The Greenhouse gas - Air Pollution INteractions and Synergies (GAINS) Model: Domestic Sector

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- Residential and commercial sector
  - Cooking and heating
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  - Lighting
- Non-technical sources
  - Road dust emissions
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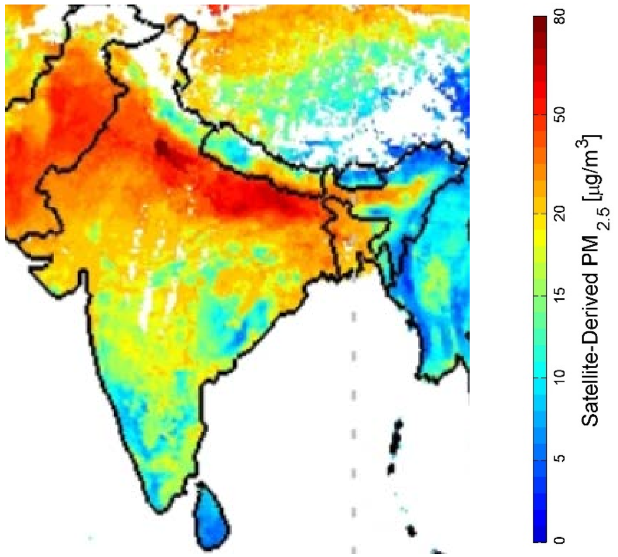
- GAINS control strategy

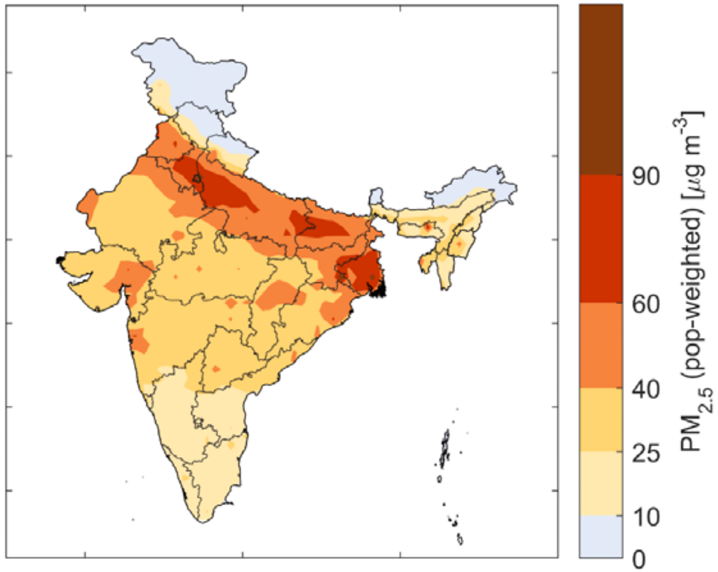
Air quality management needs to address urban and rural areas

