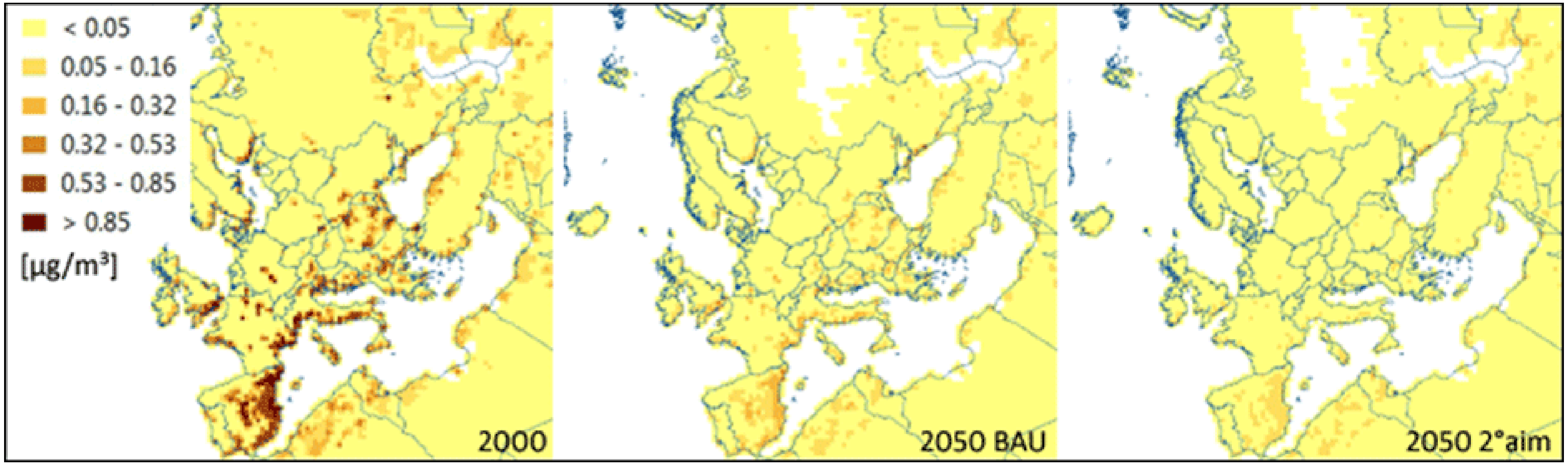
2020 BAU



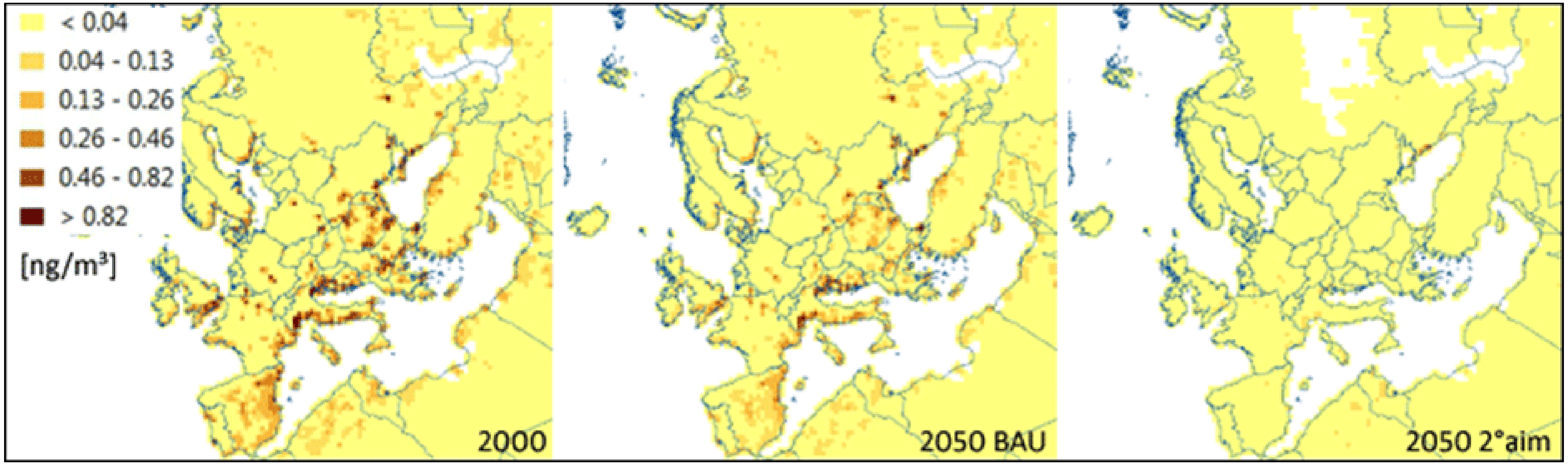
2020 2° aim

POPs Multimedia Fate Modeling (PANGEA)

Agricultural land concentration, 4PeCDF



Agricultural land concentration, PCB-153



From concentrations/levels/intake/exposures to health impacts/Dalys/monetary values

Air pollutants: Impact functions $PM_{2.5}$

Health effect	Relative Risk	Age Group	Population	Impact Function
PM2.5				
Mortality (all cause)	6% (95% CI: 2%, 11%) change per 1 µg/m3 PM2.5	Adults 30 years and older	General Population	250.4 YOLLs
Work loss days (WLDs)	4.6% (95% CI: 3.9%, 5.3%) increase per 10 µg/m3 PM2.5	15-64 Years	General Population	20,700 (95% CI: 17,600, 23,800) additional work lost days per 10 µg/m3 increase in PM2.5 per 100,000 people aged 15-64 in the general population per year
Minor Restricted Activity Days (MRADs)	7.4% (95% CI: 6.0%, 8.8%) change per 10 µg/m3 PM2.5	18-64 Years	General Population	57,700 (95% CI: 46,800, 68,600) additional MRADs per 10 µg/m3 increase in PM2.5 per 100,000 adults aged 18-64 (general population) per year
Restricted activity days (RADs)	4.75% (95% CI: 4.17%, 5.33%) change per 10 µg/m3 PM2.5	18-64 Years	General Population	90,200 (95% CI: 79,200, 101,300) additional RADs per 10 µg/m3 increase in PM2.5 per 100,000 adults aged 18-64 (general population) per year

Pesticide DRFs

Dose-response relationships: carcinogenicity for selected pesticides via food (50% fatality)

Target Class	Substance Name	Slope Factor [life-time cancer risk per mg intake per kg body and day]
Fungicides	Carbendazim	0.00239
	Chlorothalonil	0.00766
	Iprodione	0.0439
Herbicides	Bromoxynil	0.103
	Isoxaflutole	0.0102
	Molinate	0.11
	Propyzamide	0.0259
	Tralkoxydim	0.0168
	Trifluralin (*only for evaluation*)	0.00293

Air pollutants: Impact functions PM_{10}

Health effect	Relative Risk	Age Group	Population	Impact Function
PM10				
Infant Mortality	4% (95% CI: 2%, 7%) change per 10 ug/m3 PM10	1 month to 1 year	General Population	5.8 (95% CI: 2.9, 10.2) additional infant deaths per 10 µg/m3 PM10 per 100,000 live births, per year
Chronic bronchitis	22% (95% CI: 2%, 38%) change per 10 µg/m3 PM10	Adults aged 18 years and older	General Population without symptoms (90% of population)	86 (95% CI 7.8, 150) new cases per 10 µg/m3 PM10 per 100,000 adults aged 18 and older, per year
Cardiovascular hospital admissions	0.6% (95% CI: 0.3%, 0.9%) change per 10 µg/m3 PM10	All Ages	General Population	4.3 (95% CI: 2.2, 6.5) additional emergency cardiac hospital admissions per 10 µg/m3 increase in PM10 per 100,000 people (all ages) per year
Respiratory hospital admissions	0.9% (95% CI: 0.7%, 1.0%) change per 10 µg/m3 PM10	All Ages	General Population	5.6 (95% CI: 4.3, 6.2) additional emergency respiratory hospital admissions per 10 µg/m3 increase in PM10 per 100,000 people (all ages) per year

