Modelling mercury emissions and abatement scenarios with the multi-pollutant GAINS model

Virtual Workshop

Peter Rafaj, Flora Brocza

International Institute for Applied Systems Analysis (IIASA)
Energy, Climate and Environment (ECE) program
http://gains.iiasa.ac.at/

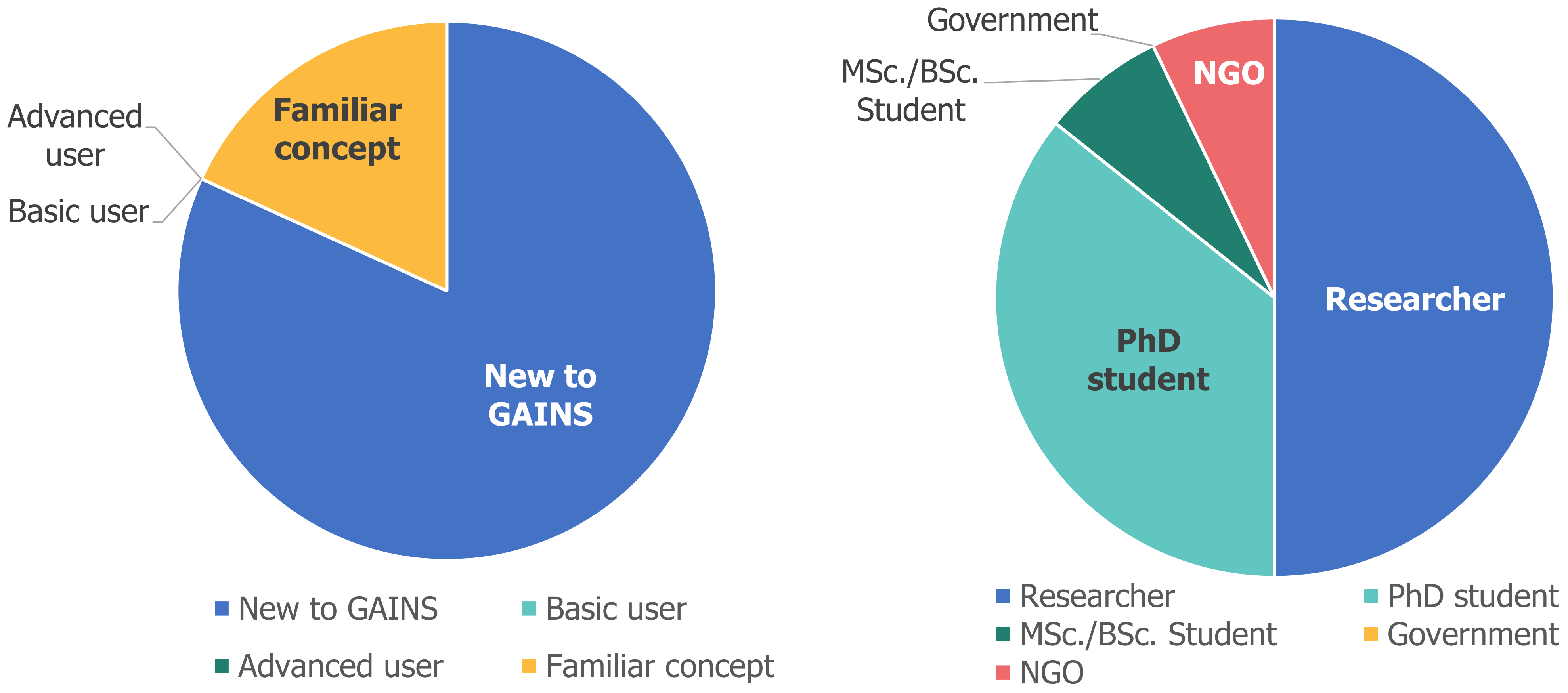
ICMGP 2022 Workshop Series

19 July 2022

Workshop Schedule

Time (CET)		
14:00 - 14:15	Welcome	
14:15 - 14:45	Introduction to GAINS	Peter Rafaj
14:45 - 15:15	Case study: a bottom-up inventory on mercury co-benefits in China's coal power sector	Jiashuo Li Sili Zhou
15:15 - 15:45	Mercury representation in GAINS	Flora Brocza
15:45 - 16:00	Break	
16:00 - 16:45	The Hg-GAINS interface	Flora Brocza, Peter Rafaj
16:45 - 17:00	Closing	

Welcome!



Advanced user
Basic user
Familiar concept
New to GAINS
New to GAINS
Basic user
Advanced user
Familiar concept
Government
MSc./BSc. Student
NGO
Researcher
PhD student
Researcher
PhD student
MSc./BSc. Student
Government
NGO

Welcome!

https://www.menti.com/4mnt5zi6i7

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Introduction to the GAINS model

Peter Rafaj

Introduction to GAINS

Greenhouse gases - Air Pollution Interaction and Synergies Model

Multi-pollutant, multi-effect integrated assessment model

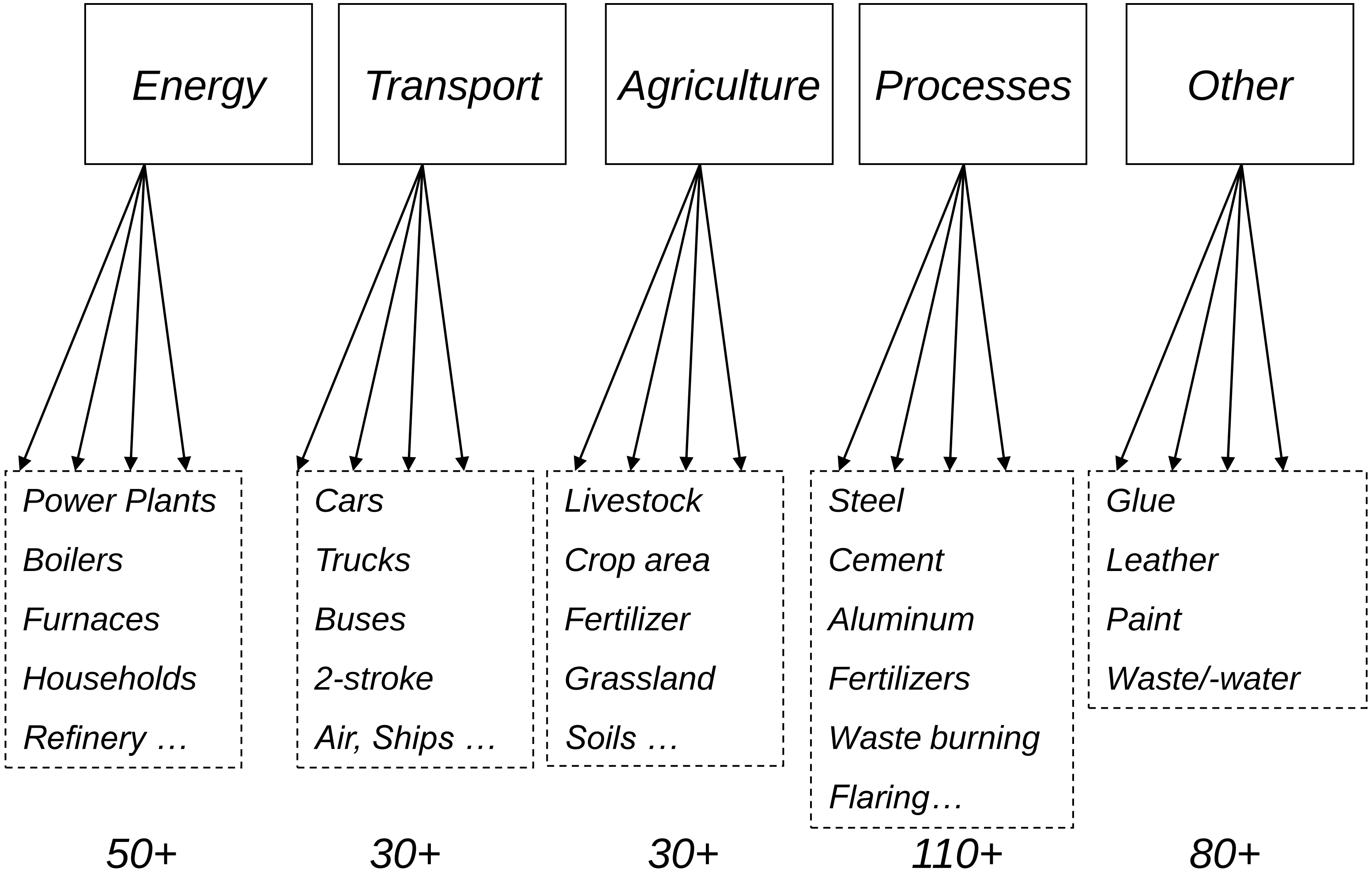
- Activity-based emissions inventory
- Simulation of future scenarios/incl. “What if policies were implemented?”
- Comparison of alternative scenarios
- Co-benefits quantification
- Cost-effectiveness analysis