Satellite-derived $PM_{2.5}$



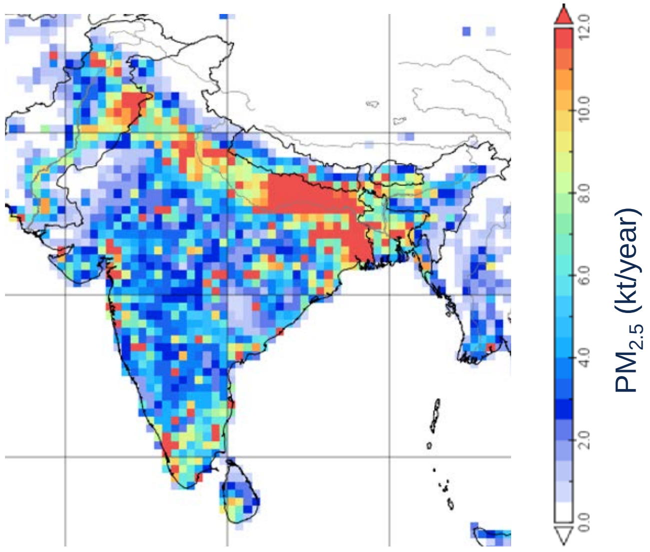
Source: NASA

Computed ambient levels of $PM_{2.5}$



Source: IIASA/GAINS

Emission densities of $PM_{2.5}$, 2015



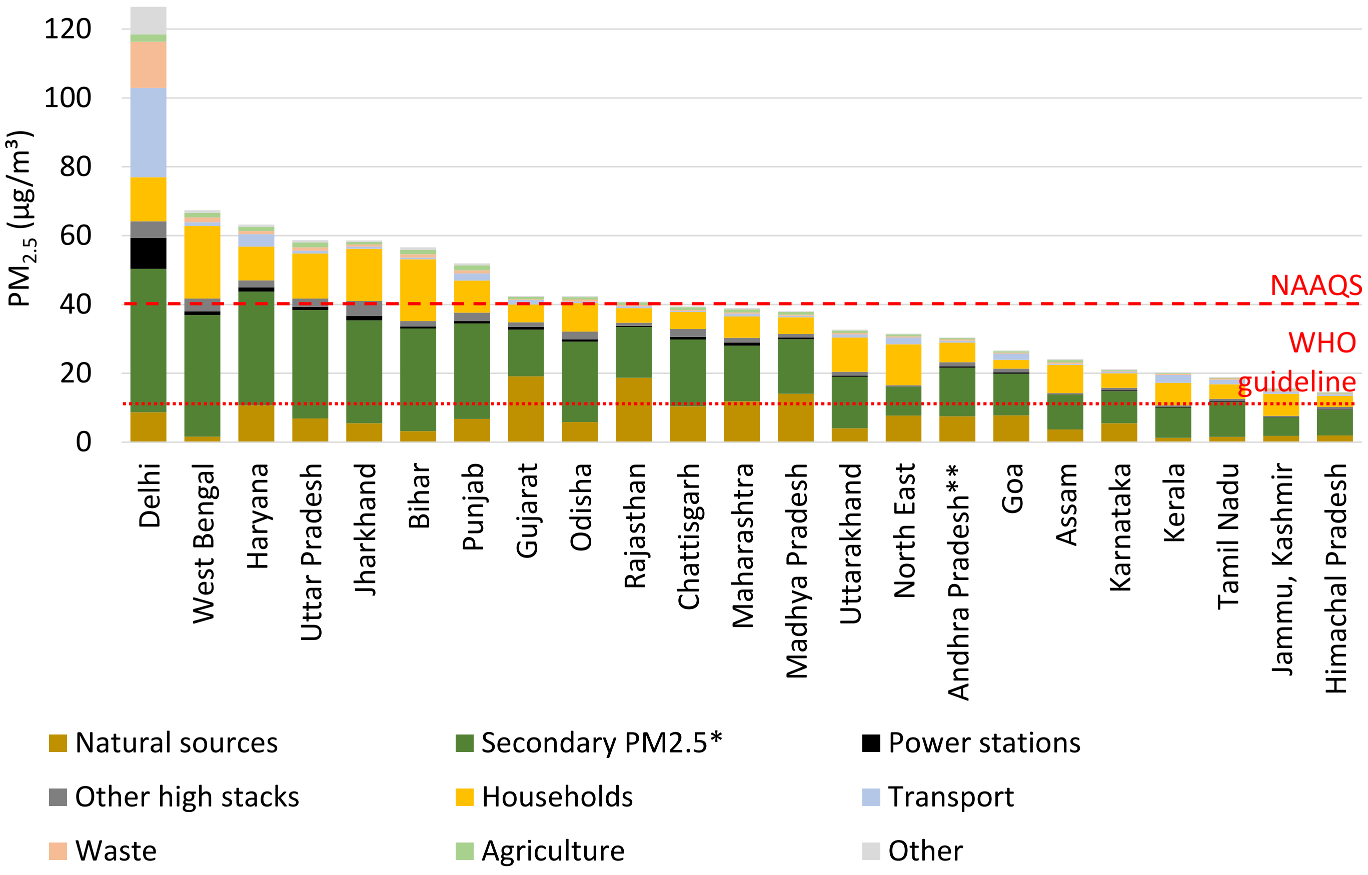
Source: IIASA/GAINS

- ❑ While current ambient $PM_{2.5}$ monitoring in India reveals high levels in urban areas, remote sensing, comprehensive air quality modelling and emission inventories suggest large-scale exceedances of the NAAQS also in rural areas.
- ❑ Household fuel combustion, small industries, burning of garbage and agricultural waste, etc., cause high emissions in rural areas too.
- ❑ Pollution from rural areas is transported into the cities (and vice versa), where it constitutes a significant share of pollution.

Source: IIASA/CEEW

Effective solutions must address all sources that contribute to $PM_{2.5}$ formation

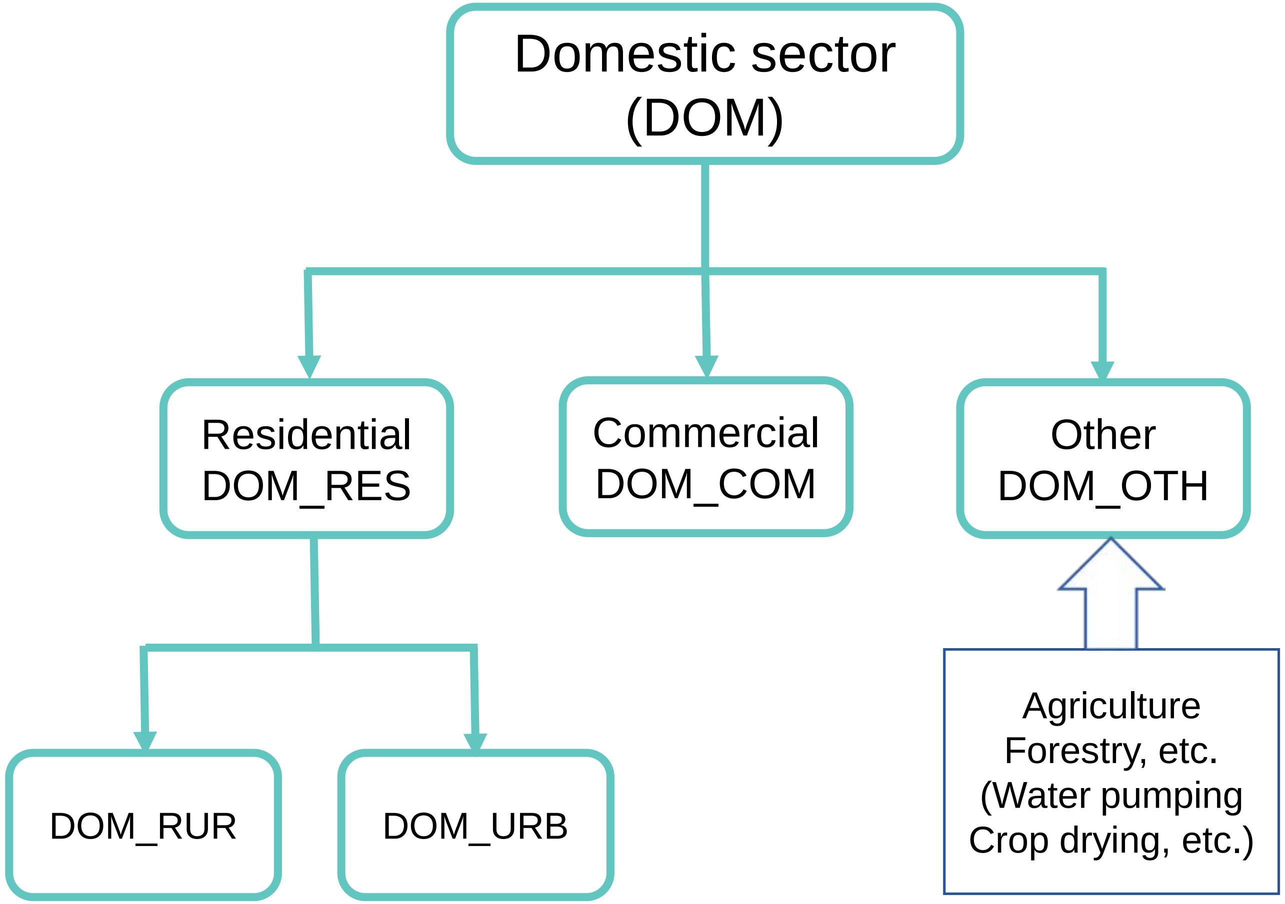
- A significant share of emissions still originates from sources associated with poverty and underdevelopment (i.e., solid fuel use in households and waste management practices).
- Any effective reduction of $PM_{2.5}$ levels in ambient air and the resulting health burden needs to balance emission controls across all these source sectors.
- A focus on single sources alone will not deliver effective improvements and is likely to waste economic resources to the detriment of further economic and social development.



*Secondary particles formed in the atmosphere from agricultural NH_3 emissions through chemical reactions with SO_2 and/or NO_x emissions;
**Including Telangana