Air pollutants: Impact functions PM_{10}

Health effect	Relative Risk	Age Group	Population	Impact Function
PM10				
Asthma medication use (children aged 5-14)	0.4% (95% CI: -1.7%, 2.6%) change per 10 µg/m3 PM10	5-14 Years	Children with Asthma (14.4% of children aged 5-14 in EU27 have asthma)	14,600 (95% CI: -62,050, 94,900) additional days of bronchodilator usage per 10 ug/m3 increase in PM10 per 100,000 children aged 5-14 years meeting the PEACE study criteria, per year
Bronchodilator usage in adults (aged 20 and older) with asthma	0.5% (95% CI: -0.5%, 1.5%) change per 10 µg/m3 PM10	Adults aged 20 years and older	Adults with asthma (10.2% of adults aged 20+ in EU27 have asthma)	91,300 (95% CI: -91,300, 274,000) additional days of bronchodilator usage per 10 µg/m3 increase in PM10 per 100,000 adults aged 20 and older with well-established asthma, per year
Lower respiratory symptoms incl.cough among children	3.4% (95% CI: 1.7%, 5.1%) change per 10 µg/m3 PM10	5-14 Years	General Population	186,000 (95% CI: 93,100, 279,000) additional symptom days per 10 µg/m3 increase in PM10 per 100,000 children aged 5-14, per year
LRS (including cough) in symptomatic adults	1.2% (95% CI: 0.1%, 2.2%) change per 10 µg/m3 PM10	Adults	Adults with chronic resp. symptoms (30%)	131,000 (95% CI: 11,000, 241,000) additional symptom days per 10 µg/m3 increase in PM10, per 100,000 adults with chronic respiratory symptoms, per year

Air pollutants: Impact functions Ozone

Health effect	Relative Risk	Age Group	Population	Impact Function
Ozone				
Mortality (all cause)	0.3% (95% CI: 0.1%, 0.4%) change per 10 µg/m3 O3	All Ages	General Population	2.8 (95% CI: 0.92, 3.7) additional deaths (or life years lost) per 10 µg/m3 increase in O3 per 100,000 population (all ages), per year
Respiratory hospital admissions (adults aged 65+)	0.5% (95% CI: -0.2%, 1.2%) change per 10 µg/m3 O3 (8-hr daily average)	Adults aged 65 years and older	General Population	12.5 (95% CI: -5.0, 30.0) additional emergency respiratory hospital admissions per 10 µg/m3 increase in O3 per year per 100,000 people aged 65+, per year
Bronchodilator usage in children (general population)	21% (95% CI: 2.9%, 39%) change per 10 ug/m3 O3	5-14 Years	General Population	24,500 (95% CI: 3,400, 45,600) additional days of bronchodilator usage per 10 µg/m3 increase in O3 per 100,000 children aged 5-14 (general population), per year
Bronchodilator use in adults (aged 20 and older) with asthma	0.6% (95% CI: -0.2%, 1.4%) change per 10 ug/m3 O3	Adults aged 20 years and older	Adults with asthma (10.2% of adults in EU27 have asthma)	70,100 (95% CI: -23,400, 164,000) additional days of bronchodilator usage per 10 ug/m3 increase in O3 per 100,000 adults aged 20 and older with persistent asthma, per year

Air pollutants: Impact functions Ozone

Health effect	Relative Risk	Age Group	Population	Impact Function
Ozone				
Lower respiratory symptoms (LRS) (excluding cough) among children in general population (5-14)	3.0% (95% CI: -7.9%, 15%) change per 10 µg/m3 O_3	5-14 Years	General Population	16,000 (95% CI: -43,000, 82,000) additional days of LRS (excluding cough) per 10 µg/m3 increase in O_3 per 100,000 children aged 5-14 years, per year
Cough (days) among children in the general population (5-14)	4.7% (95% CI: -0.9%, 11%) change per 10 µg/m3 O_3	5-14 Years	General Population	93,000 (95% CI: -17,700, 217,000) additional cough days per 10 µg/m3 increase in O_3 per 100,000 children aged 5-14 years per year
Minor Restricted Activity Days (MRADs)	1.48% (95% CI: 0.57%, 2.38%) change per 10 µg/m3 O_3	18-64 Years	General Population	11,500 (95% CI: 4,400, 18,600) additional MRADs per 10 µg/m3 increase in O_3 per 100,000 adults aged 18-64 (general population) per year

DALYs: duration in fraction of year, DALY= weight*duration,

endpoint	weight	duration
Bronchodilator Usage Adults and Children	0.22	0.00274
Cardiac Hospital Admissions	0.71	0.038
Chronic Bronchitis	0.099	10
Infant Mortality	1	80
Lower Respiratory Symptoms Adults and Children	0.099	0,00274
Respiratory Hospital Admissions	0.64	0.038
Minor Restricted Acitvity Day	0.07	0.00274
Restricted Acitvity Day	0.099	0.00274
Work Loss Day	0.099	0.00274
Years Of Life Lost chronic. Mortality	1	1
Cough Days	0.07	0.00274
Lower Respiratory Symptoms Children Excl Cough	0.099	0.00274
Respiratory Hospital Admissions	0.64	0.038

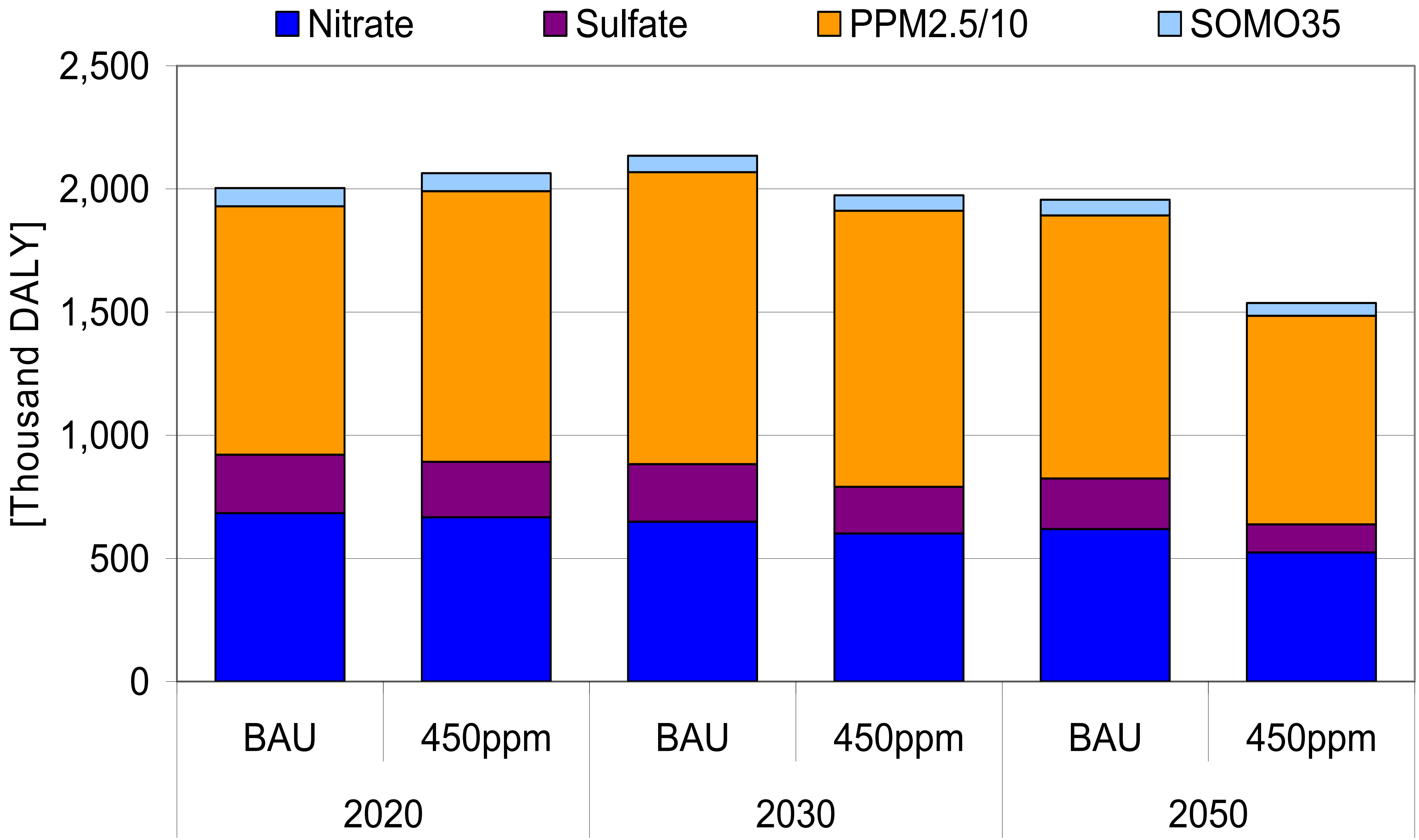
Monetary values of health endpoints (EUR 2010)

Health End-Point	Low	Central	High	per case
Increased mortality risk - VSLacute	1,121,433	1,121,433	5,607,164	Euro
Life expectancy reduction - Value of Life Years chronic	40,500	59,810	213,820	Euro
Sleep disturbance	400	1,045	1,320	Euro/year
Hypertension	740	800	930	Euro/year
Acute myocardial infarction	2,200	4,470	31,660	Euro
Lung cancer	69,080	719,212	4,187,879	Euro
Leukaemia	2,045,493	3,974,358	7,114,370	Euro
Neuro-development disorders	4,486	14,952	32,895	Euro
Skin cancer	10,953	13,906	26,765	Euro
Osteoporosis	2,990	5,682	8,074	Euro
Renal dysfunction	22,788	30,406	40,977	Euro
Anaemia	748	748	748	Euro