Emission calculation principles

$$E_i = \sum_{j,k,m} E_{i,j,k,m} = \sum_{j,k,m} A_{i,j,k} ef_{i,j,k} (1 - eff_m) X_{i,j,k,m}$$

i,j,k,m	Country, sector, fuel, abatement technology
E_i	Emissions in country *i*
A	Activity in a given sector
Ef	“Raw gas” emission factor
eff_m	Reduction efficiency of the abatement option *m*
X_m	Implementation rate of the considered abatement measure *m*

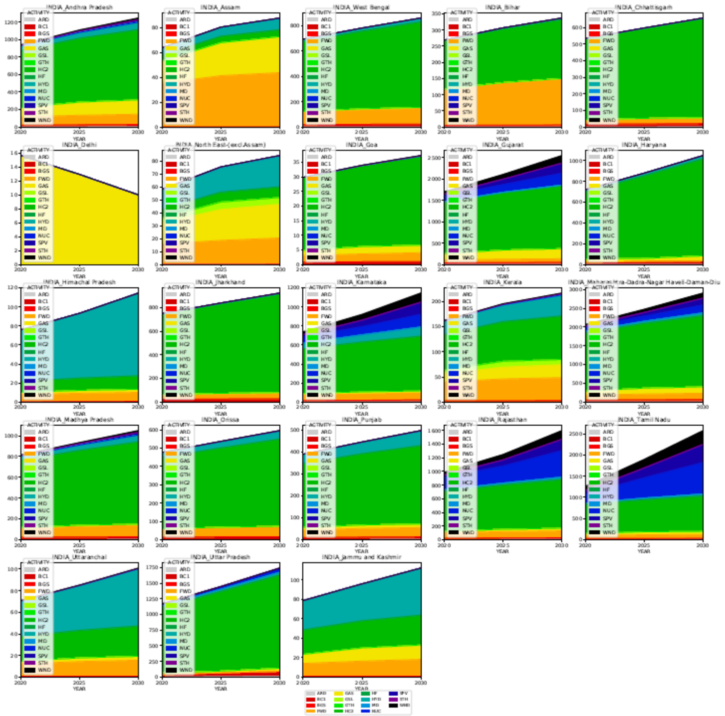
300+ Sectors in GAINS



Developing future scenarios

Pulling it all together

Activity data



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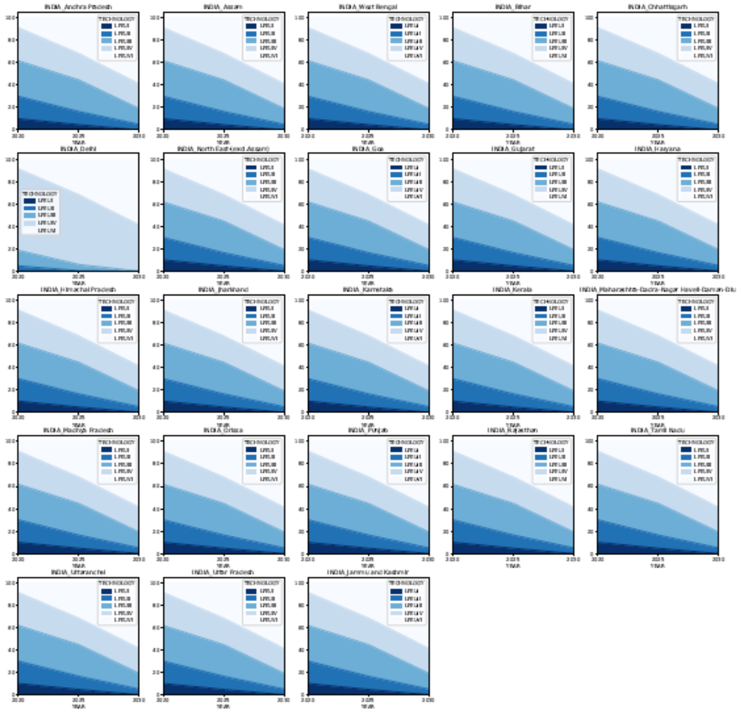
Control strategies



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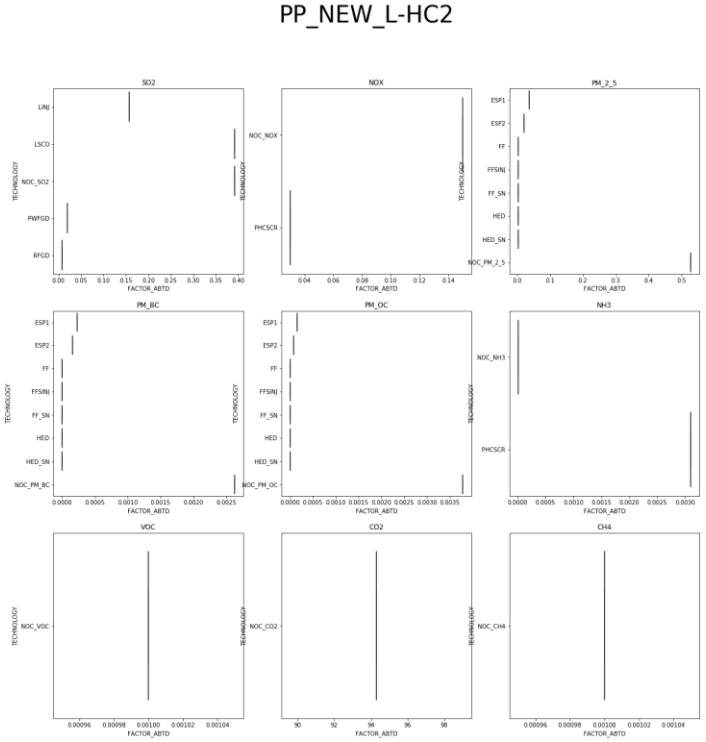
Emission factors



THE RELATIONSHIP BETWEEN AIR POLLUTANTS AND GHGs

	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	●	●	●	●	●	●	○	●	○	○
Carbon deposition to the Arctic and glaciers	●									

Note: ● – important impact; ○ – small impact. GWP – global warming potential.