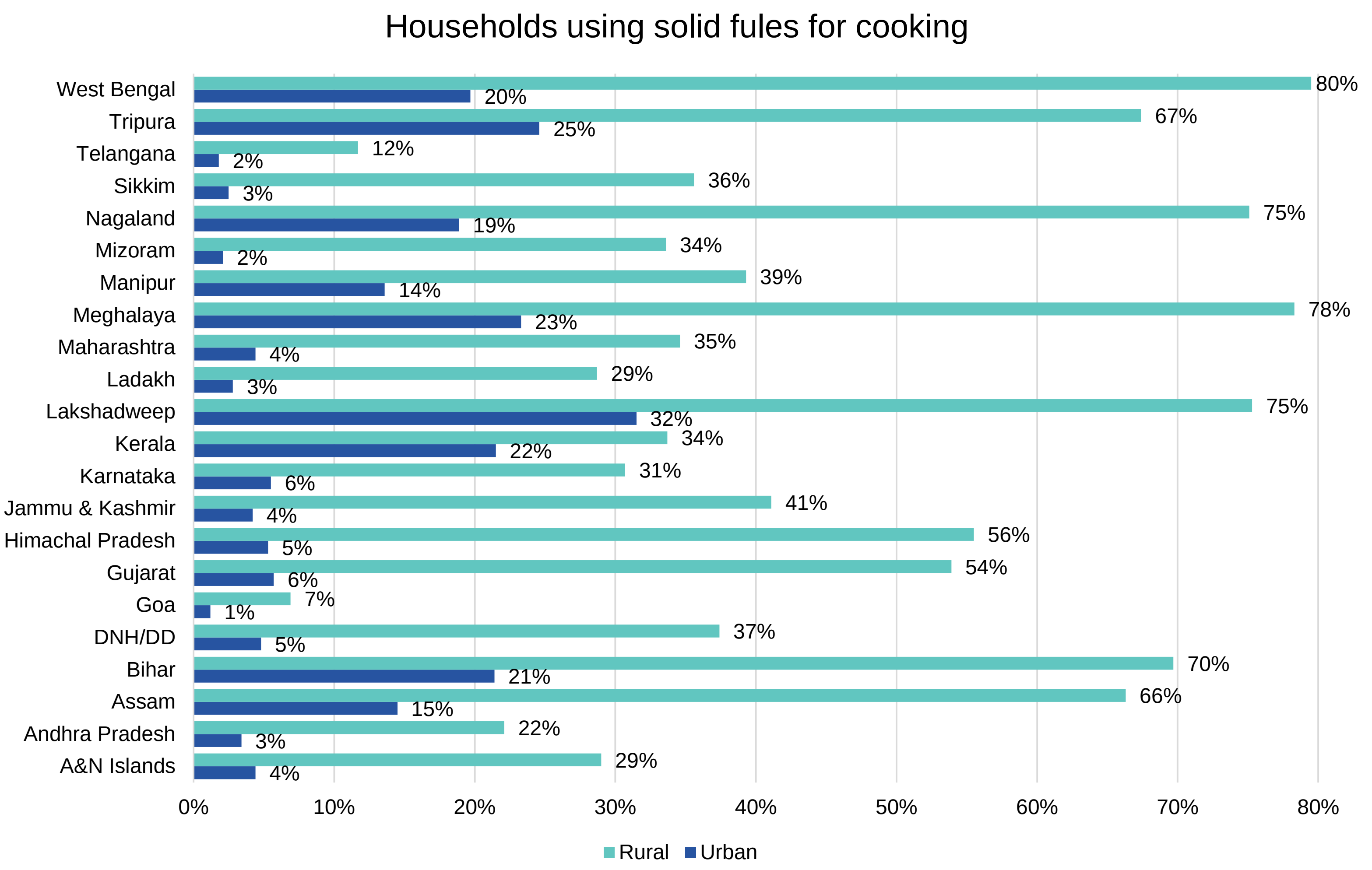
Source: IIASA/CEEW

Domestic sector in GAINS



Air pollution from households

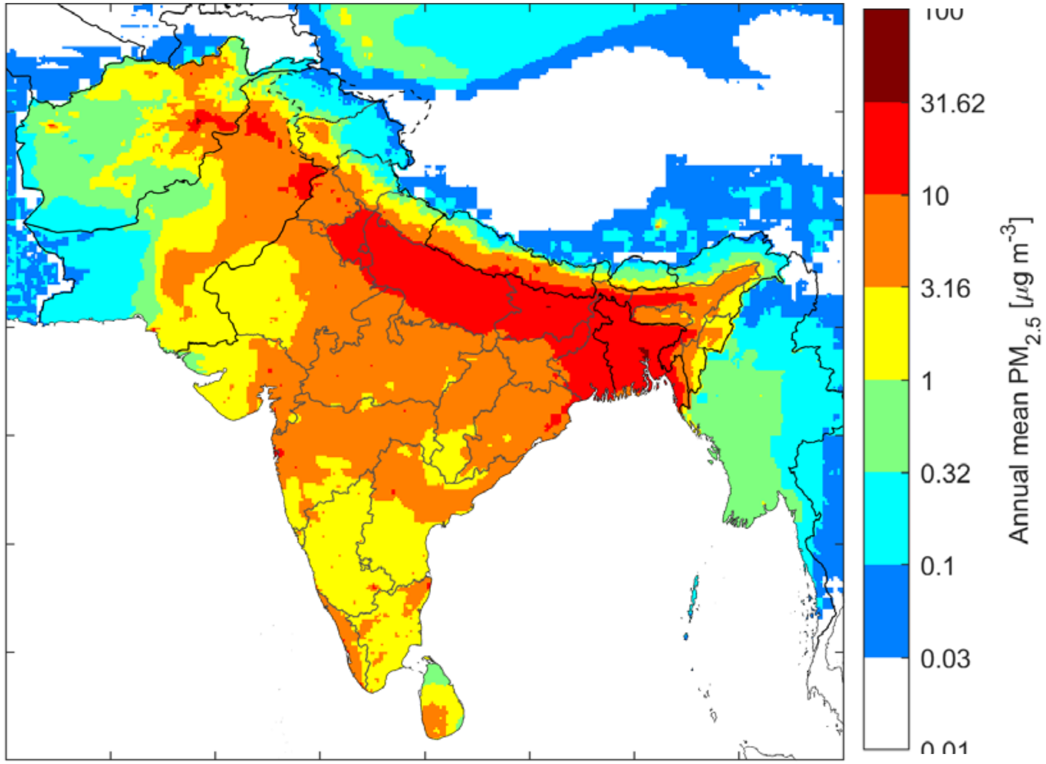
- According to a recent Global Burden of Disease (GBD) estimation, solid fuel burned for cooking accounted for 0.6 million premature deaths in 2019 in India.
  - Caused mainly by combustion of solid fuels (Fuelwood, agricultural residues, cow dung, lignite/coal, charcoal)
  - Large differences across States (≈80% households in rural West Bengal use solid fuels for cooking).
  - High contribution to ambient PM2.5 concentrations (≥50% in primary $PM_{2.5}$)



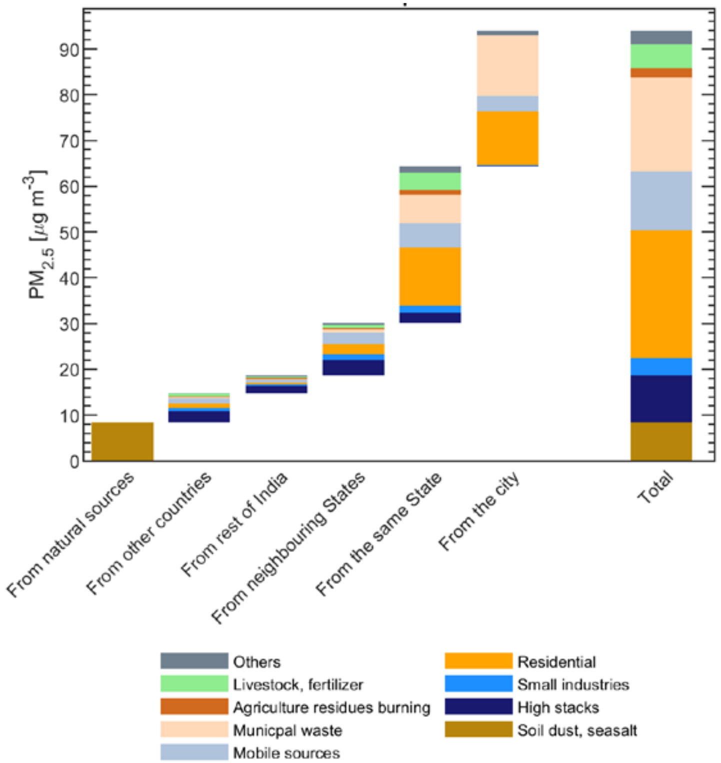
Source: NFHC-5 (2019-2020) 22 STATES/UTs FROM PHASE-I