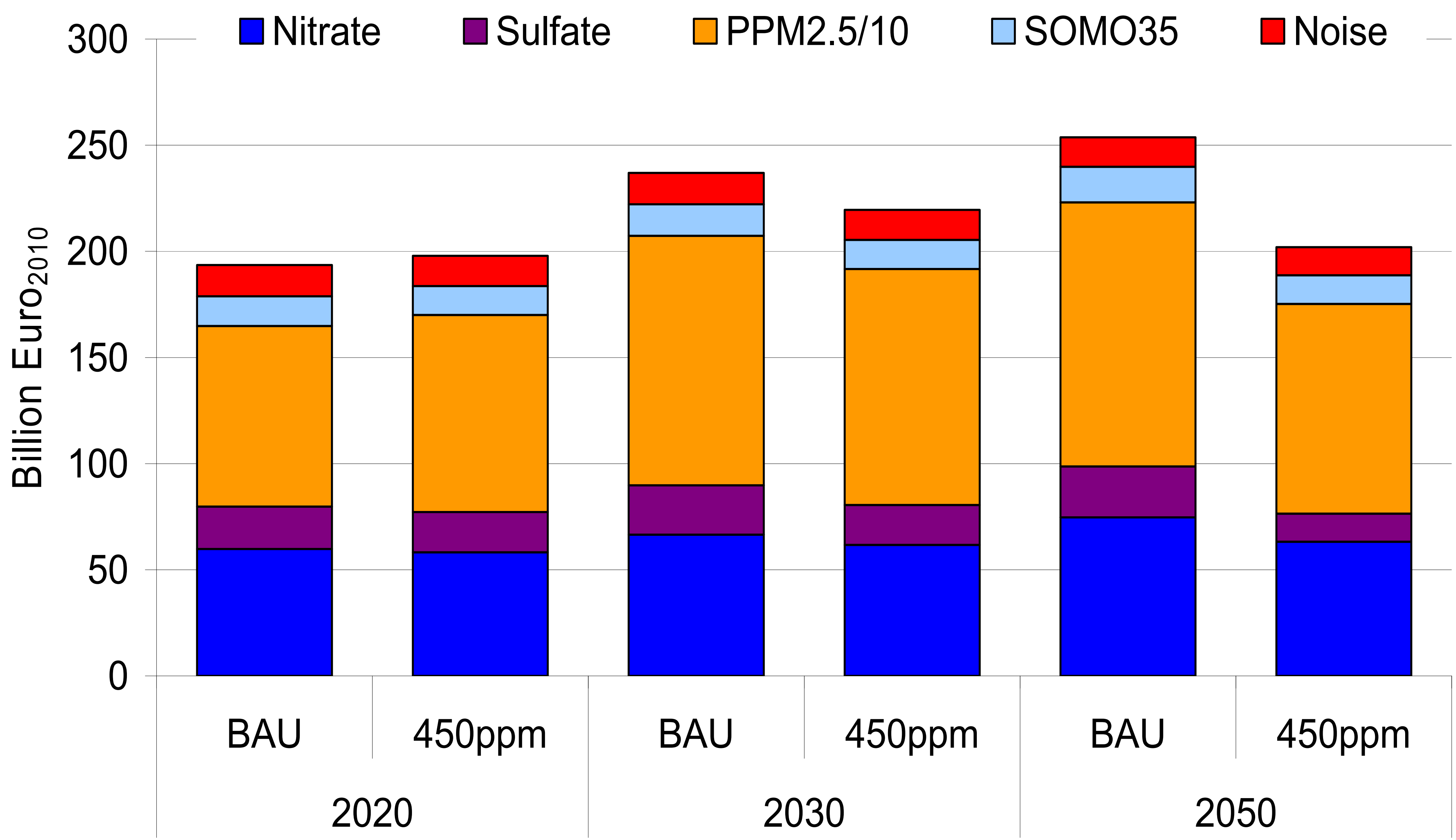
Air pollutants – monetary values (EUR 2010)

Health End-Point	Central	per case
Increased mortality risk (infants)	4,485,731	Euro
New cases of chronic bronchitis	66,000	Euro
Increased mortality risk - Value Of Life Years	89,715	Euro
Respiratory hospital admissions	2,990	Euro
Cardiac hospital admissions	2,990	Euro
Work loss days (WLD)	441	Euro
Restricted activity days (RADs)	194	Euro
Minor restricted activity days (MRAD)	57	Euro
Lower respiratory symptoms	57	Euro
LRS excluding cough	57	Euro
Cough days	57	Euro
Medication use / bronchodilator use	80	Euro

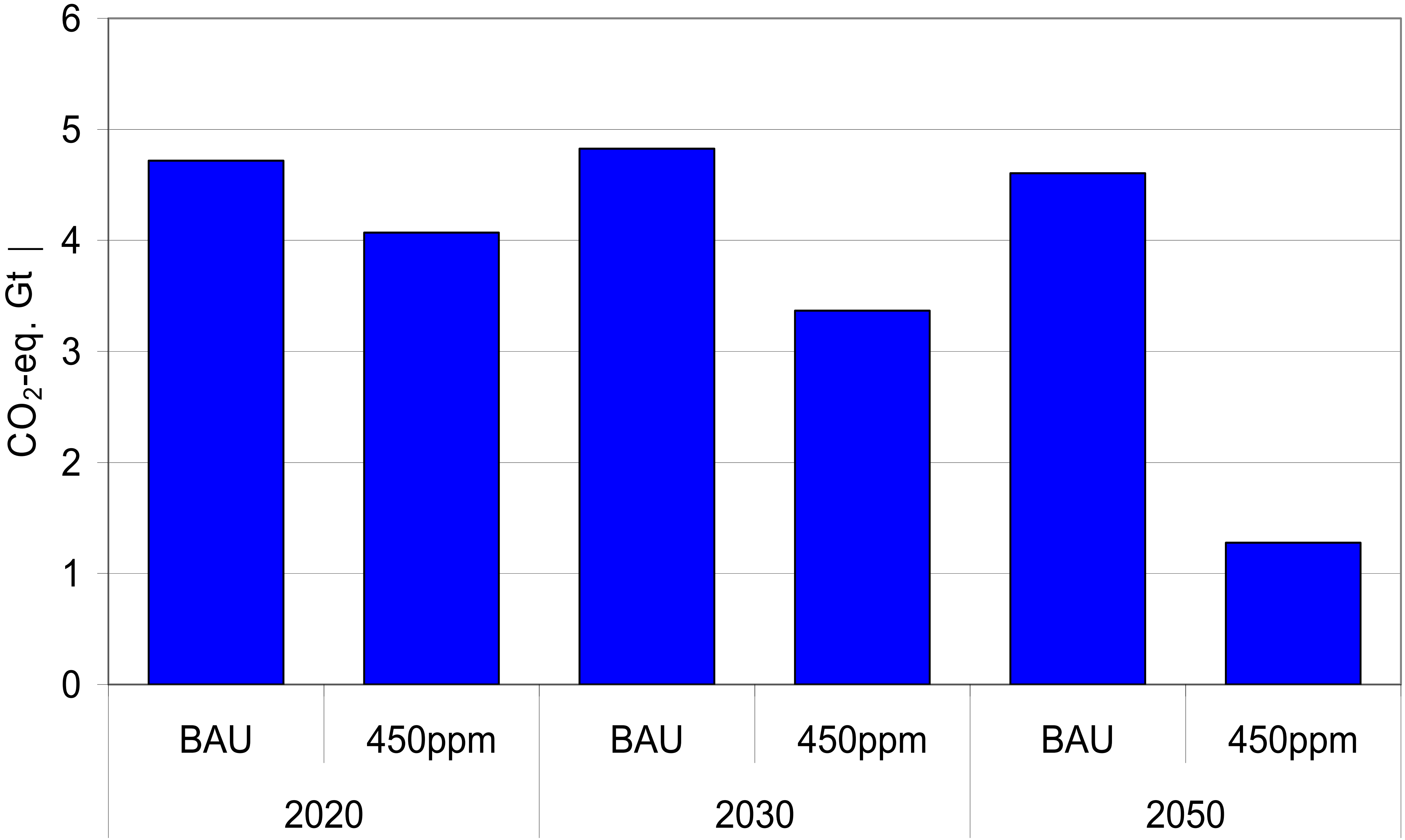
Human health impacts by primary pollutant