GAINS model –
the central analytical tool for air pollution negotiations in Europe

Convention on Long-range Transboundary Pollution

1994 Second Sulphur Protocol

1999 Gothenburg Multi-pollutant/Multi-effect Protocol

2012 Revised Gothenburg Protocol

2021-22 Review of the Gothenburg Protocol

IIASA designated as EMEP Centre for Integrated Assessment Modelling

European Union

1995 EU Acidification Strategy

2001 National Emission Ceilings Directive

2005 Thematic Strategy on Air Pollution

2016 Clean Air Policy Package

2017-22 Clean Air Outlooks

2017-22 Support climate policy development (Green Deal)

2021-22 Revision of Ambient Air Quality Directive

IIASA leads the "European Consortium for Modelling of Air and Climate Strategies"

FURTHER AIR QUALITY IMPROVEMENTS IN ASIA REQUIRE A RE-ORIENTATION OF CURRENT POLICIES

Measures already in place in 2015
- Vehicle emission standards
- TSP controls at large plants

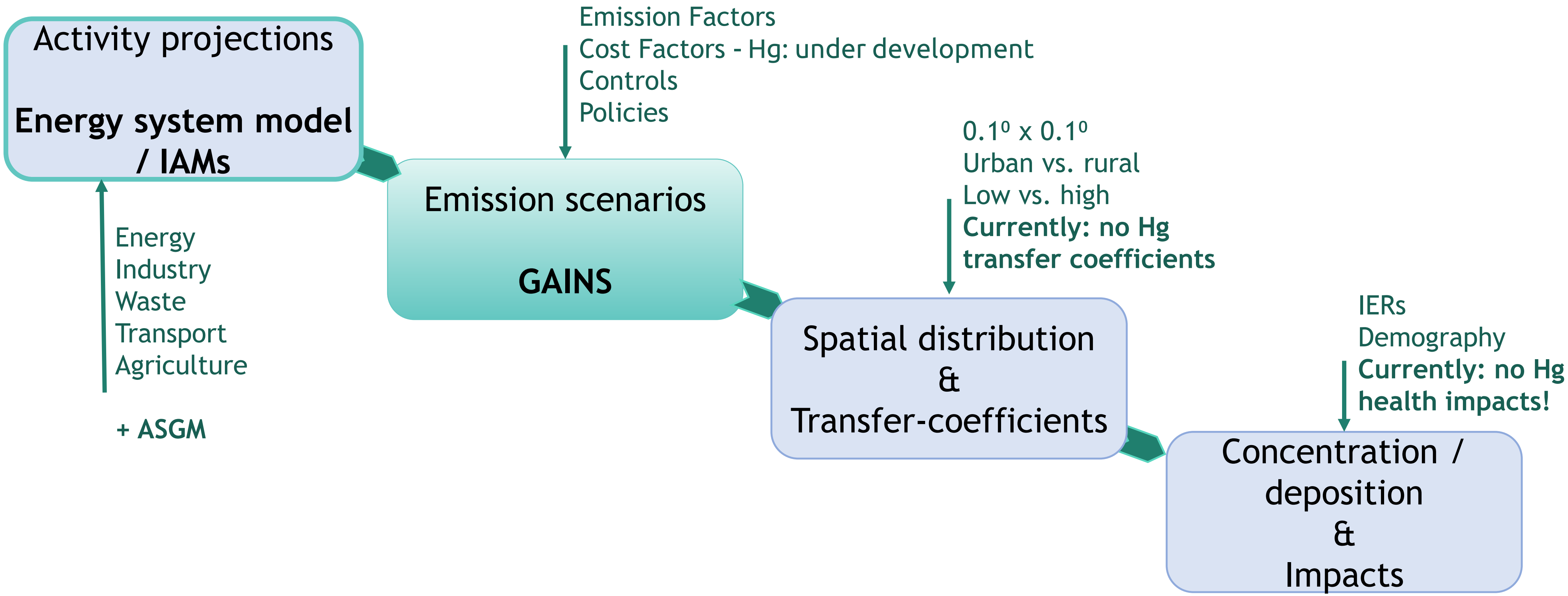
Post-2015 legislation
- SO_2+NO_x controls at stationary sources

Other 'conventional' PM controls

'Next stage' air quality measures
- Fertilizer use, manure management, open biomass burning, residential waste burning, I&M of vehicles

SDG measures
- Clean cooking fuels, renewable energy
- Energy efficiency, waste management
- Public transport and electric vehicles

From exogenous inputs to the GAINS model runs

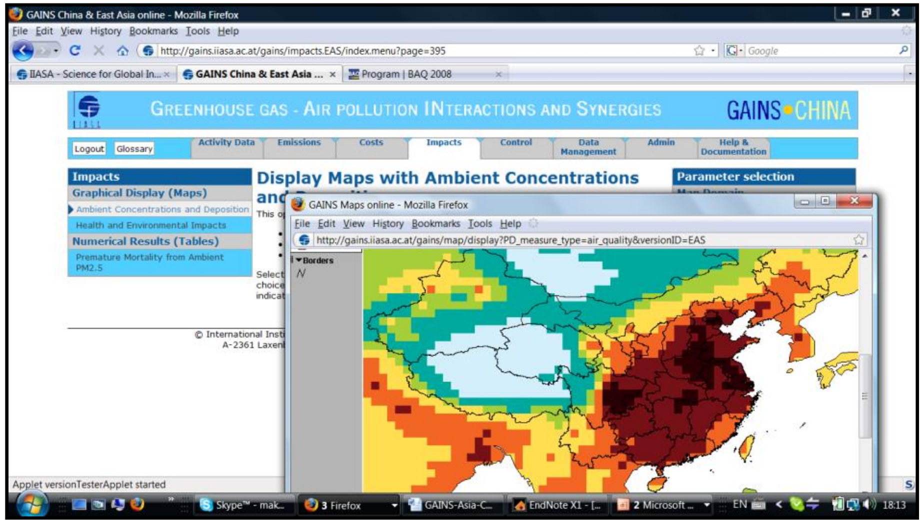


The GAINS model implemented for several regions with varying scientific and policy objectives

- Implemented/applied for:
  Europe, Asia, Latin America, Arctic, Italy, Netherlands, Sweden, Korea, Beijing, Annex I (GHG), and global

- Access to on-line versions
  http://gains.iiasa.ac.at/models
  - Europe
  - East Asia
  - South Asia
  - Global

- Implementations for other countries/regions are possible … some underway



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Case study: a bottom-up inventory on mercury co-benefits in China's coal power sector

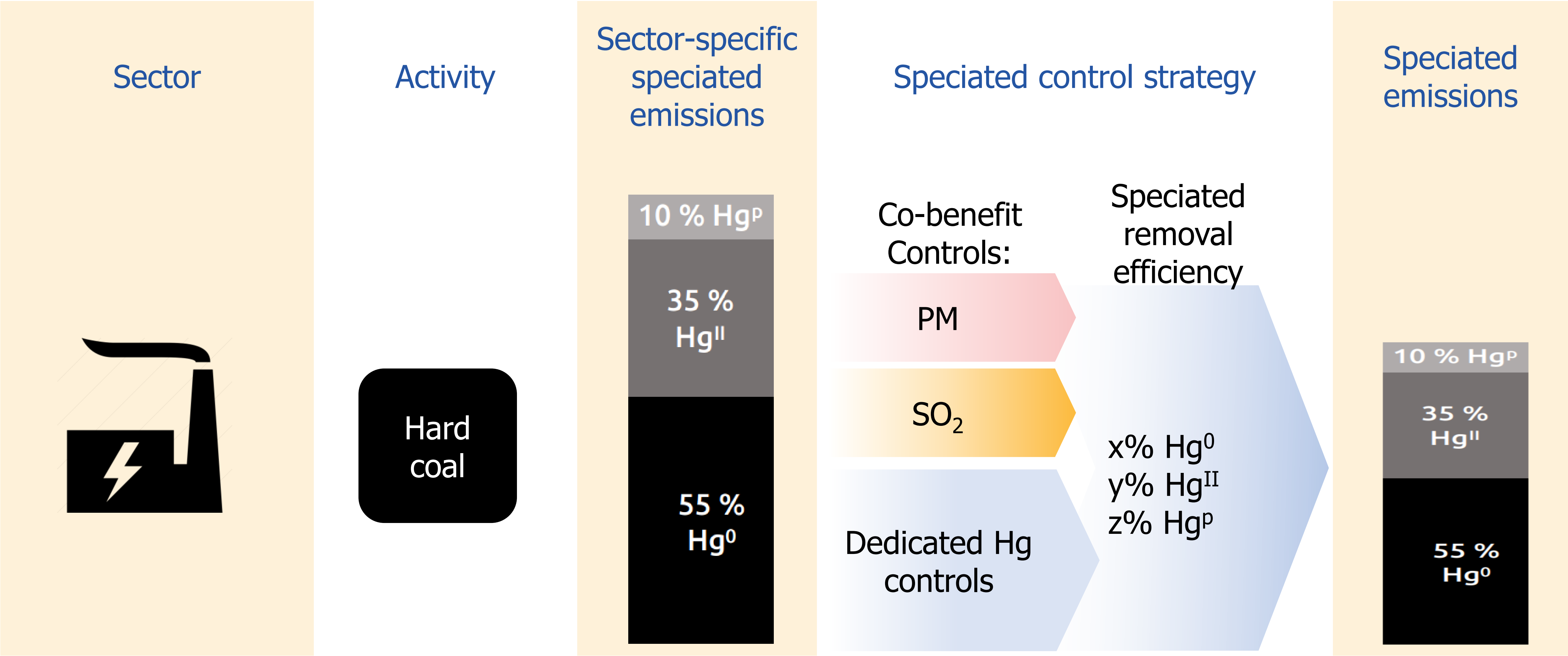
Sili Zhou[1], Jiashuo Li[2]