High contribution to ambient $PM_{2.5}$ concentrations

$PM_{2.5}$ concentration from residential and commercial sector



Source apportionment of (population-weighted) $PM_{2.5}$ exposure - Kanpur 2018

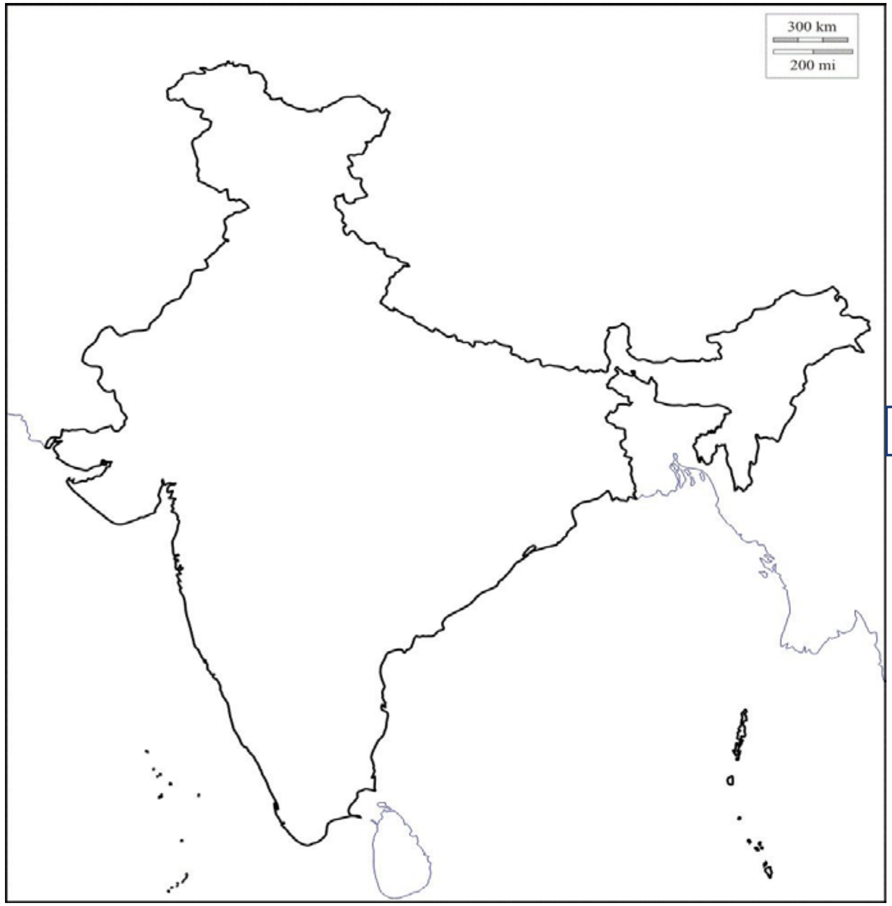


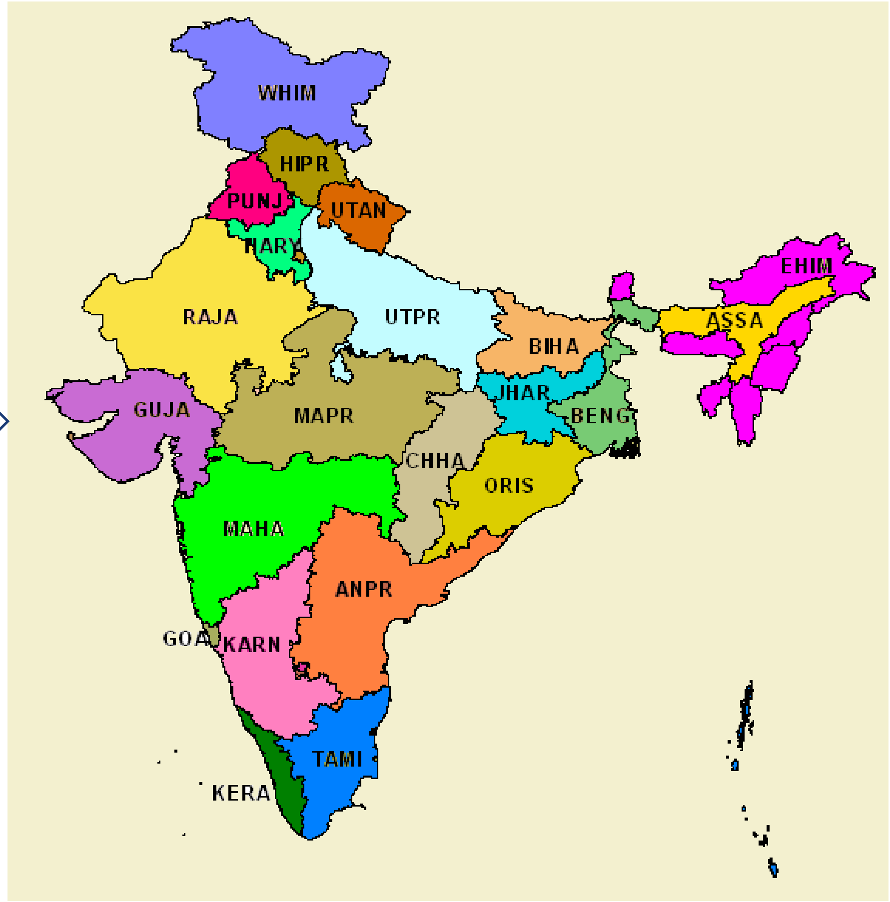
Source: IIASA GAINS

Mapping to the GAINS structure (example)

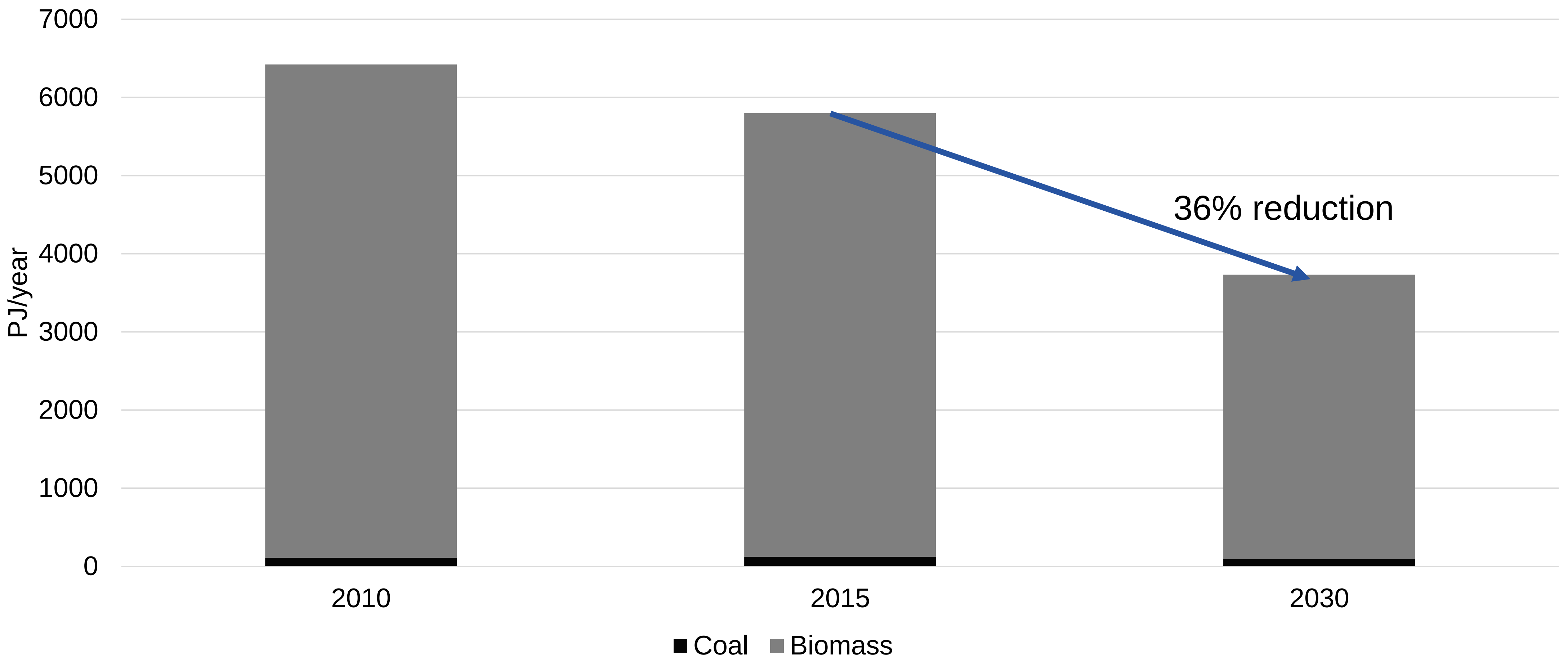
CD-LINKS sector	CD-LINKS fuel		GAINS fuel	GAINS sector		
	Biomass	←	OS1, OS2	Residential	←	DOM_U
	Coal	←	HC1, HC2, HC3, BC1, BC2, DC	(DOM_S)	←	DOM_R
Residential	Gases	←	Gas			
and	Liquids	←	MS, GSL, LPG, HF	Services		
Commercial	Electricity	←	ELE	(DOM_COM)		
	Heat	←	HT			
	Geothermal	←	GTH	Others		
	Solar	←	STH	(DOM_OTH)		