External costs by primary pollutants

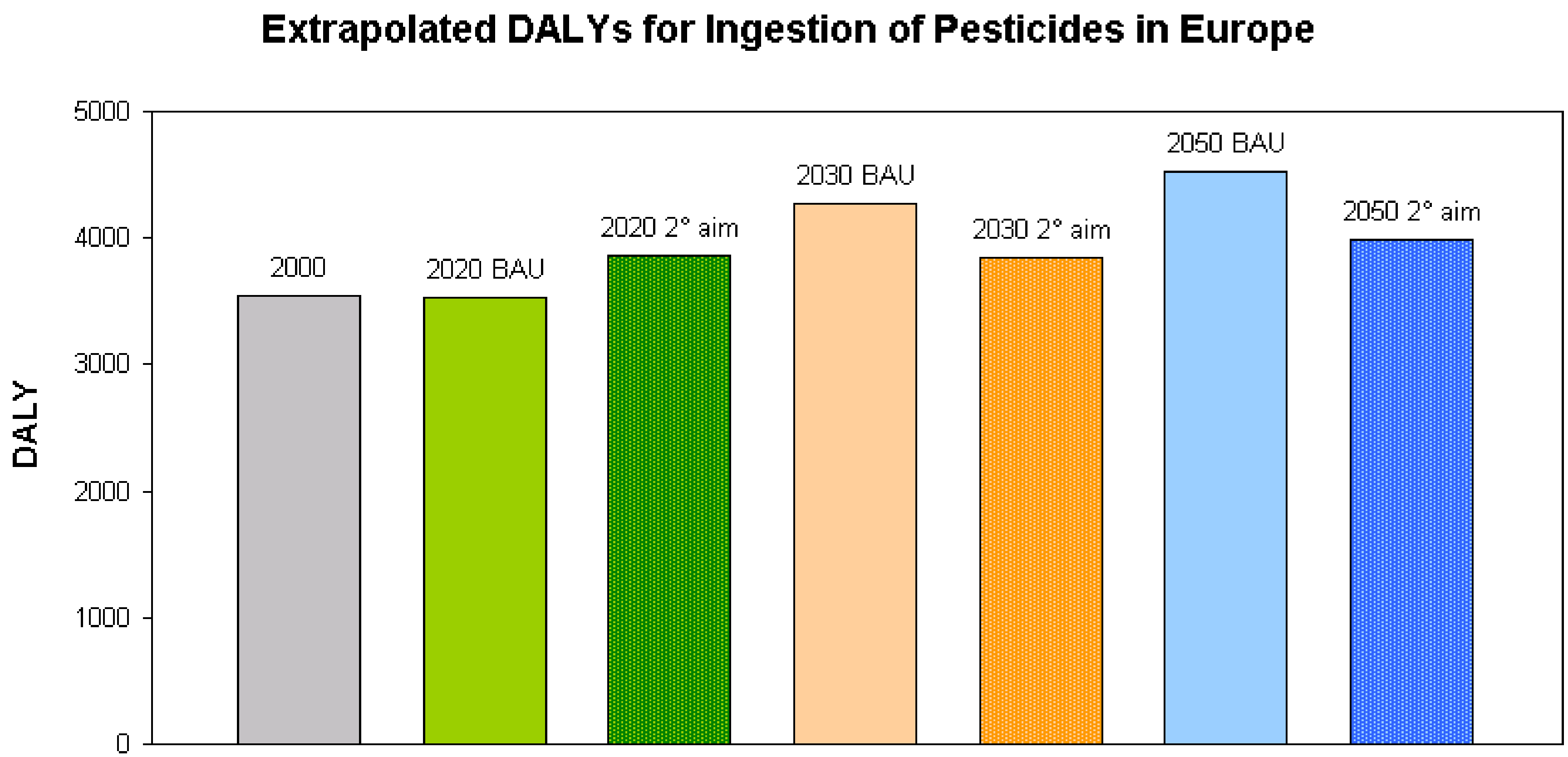


CO_2-eq. emisisons



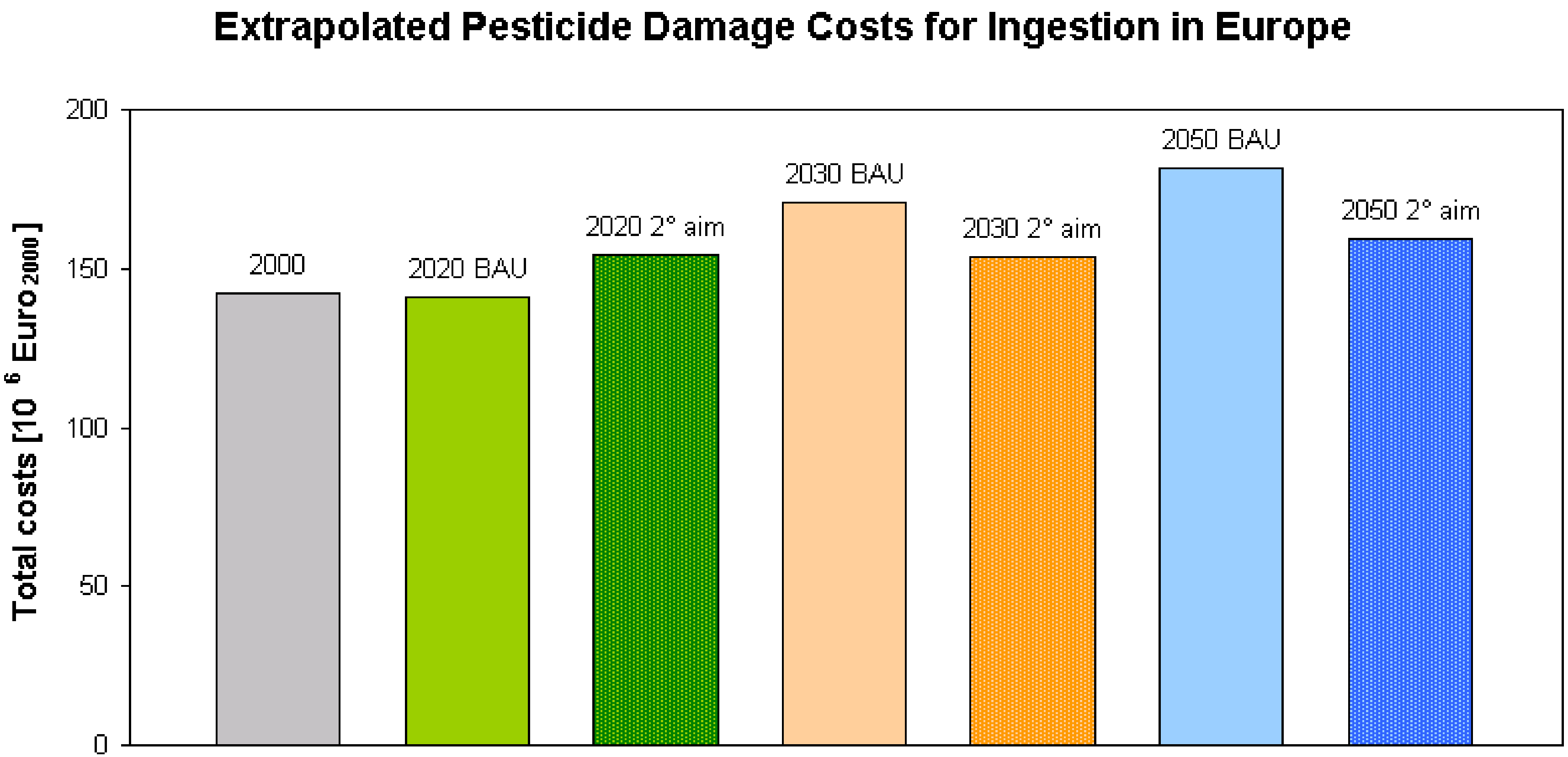
Pesticide DALYs – ingestion, total EU

DALYs (extrapolated to all pesticides used in Europe; estimated)