1 School of Energy and Power Engineering, Huazhong University of Science and Technology
2 Institute of Blue and Green Development, Shandong University

Mercury representation in GAINS

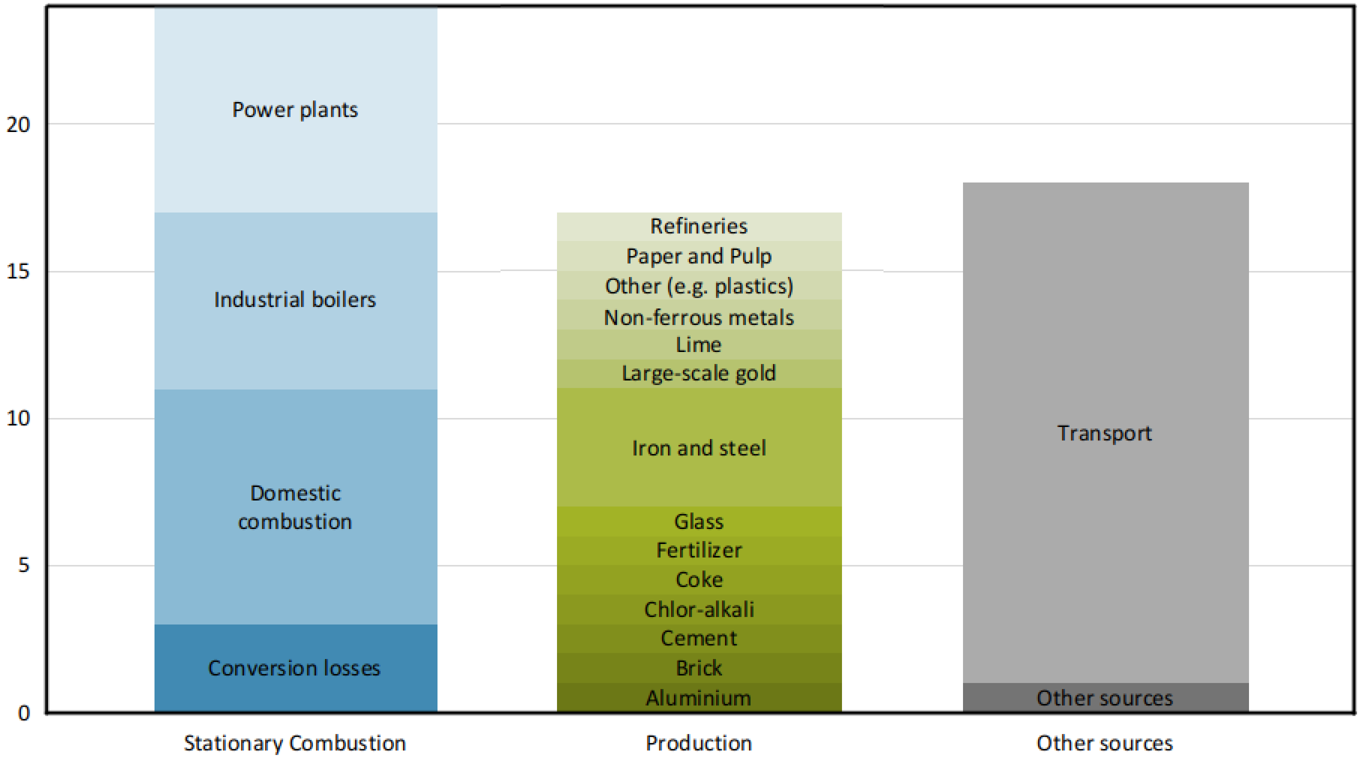
Flora Brocza

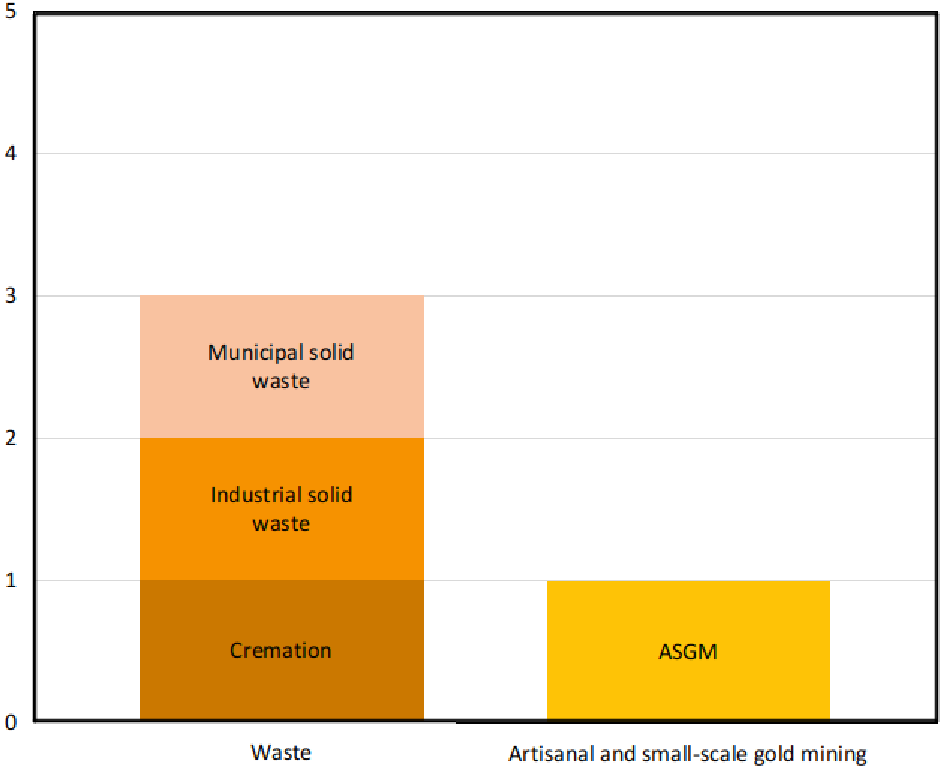
Mercury representation in GAINS



Sectoral resolution of mercury emissions in GAINS

Y-axis: Number of GAINS sectors with associated Mercury emissions





Further split according to fuel types:
Brown coal (2), hard coal (3), coke,
biomass, waste, diesel, heavy fuel oil, ...

Activity data

Hard coal

Historical years:

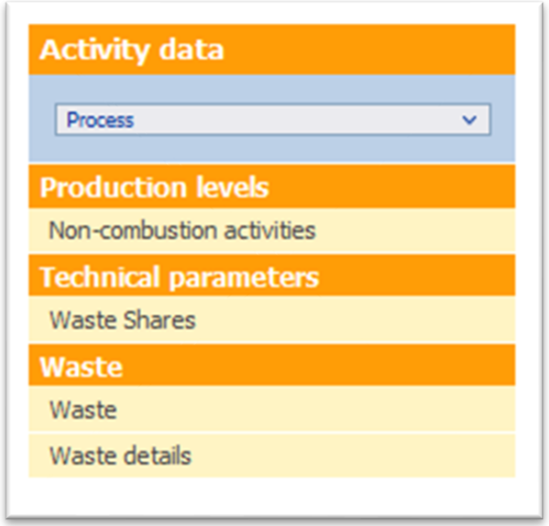
- E.g. Eurostat, IEA statistics, national and sub-national stats (f.ex. Chinese Energy Yearbook)

Projections:

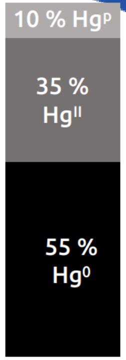
- Integrated Assessment Models (IAMs)
  - MESSAGEix (global)
  - PRIMES (Europe)
  - IEA World Energy Outlook

Additional Hg-specific activities & shares:

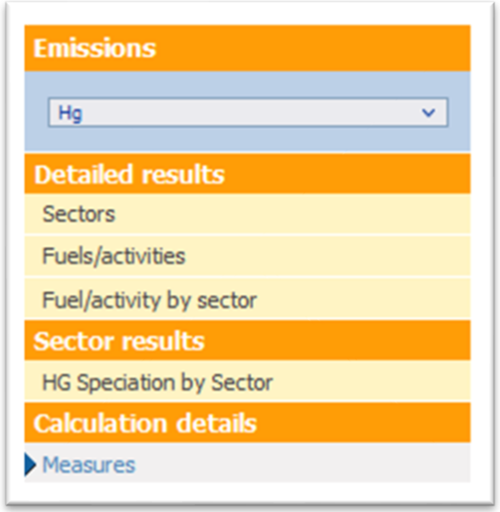
- Global Mercury Assessment
  - E.g. ASGM, VCM, Hg mining
- USGS Minerals Yearbooks
  - E.g. gold, shares of non-ferrous metals, iron & steel
- Other literature sources
  - E.g. shares of population that is cremated



Hg emission factors



- Various literature sources
  - Global Mercury Assessments (GMA), UNEP reports, USGS, surveys,…
  - See Rafaj et al. 2013 (DOI: http://dx.doi.org/10.1016/j.atmosenv.2013.06.042
- Speciation
  - Literature review! --> total EF distributed over species
- Comparison to GMA values:
  - Coal combustion:
    - GMA '18: g Hg / t coal combusted -- GAINS: t Hg/ PJ coal combusted
  - Non-ferrous metals:
    - Emission factor regionalized to represent shares of Cu/Zn/Pb produced in each GAINS region; GAINS activities also include other NFME
  - Iron and Steel production:
    - sintering, lime production, pig iron production in blast furnace, basic oxygen furnace, electric arc furnace are all separate GAINS sectors



Control strategies

GAINS simulates **current** and **future policies** to control individual air pollutants.

- Complete list of applied controls per sector and activity for all years
- Info collected from policy documents & country experts, continually updated

PM, SO_2, CH_4, CO_2, CO, VOC, F gases, NOx, N_2O, NH_3, **Hg**

Even before adding Hg-specific information…
GAINS already includes very detailed, region-specific information on co-benefit controls!

Control technologies for mercury:

Co-benefit between PM, SO_2, Hg controls considered through calculation of “overlaps”

- PM and SO_2 controls clustered based on mercury removal efficiency
    - Dedicated mercury (...combined with PM + SO_2) controls
    - PM + SO_2 controls
    - Only PM controls

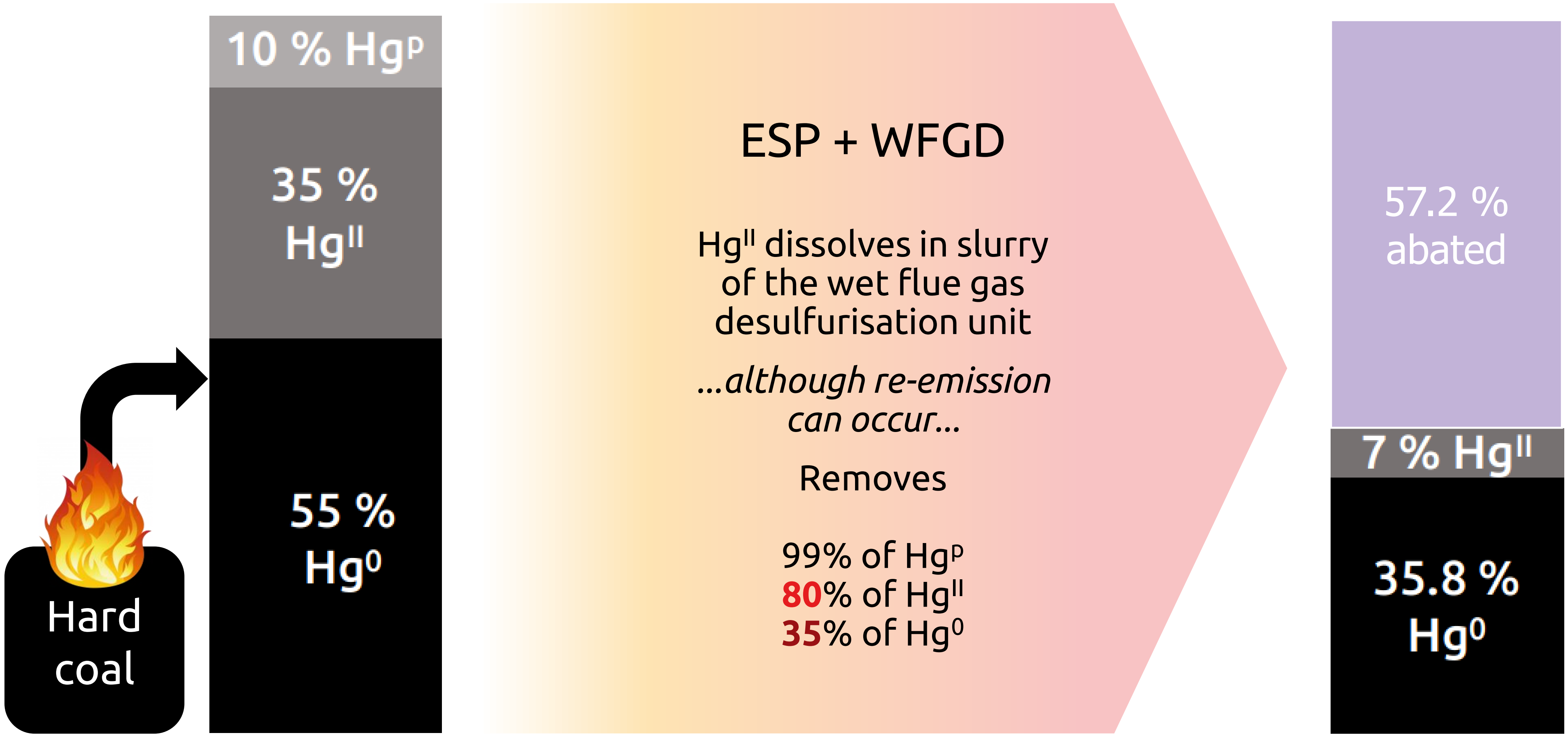
Mercury controls

- Washed / halogen-treated coal
- Stationary sorbent units
- Sorbent injection with and without additional fabric filter

Why not NOX controls?

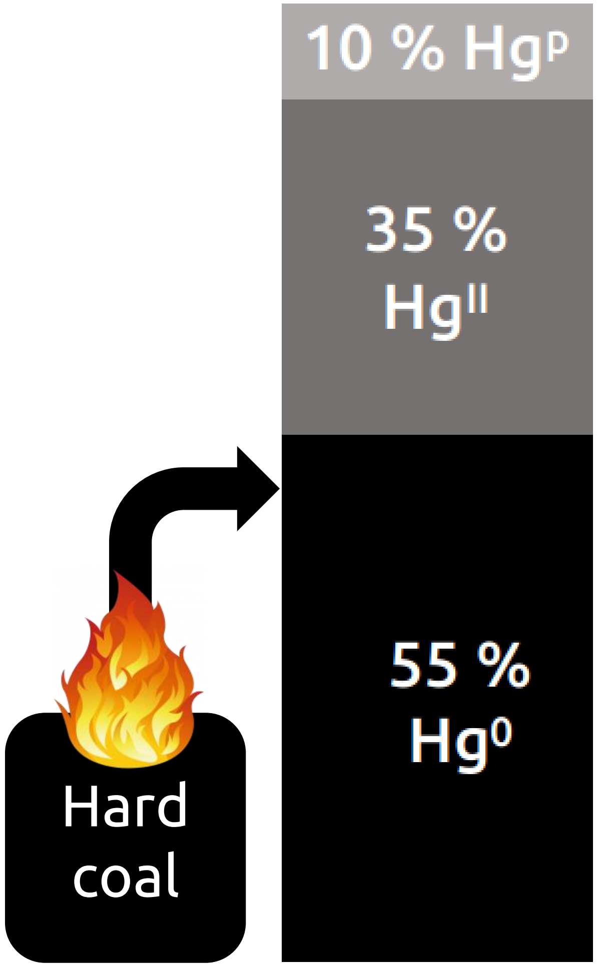
Example 1: Co-benefit from PM and SO_2 control