Model linkage





Solid fuels use in households



Source: IEA/WEO (2020) Stated Policies Scenario

Household energy consumption for cooking

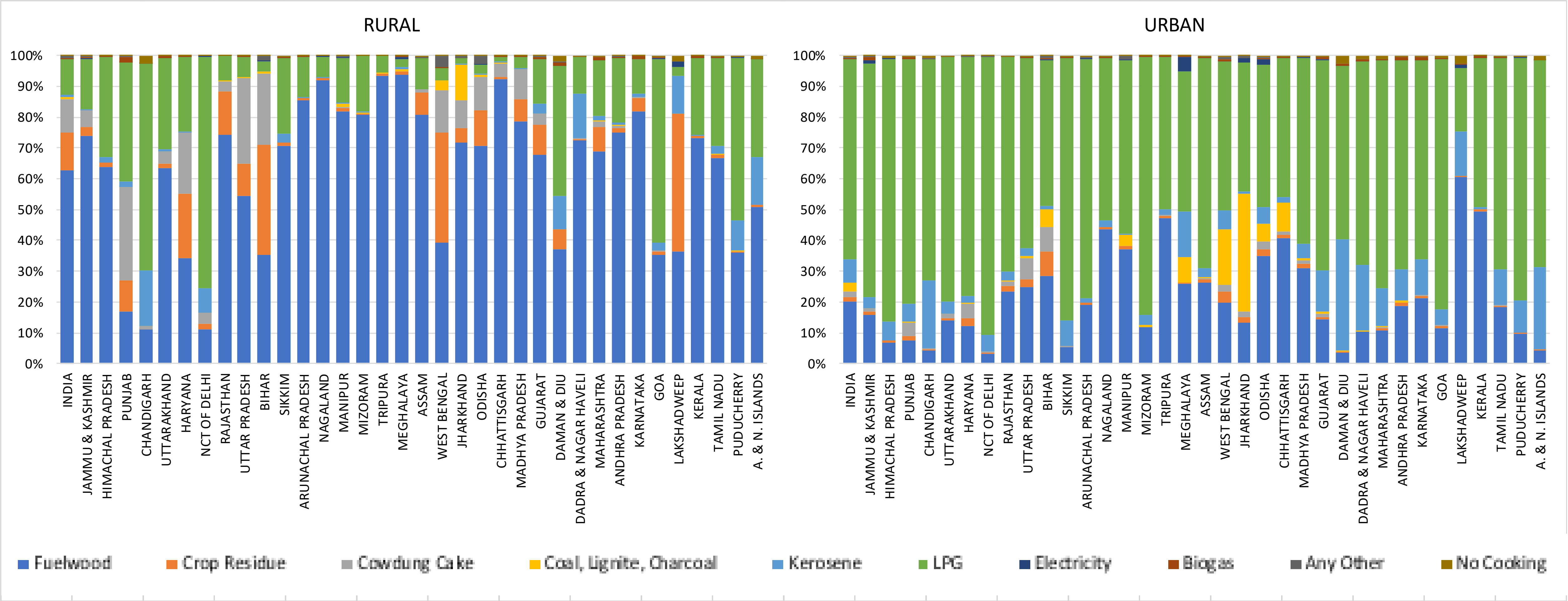
- Annual primary energy requirement for cooking
  - $APE_{cooking} = 365*A_{fw}*CV_{fw}$
- Annual useful energy requirement for cooking (annual)
  - $AUE_{cooking} = 365*A_{fw}*CV_{fw}*\eta_{stove,fw}$

- Calorific value of fuelwood (MJ/kg)
- Efficiency of traditional cookstove (%)
- Average fuelwood consumption (kg/HH/day)

- Daily useful energy requirement for cooking = 12.13 MJ/HH/Day
- An average of 138 kg of LPG is required per household per annum to meet household cooking energy needs
  - ≈9–10 LPG cylinders of 14.2 kg each in a year
  - ≈11.3 to 12.5 MJ/HH/Day

State-wise distribution of households by type of fuel used for cooking in rural and urban areas in India

for



Source: Census (2011)

Household energy demand for cooking

- Annual primary energy demand for cooking ($APE_{cooking}$)

$$APE_{cooking} = 365 \sum_{i=j=1}^{m,n} \frac{N_j \xi_{i,j} UE_{cooking}}{\eta_{stove,i}}$$

Where

$N_{i,j}$ = Number of households using i^{th} fuel in j^{th} State/UT

$\xi_{i,j}$ = % of households using i^{th} fuel in j^{th} State/UT

$\eta_{stove,i}$ = Efficiency of utilization of i^{th} fuel

- Data sources
  - Census of India;
  - NSSO;
  - CSO;
  - NCAER;
  - Demographic and Health Survey (DHS)/IIPS

Residential–commercial sector:
fuel and source structure in GAINS

Fuels	Non-specific	Lighting	Three-stone	Fireplace	Stove*	Household boiler		Medium boiler	
						Manual	Auto	Manual	Auto
Gaseous fuels	×								
Liquid fuels	×	×							
Charcoal	×								
Coal					×	×	×	×	×
Biomass									
- Fuelwood			×	×	×	×	×	×	×
- Agricultural residue			×		×		×		×
- Dung cake			×		×				

* Distinguishing cooking and heating stoves as separate categories.

X The cross indicates the combinations defined in the GAINS model.

Mitigation measures distinguished in the residential–commercial sector in GAINS

Control option	Non-specific	Lighting	Three-stone	Fireplace	Stove		Household boiler		Medium boiler	
					Cooking	Heating	Manual	Auto	Manual	Auto
Improved	×			×	×	×	×			
New				×	×	×	×			
Fan stove					×					
Coal briquettes					×	×				
Hurricane lamp		×								
LED[a] lamp		×								
Pellets						×	×	×	×	×
Cyclone									×	×
ESP[b]						×	×	×		×

[a] Light-emitting diode. [b] Electrostatic precipitator.