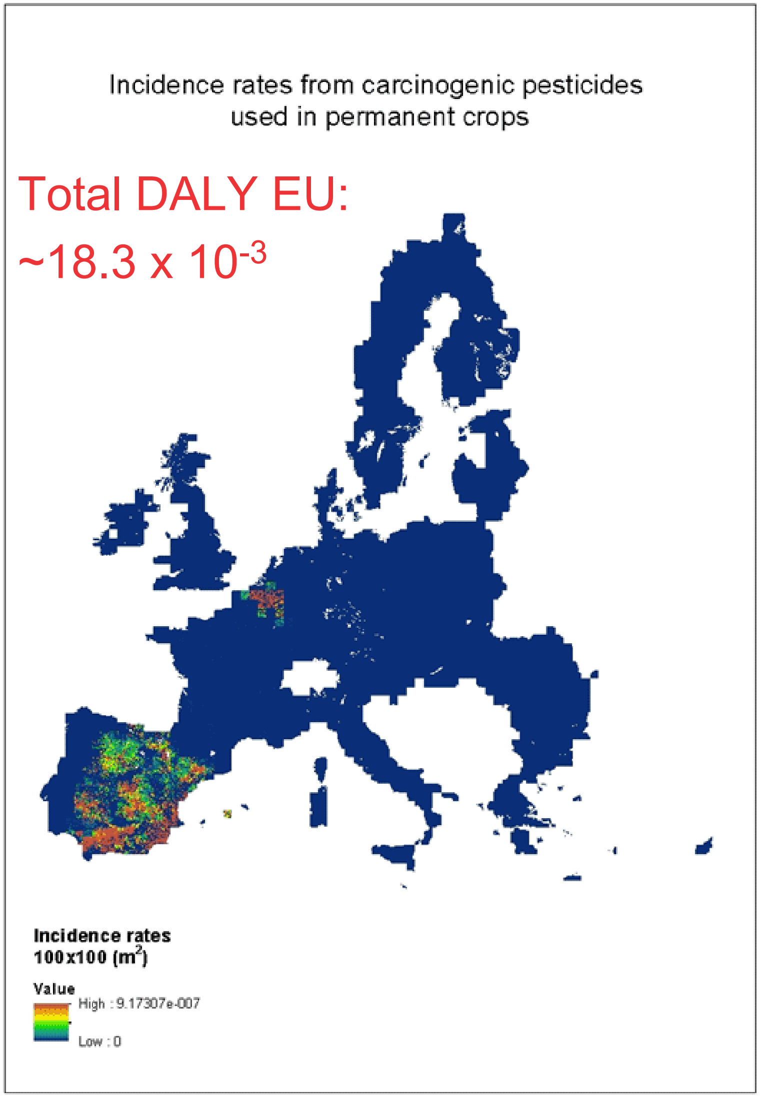
Pesticide Damage Costs – ingestion, total EU

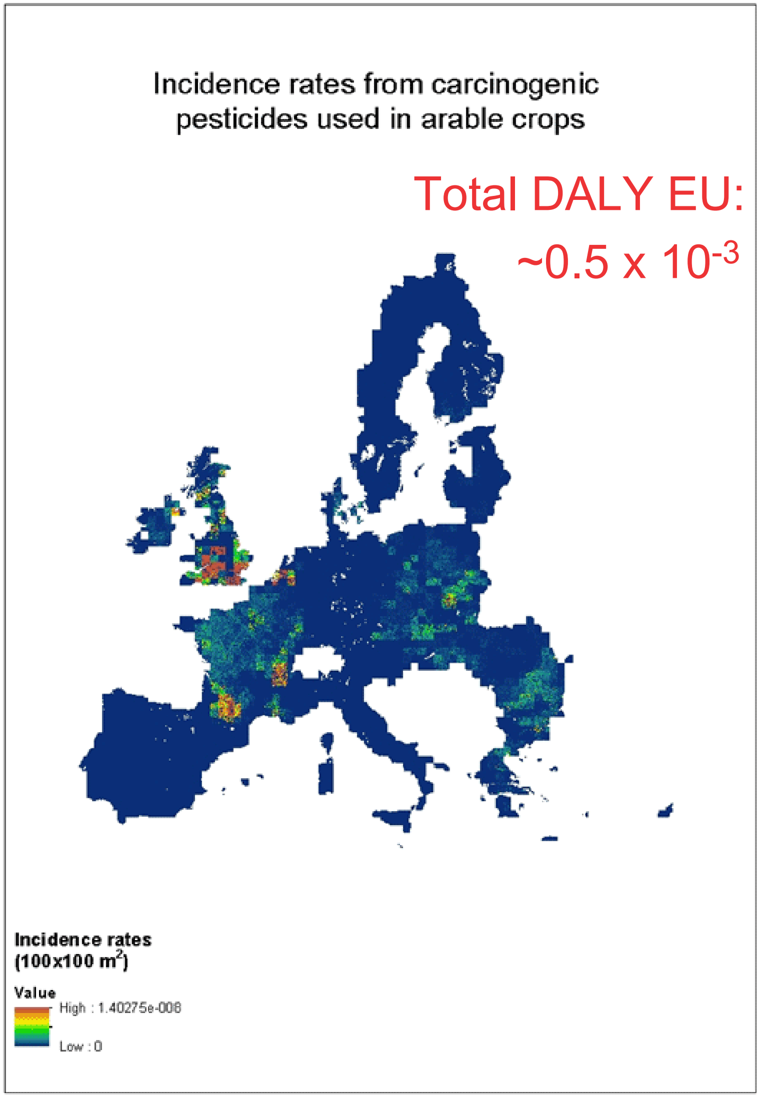
Damage costs (extrapolated to all pesticides used in Europe; estimated)



Pesticide DALYs – inhalation, by-standers

DALYs (inhalation from by-standers and applicants)





Pesticide DALYs – inhalation, general public

DALYs (inhalation of general public after dispersion modelling, trifluralin as test chemical)

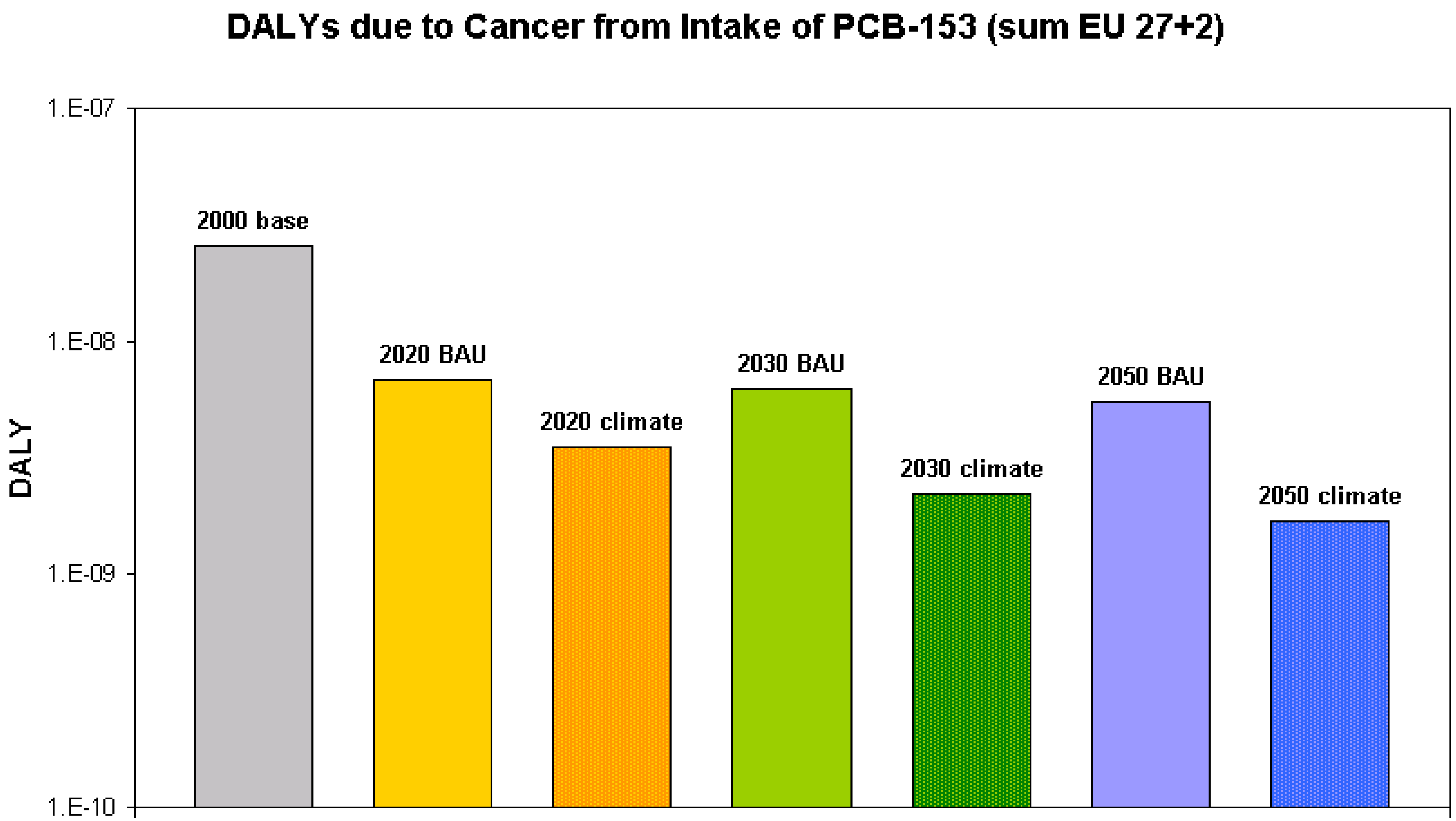
Assuming inhalation rate of 20 m³/day per person