Fuel = Hard coal, sector = existing power plant (built before 2000), >50MW_{th}



Example 2: Sorbent Injection + Fabric Filter

Fuel = Hard coal 1, sector = existing power plant >50MW



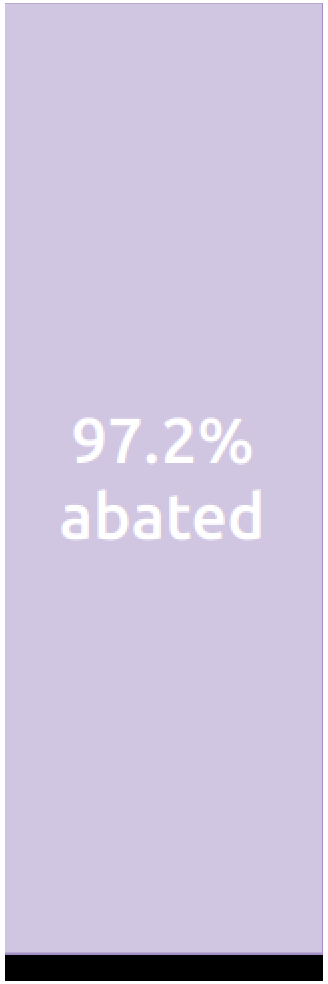
FFSINJ

Hg^{0}, Hg^{II} bind to the (activated carbon) sorbent, can now be collected in dust control

Removes

99.98% of Hg^{P}
99.98% of Hg^{II}
95% of Hg^{0}

Co-benefit with PM control (e.g. existing ESP, HED)



Additional mercury control technologies

Cement & lime production

- Dust shuttling

Non-ferrous metal smelting, large-scale gold

- Acid plants

Small-scale gold production

- Ban
- "Good practice": e.g. use of retorts, lower mercury quantities per unit of ore

Chlor-alkali production

- Ban

Cremation

- "Good practice"

Mercury emission control

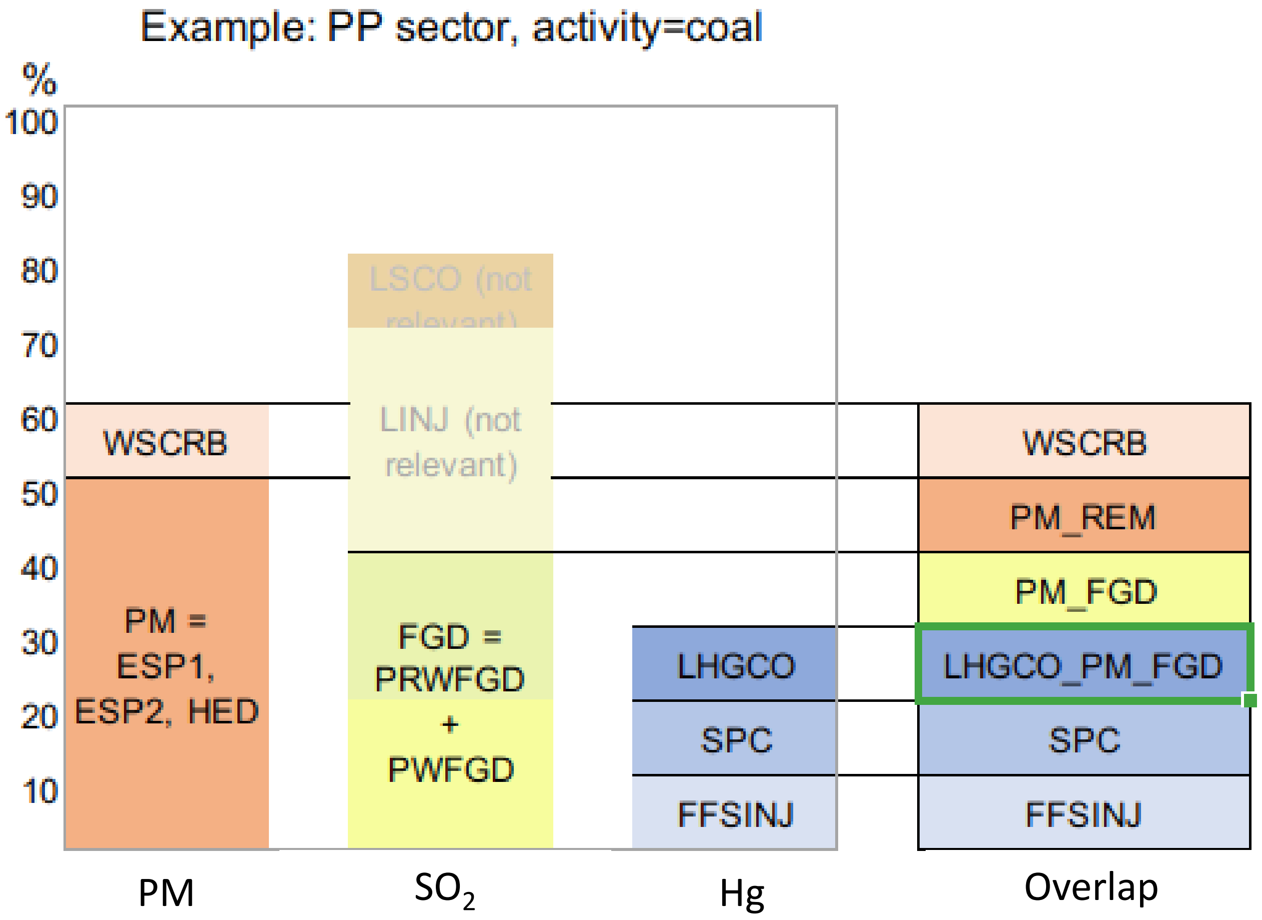
Example: Power plants built before 2000 in China, fuel = hard coal;

PP_EX_L, HC, Technology: co-benefits from particulate matter control (PM_REM)