Kerosene lighting

- Annual kerosene consumption ($AKC_{lighting}$) for lighting in GAINS region “i” in year “y” is estimated by using the following ex-pression:

$$AKC_{lighting} = \left(\frac{POP_{i.y}}{HHS_{i.y}}\right)\left(1 - ELE_{i.y}\right) 365 \sum_{j=1}^{n} N_{i,j,y} h_{i,j,y} CV_k f_{i,j,y} \, SC_j$$

- where
  - POP = population,
  - HHS = household size,
  - ELE = electrification rate,
  - f = share of device type “j” (either wick lamps or hurricane lanterns),
  - N = number of kerosene lamps,
  - h = daily operating hours,
  - SC = specific kerosene consumption of a device
  - CV_k = calorific value of kerosene

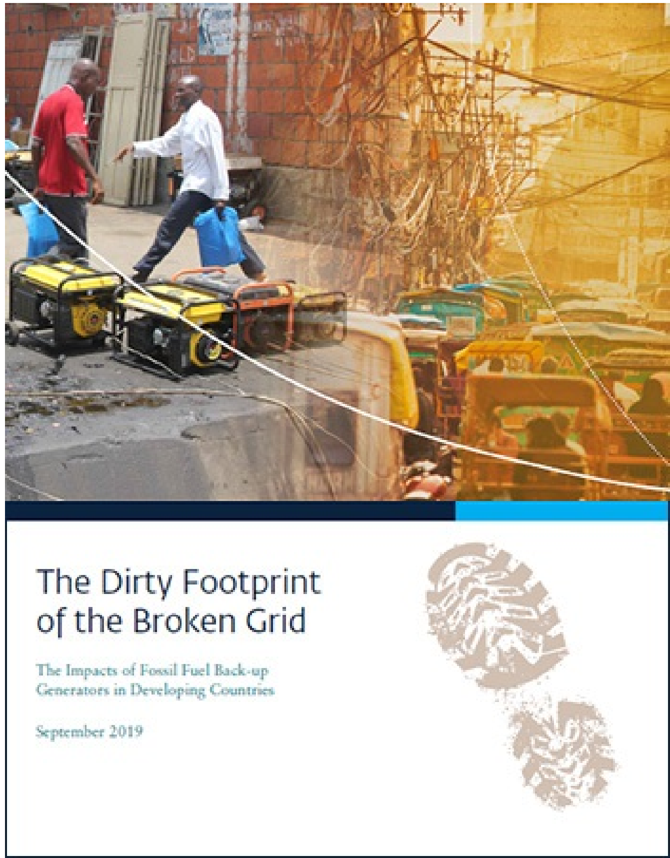
Diesel generators

- Fossil fuel-burning backup generators in developing countries produce as much energy as 700-1,000 coal-fired power stations, consume USD 50 billion in annual spending, and emit dangerous chemicals into homes and businesses.

- In 2019, DG sets accounted for 16 GW of the captive capacity in India (CEA, 2019).
  - Low capacity utilization (3%)
  - Official data only include units of ≥1 MW

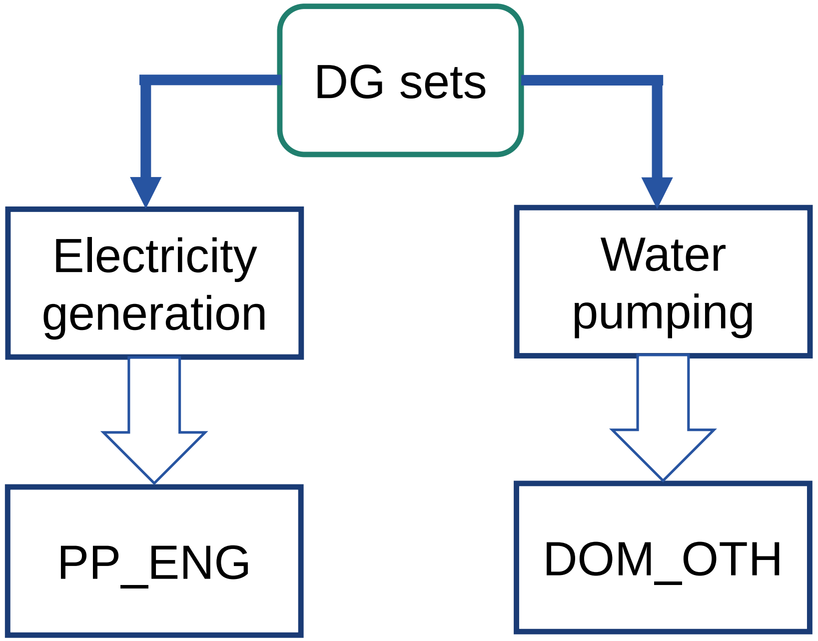
- Manufacturer data indicate that total capacity could be around 72 GW and may be even as high as 90 GW with around 5-8 GW of sales annually.

- Given high uncertainties regarding the true extent of India’s captive fleet, in particular DG sets with a capacity of <1 MW, it remains essential to improve data quality in order to set up a policy framework tailored to the captive segment’s particularities and enable an adequate monitoring.



Diesel generators (Contd...)

- ❑ Residential (small back-up generators)
- ❑ Commercial (small, medium and large BUGS)
- ❑ Other (small, medium and large DG sets)
    - o 30 million diesel/electric pumps



❑ Data and Information gaps

- Number of diesel generators (residential, commercial, industry, agriculture, etc.) or installed capacity
- Capacity factor (3%???)
- Emission factor
    - Age (New/Old)
    - Type (Large/small)

Emissions

- Total emissions are determined by combination of
  - activity levels
  - control strategies
  - emission factors

- Emissions

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

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	: Implementation rate of the considered abatement measure