→ < 6.5 DALY in Europe in 2000 baseline scenario due to inhalation of trifluralin

Comparison with ingestion exposure:

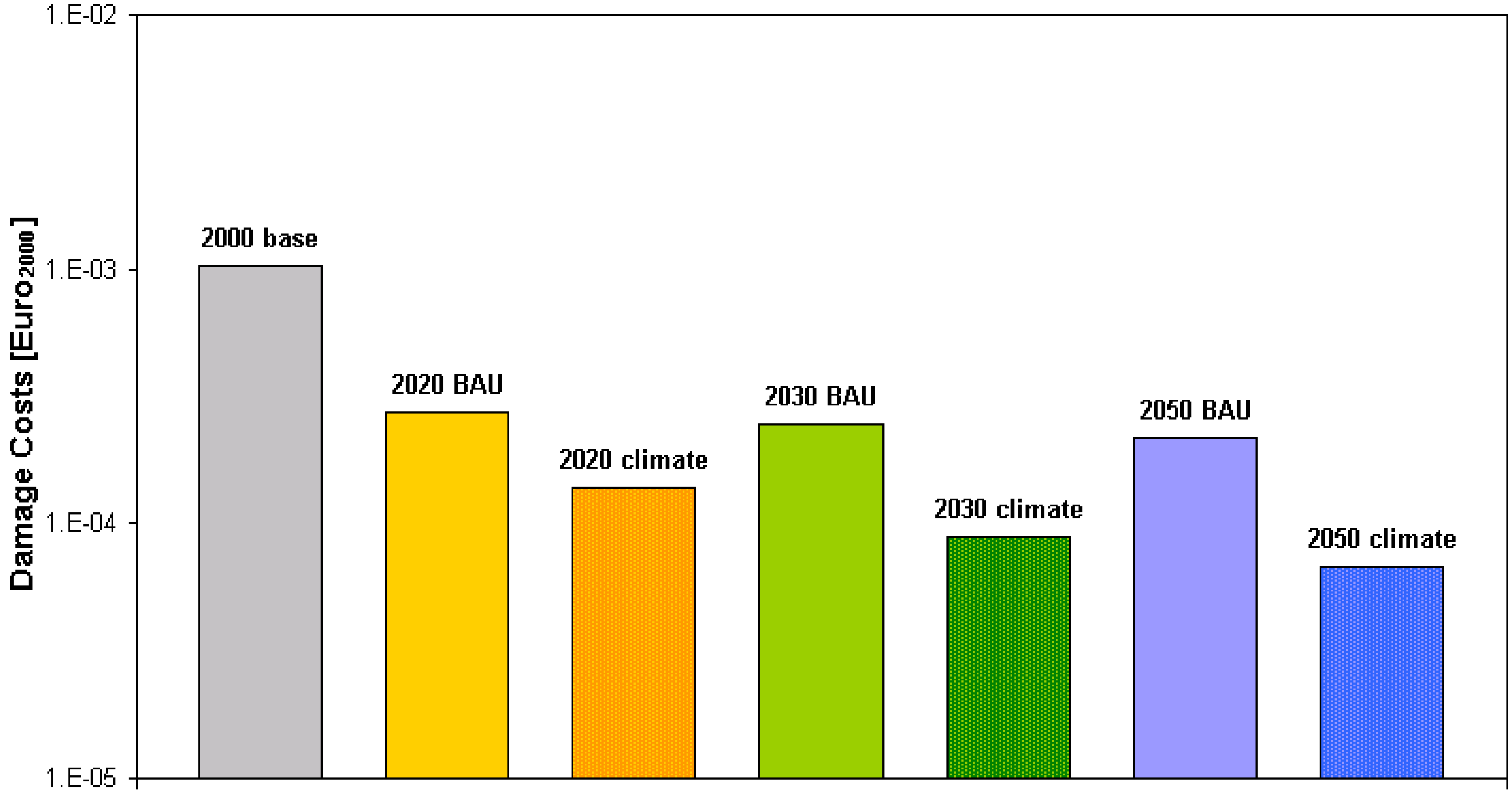
→ < 2500 DALY in Europe in 2000 baseline scenario due to ingestion of trifluralin via ingestion

DALYs due to PCB-153 – total EU



Damage Costs of PCB-153 – total EU

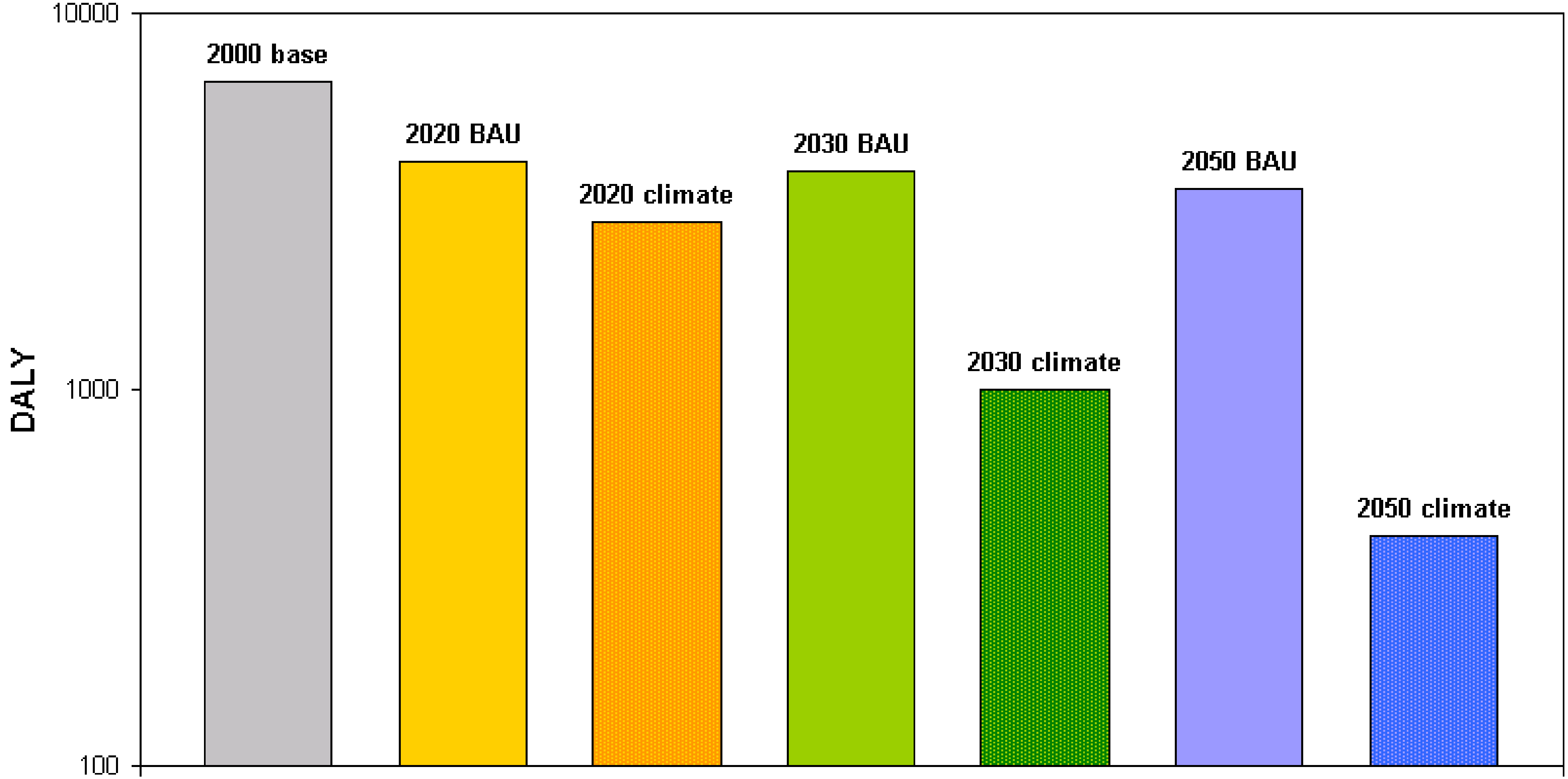
(non-dioxin like PCBs show other health effects than PCB-153, but so far not quantified)