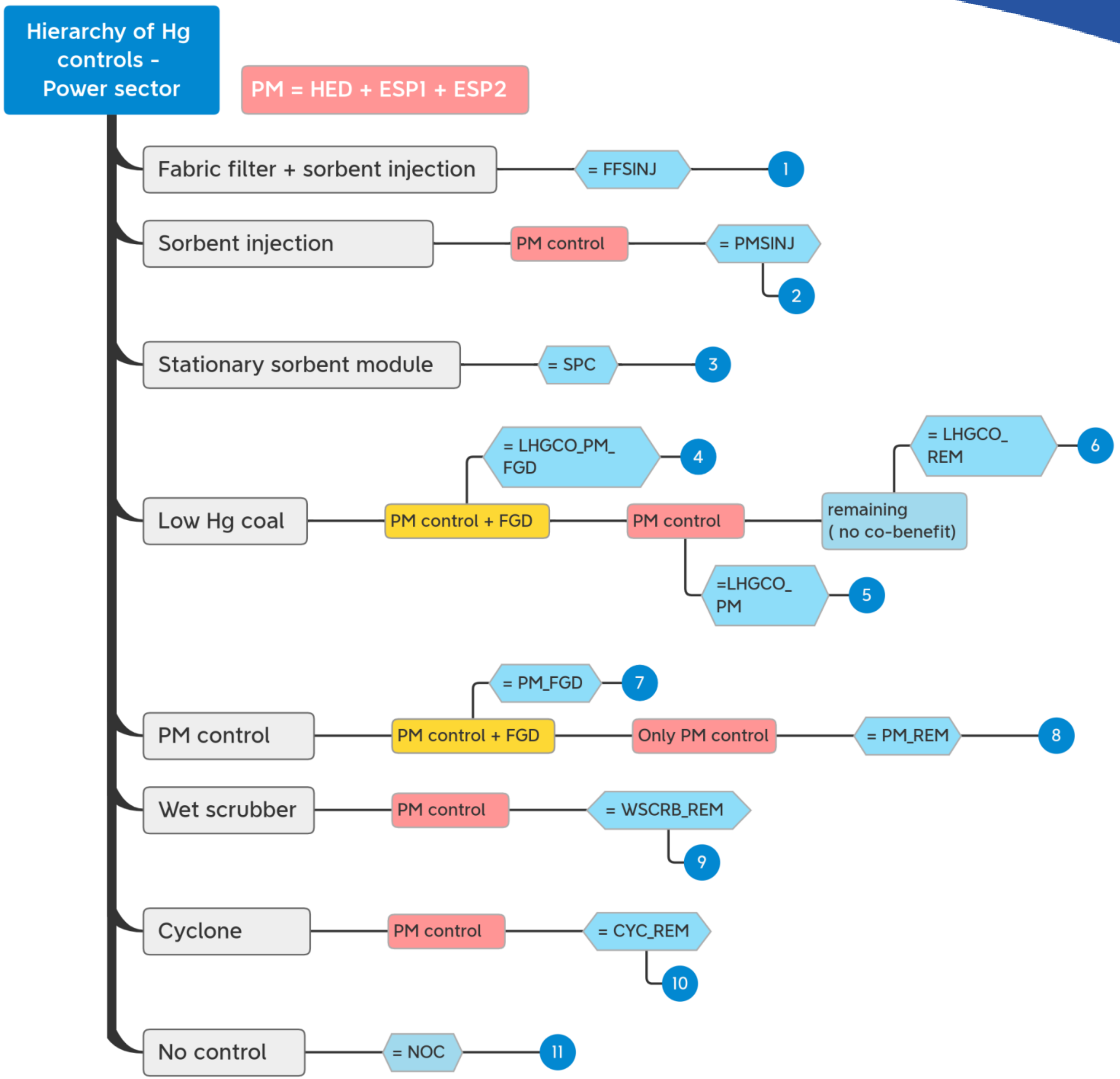
Species	Unabated emission factor: EF_NOC [g/GJ]	Speciation of unabated emissions [Shares]	Removal efficiency [%]	Abated emission factor [g/GJ]	Speciation of abated emissions [Shares]
Hg^0			35		0.51
Hg^{II}			55		0.47
Hg^p			97		0.02
total	0.00734		(0.55 x 0.35 + 0.35 x 0.55 + 0.10 x 0.97) = 0.482	0.482 x 0.00734 = 0.00354	

Combining PM, SO2 & Hg controls

- more efficient technologies take precedent over others;
- assumption: Hg-specific control equipment will be installed where high-efficiency PM and SO_2 control are already in place



Decision tree



What type of scenarios can be developed?

1. Can stringent emission targets be met by JUST the use of co-benefit technologies? → **Current legislation (CLE)** — only co-benfits from PM, SO_2 controls

2. What Hg emission trajectory are we on, considering commitments resulting from the Minamata convention? → **CLE + Minamata**

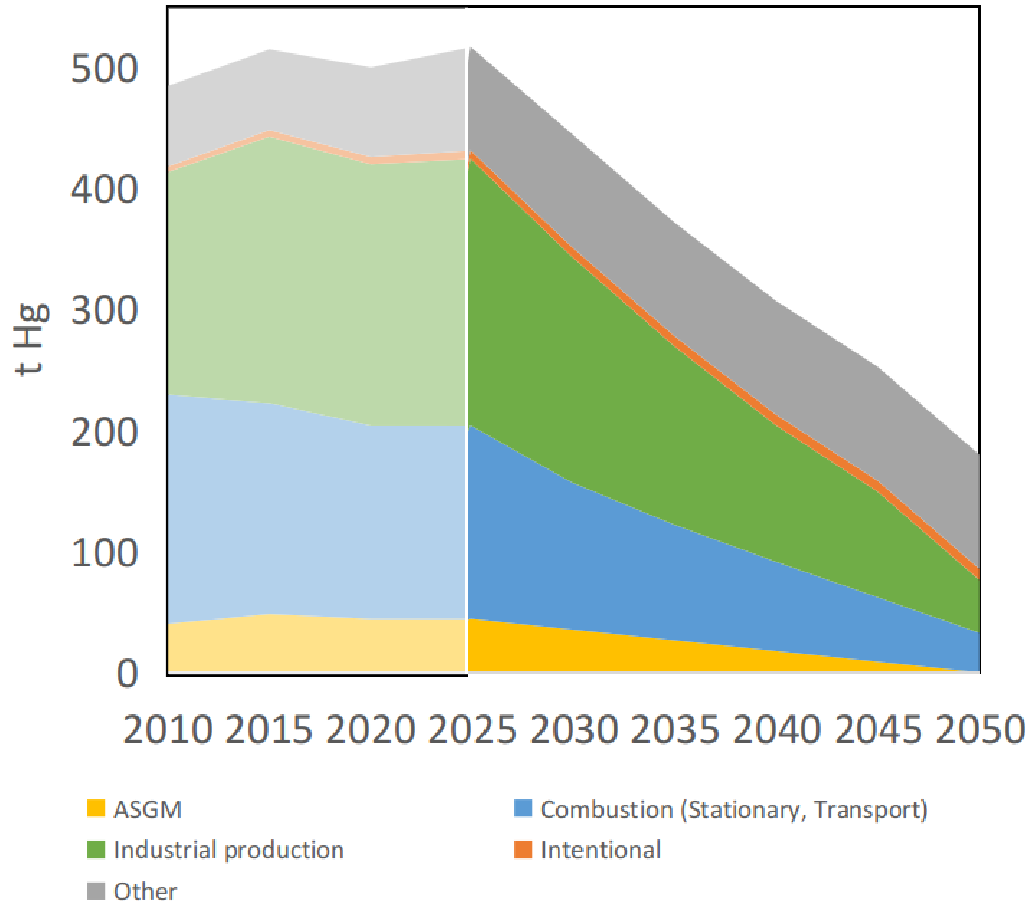
3. How will the relative importance of different emission sources change in a 1.5°C world? → **Climate targets + CLE**

4. What total Hg / Hg^0 reduction can be achieved using the currently available technologies? → **Maximum feasible reduction (MFR)** — Hg-MFR, Hg^0-MFR