Cost calculations in GAINS

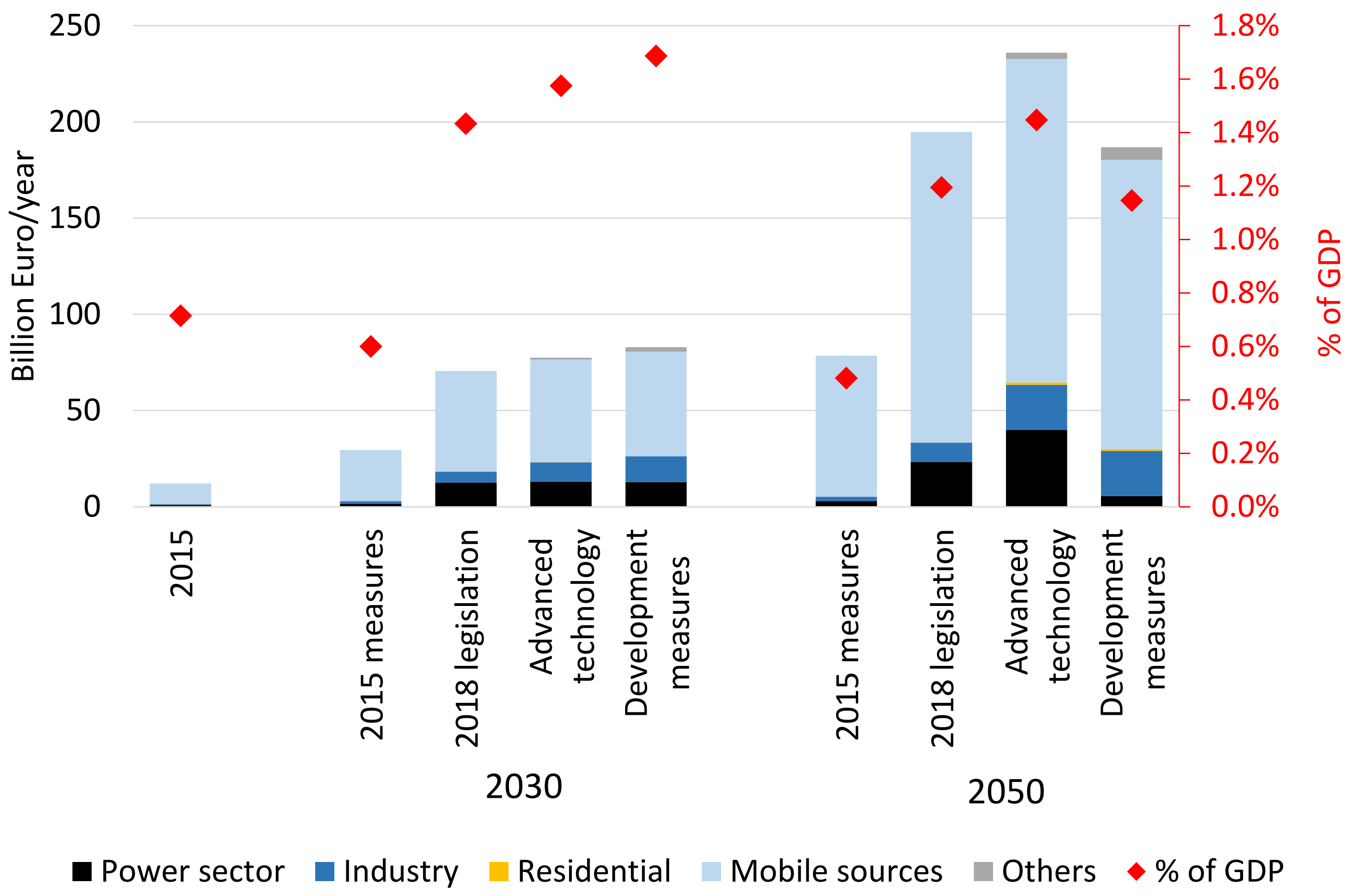
$$C = Iann + OMfix + OMvar$$

$$\text{Where } Iann = I \times \left[\frac{(1+r)^{T_m} \times r}{(1+r)^{T_m} - 1} \right]$$

- All costs in constant Euro 2015
- Net of taxes
- Annual costs method
- Costs based on international investment and operating experience
- Includes common- and country-specific components
- Three levels of discount rate: social (4%), business (10%), private (20%)

Air pollutant emission control costs

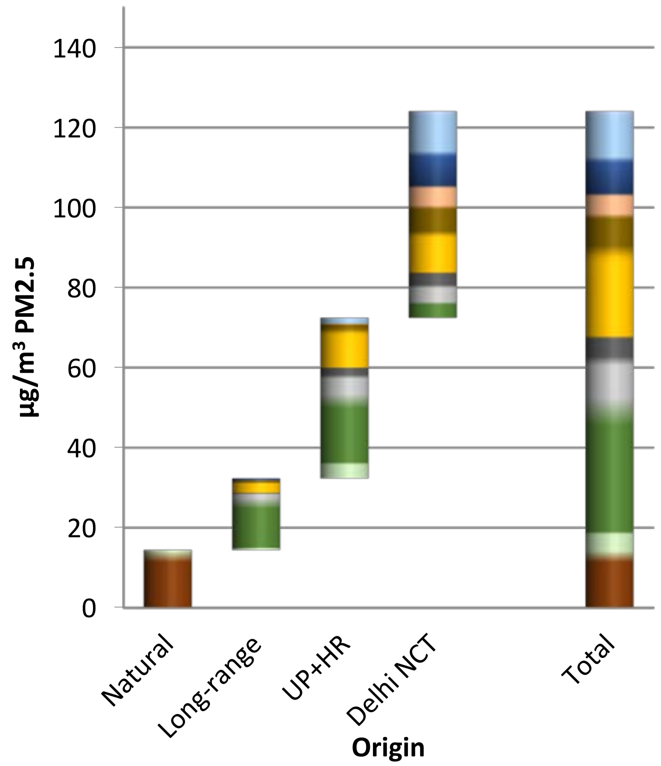
- Air pollution emission control costs accounted for about 0.7% of the GDP in 2015. This share will increase to 1.4-1.7% of GDP in 2030. More than 80% of total costs emerged for mobile sources.
- In 2050, with an almost 10-fold increase in GDP, air pollution controls will consume 1.1-1.5% of the GDP.