DALYs due to 2,3,4,7,8-PeCDF – EU29

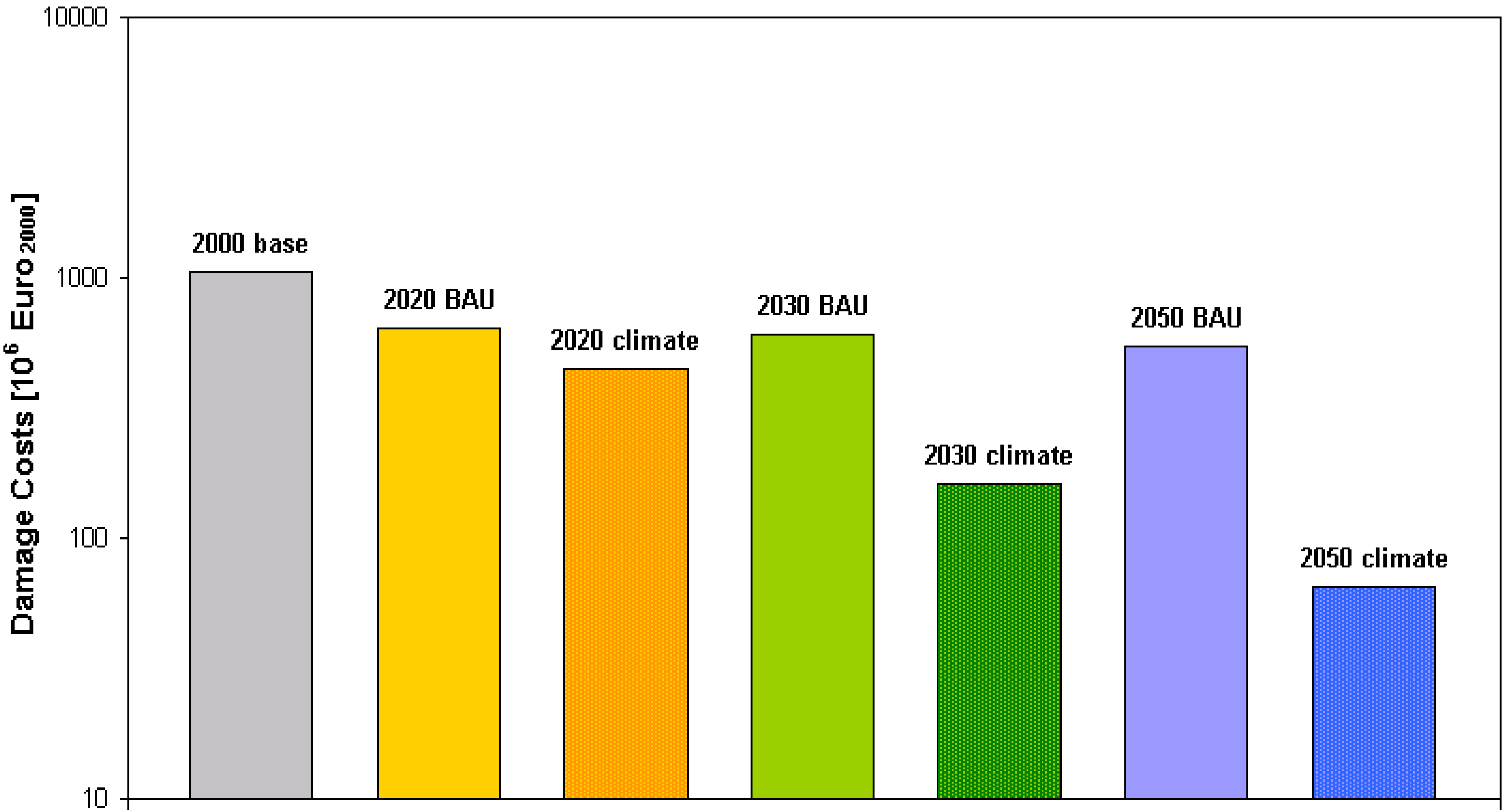
For 4pentaclorodibenzofuran,

impacts from all dioxins and furanes ca. 2,5 times higher



Damage Costs of Dioxins – total EU

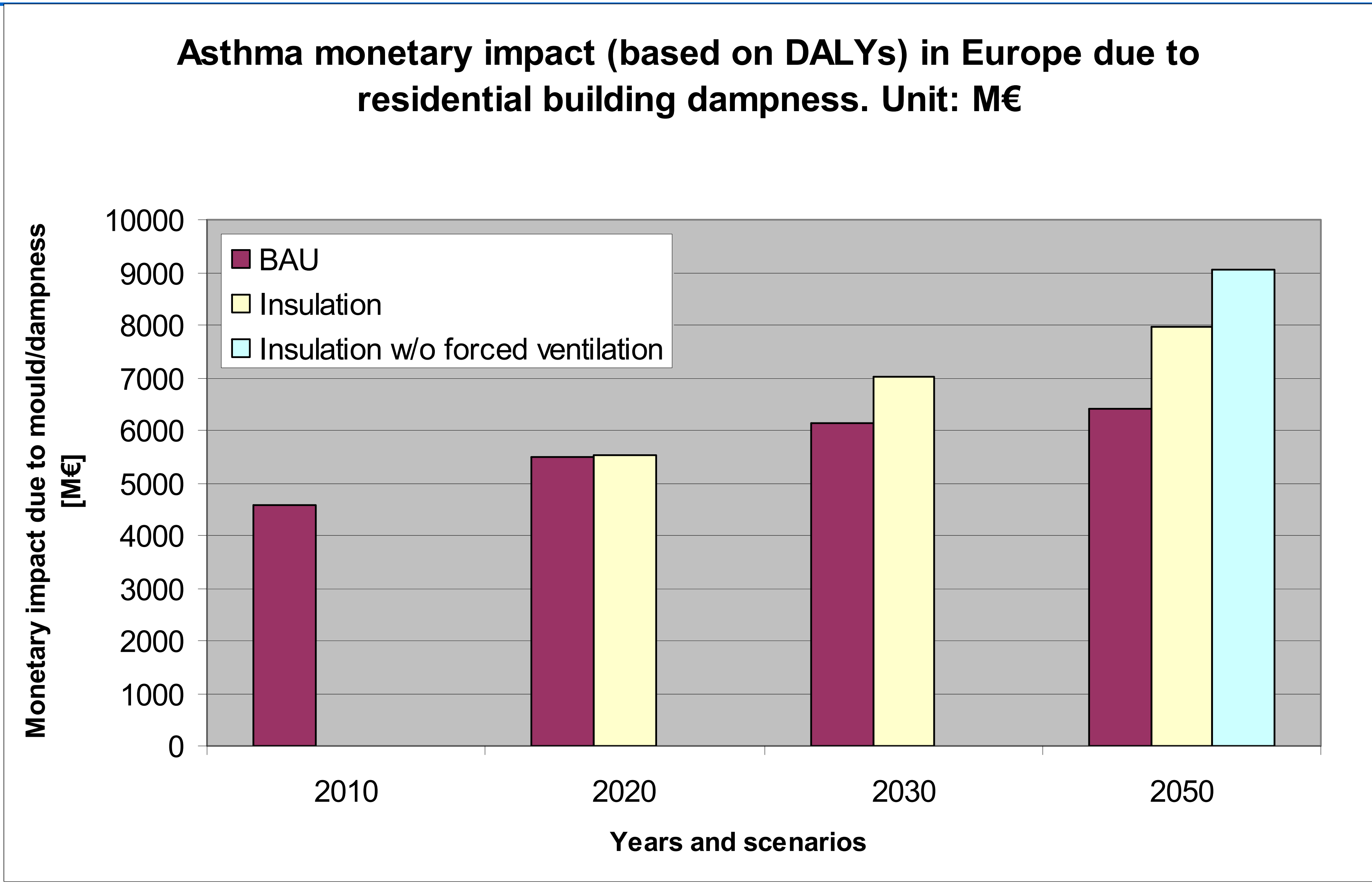
Damage costs (extrapolated to overall Dioxin/Furan congener mix; estimated)