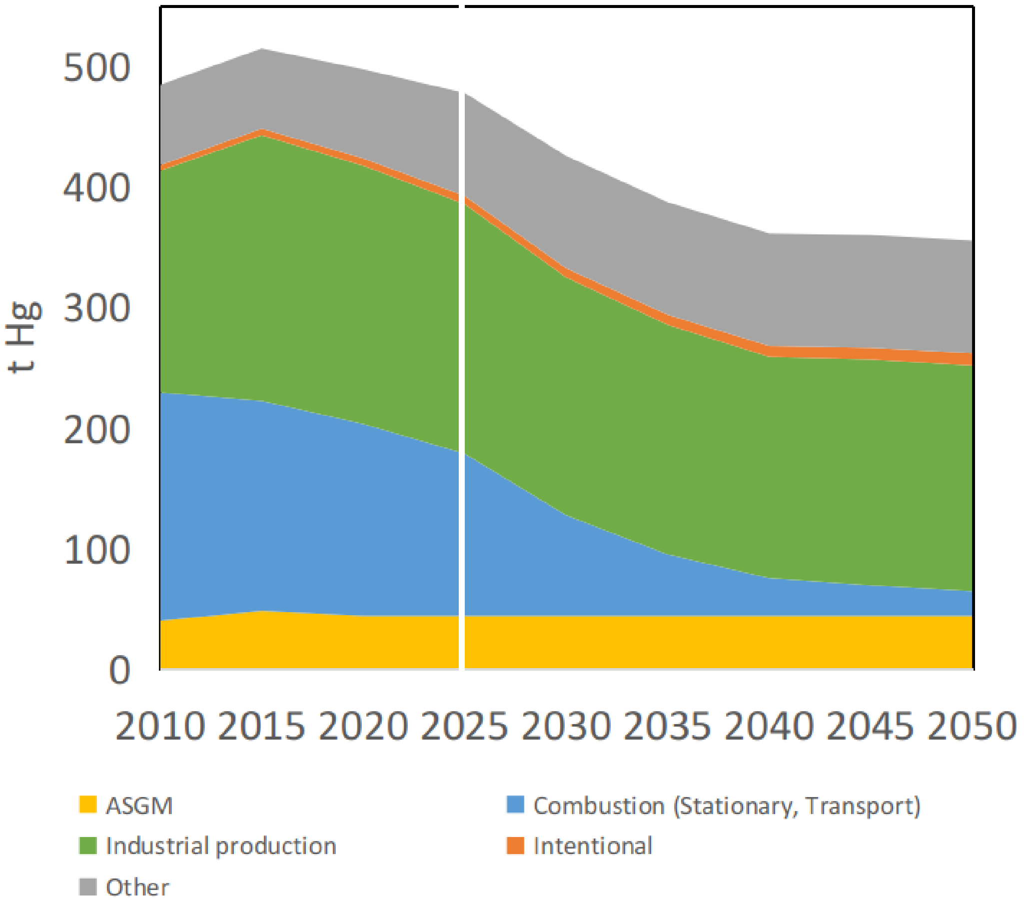
Scenarios

	NDC_CLE Baseline	1.5_CLE Climate targets + CLE	Hg-MFR Baseline + Hg MFR
Power plants	NOC PM+SO2	NOC PM+SO2	NOC Hg
Other combustion	PM PM+SO2	PM PM+SO2	PM PM+SO2 Hg
Production	PM BAN N/A	PM BAN Hg	Hg BAN Hg
Mining & metal production	NOC Hg PM+SO2	NOC Hg NOC	NOC Hg
Waste	NOC Hg	NOC Hg	Hg
ASGM	BAN	NOC	BAN
Others	PM NOC	PM NOC	PM NOC

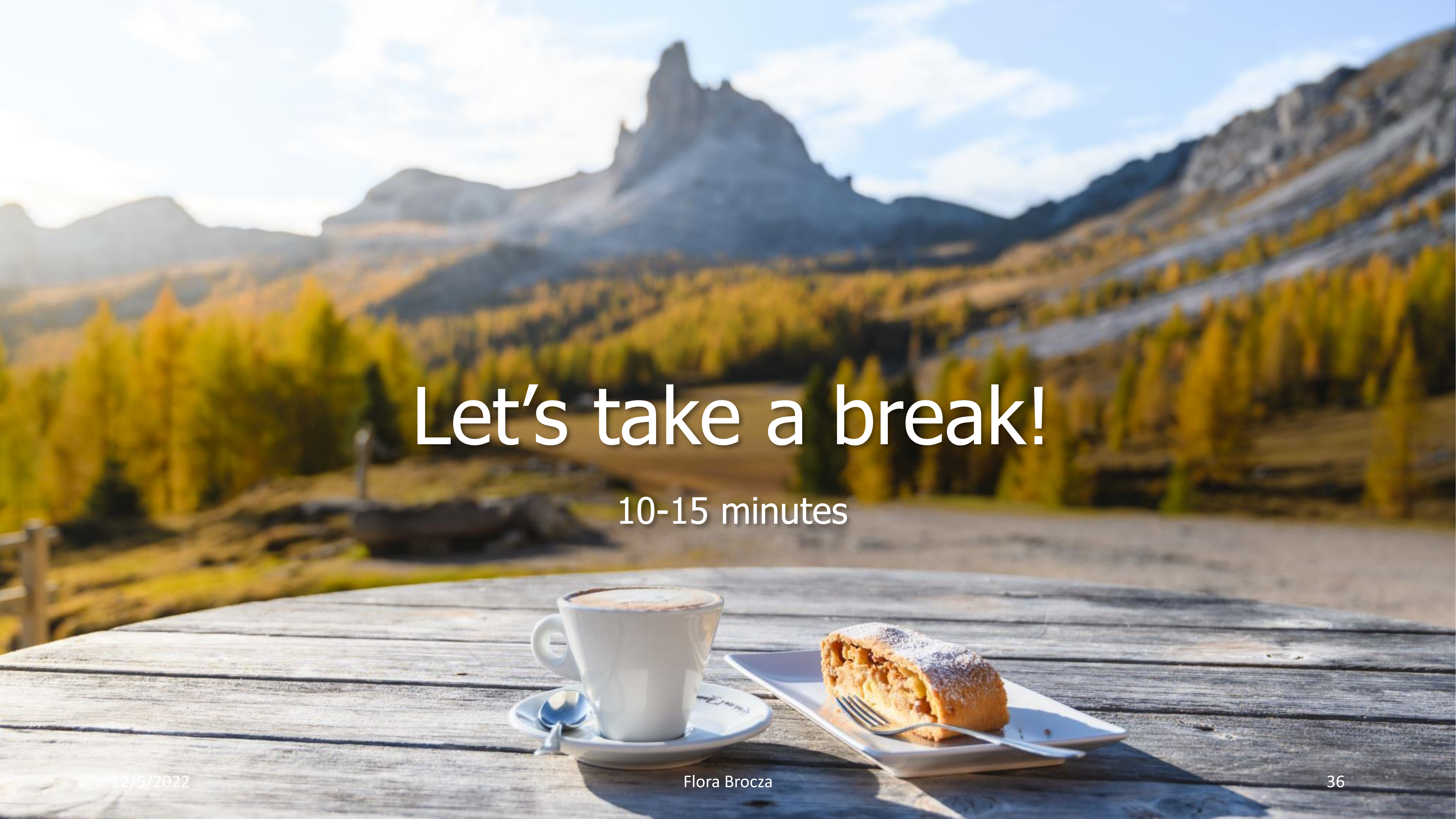
CHINA
Baseline, MFR for mercury



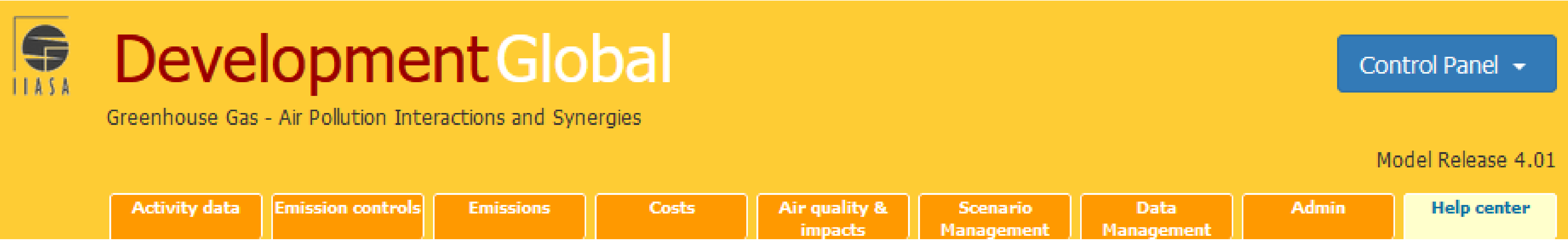
Net-zero carbon



MFR ... Maximum Feasible Reduction
ASGM ... Artisanal and Small-scale Gold Mining


Let’s take a break!
10-15 minutes

The GAINS interface



Currently not active
for mercury

(Costs in development)

How can I use the GAINS model?

Live GAINS model & registration:

http://gains.iiasa.ac.at/models/

As soon as mercury goes 'live' in the next months, we will inform all workshop participants!

Discussion

Quantification of co-benefits

- HG-GAINS can quantify co-benefits from PM, SO_2 and climate policy
- Large co-benefit mercury reduction to be can beachieved even in the baseline scenario.
- Stringent climate policy will drastically reduce Hg emissions, especially from energy generation and stationary combustion of fossil fuels

Link to Minamata

- Calculate impacts of Best Available Technologies from different emission sources
  - through control strategy
  - through adjustment of activities, emission factors

Outlook

Open Hg module to external users (via online interface)

Implementation of cost factors

Cost-effectiveness analysis