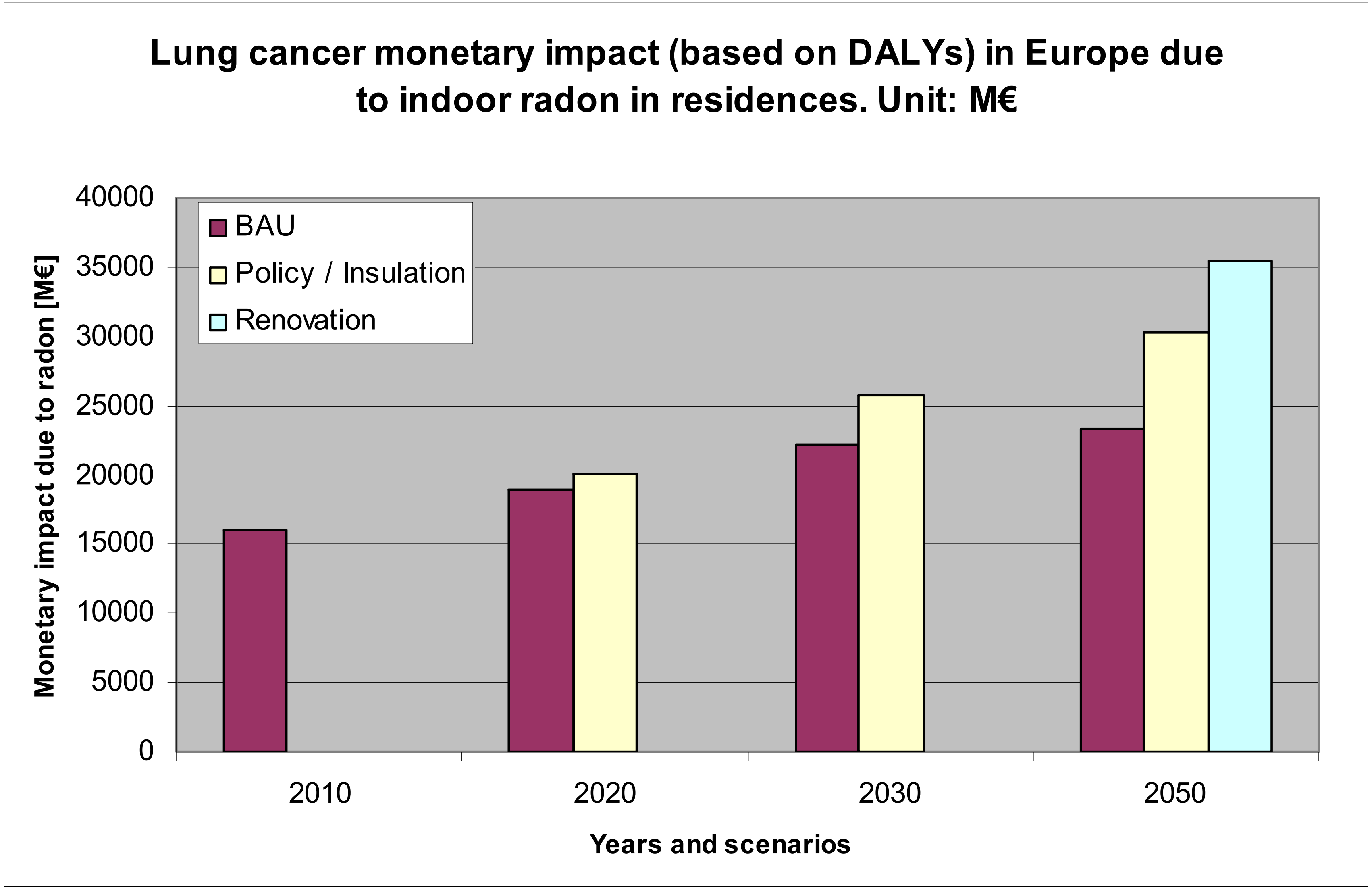
Heat stress (1000 premature deaths/a)

	2010	2030	2050
Reference	14,6 (8-23)	41,2 (22-67)	78,4 (42-123)
2° scenario	14,6 (8-23)	38,4 (21-61)	46,3 (24-77)
difference		2,8	32,1

Mould - dampness (1000M€ = ca. 17 000 DALYs)



Radon


Lung cancer monetary impact (based on DALYs) in Europe due to indoor radon in residences. Unit: M€
Monetary impact due to radon [M€]
40000
35000
30000
25000
20000
15000
10000
5000
0
BAU
Policy / Insulation
Renovation
2010
2020
2030
2050
Years and scenarios

Overall:

- **In 2050 reduction of ca 3,2 billion t CO2-eq. and**
- **reduction of environmental health damage by ca 450 000 DALYs or 50 billion €**
- **= additional benefit of ca 15 € per t of CO2 eq. or ca. 0,15 mDalys per t of CO2 reduced**

However:

2020: - 5 €/t CO2; - 0,08 mDALYs/t CO2

2030: 9 €/t CO2; 0,14 mDALYs/t CO2

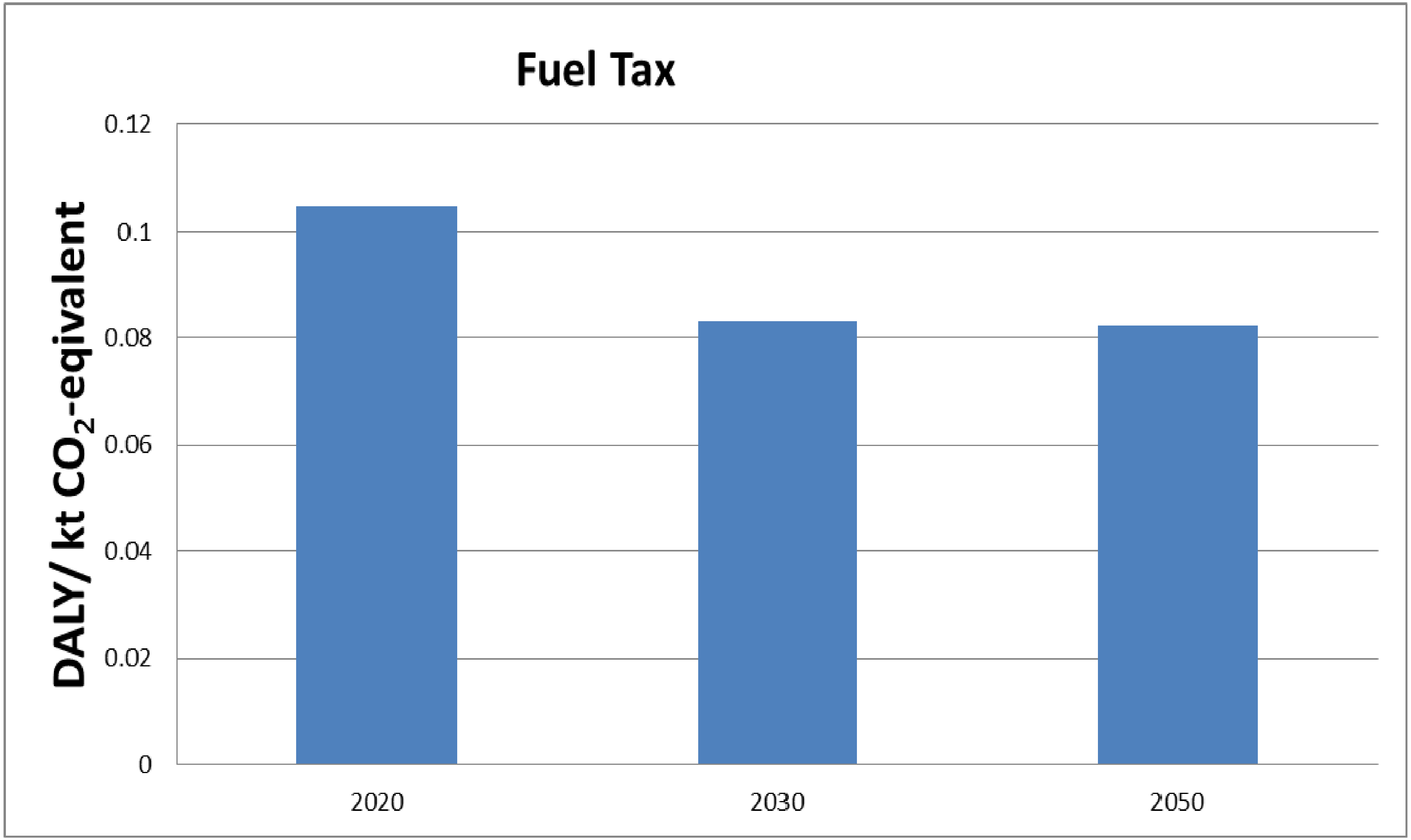
-> Assessment of single measures embedded in full scenario is necessary

Insulation Scenario - Results

Change (between insulation and BAU/Ref) in different metrics due to renovation (= *additional* DALYs and damage costs)

Pollutant	DALYs	Damage costs
Radon	264,171	12,232 Mio. EUR
Mould	58,857	2,656 Mio. EUR

Fuel Tax


Fuel Tax
DALY/ kt CO_2-eqivalent
0.12
0.1
0.08
0.06
0.04
0.02
0
2020
2030
2050

Conclusions

i. **The impact of most climate change mitigation policies on environmental human health is about as important as the climate change effects.**

ii. **Some policies, especially biomass burning and reducing air exchange rates in houses, cause quite high additional health impacts.**

iii. **The analysis allows a ranking of stressors in environmental media with regard to overall health impacts:**

PM -> noise, radon -> ozone -> mould -> dioxins, heat waves-> pesticides -> PCBs

iv. **In general: relevant 'side effects' will change policy recommendations substantially, should thus be taken into account when making decisions and can be taken into account using th IEHIA methodology**

More information: www.integrated-assessment.eu