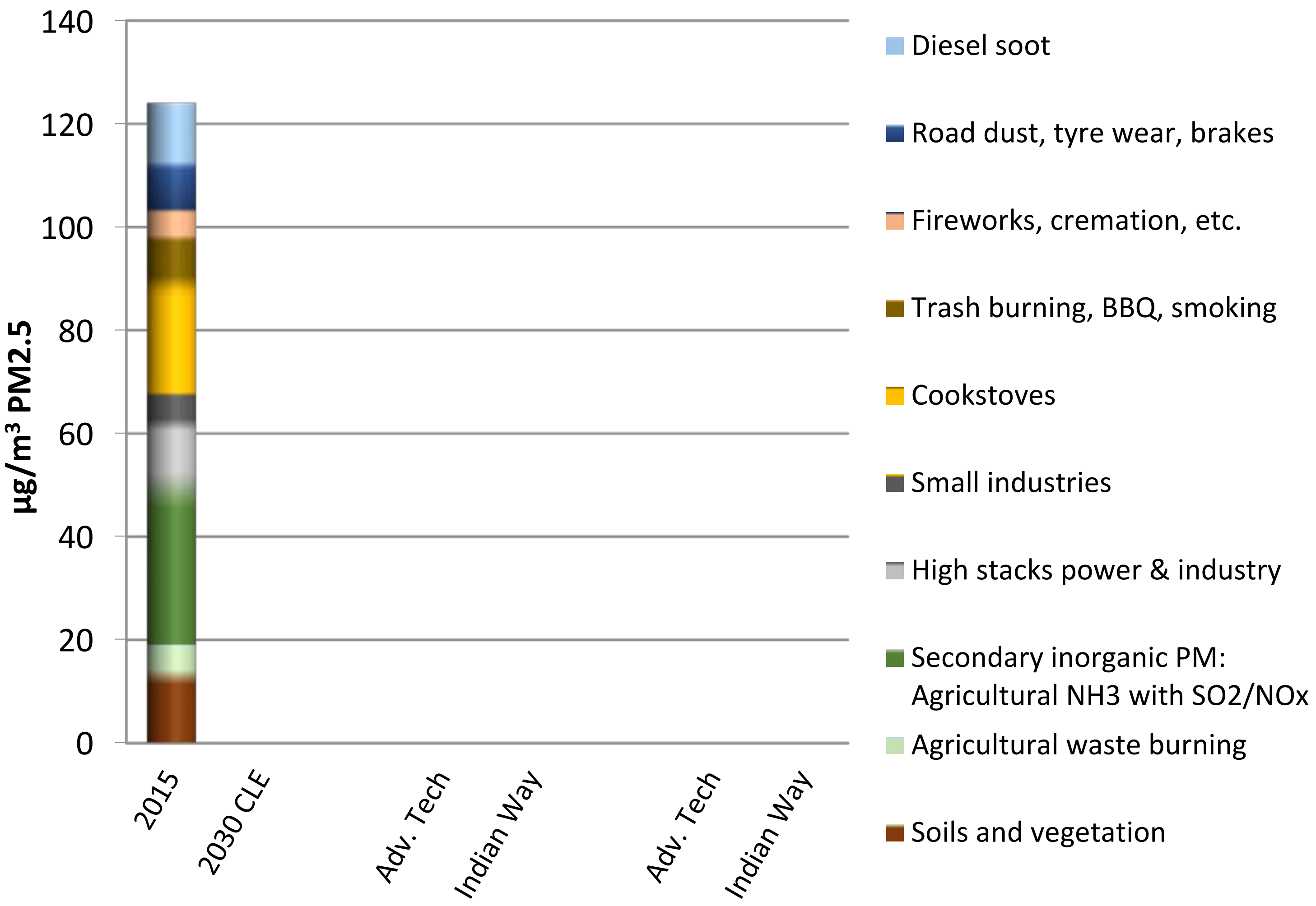


Source: IIASA/CEEW

Other sources: Non-exhaust emissions from transport

Non-exhaust emissions (NEE) of particulate matter (PM) from brake, tyre, road pavement, as well as resuspension of already deposited road dust.





Source: IIASA/NEERI

Other sources: PM emissions from construction activities

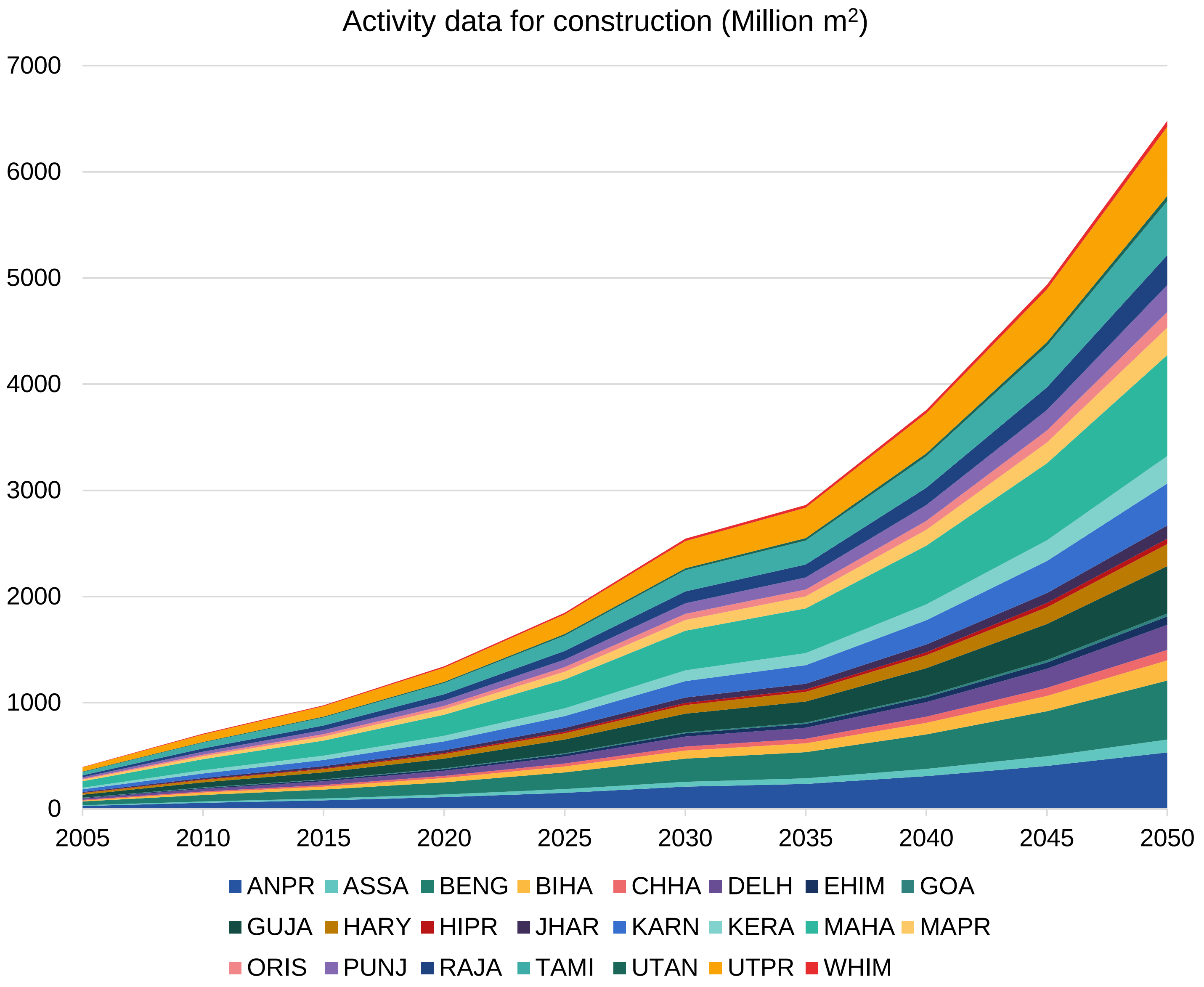
Source : Scraper loading /unloading/transit,
Truck loading/dumping,
Mud and dirt carryout

Activity : NOF

Sector : CONSTRUCT

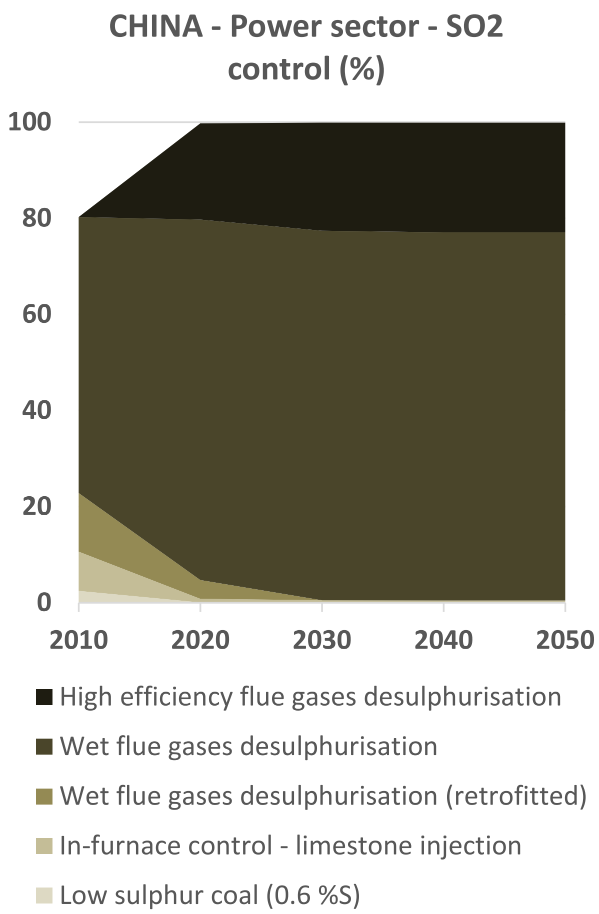
Unit : Million m^2

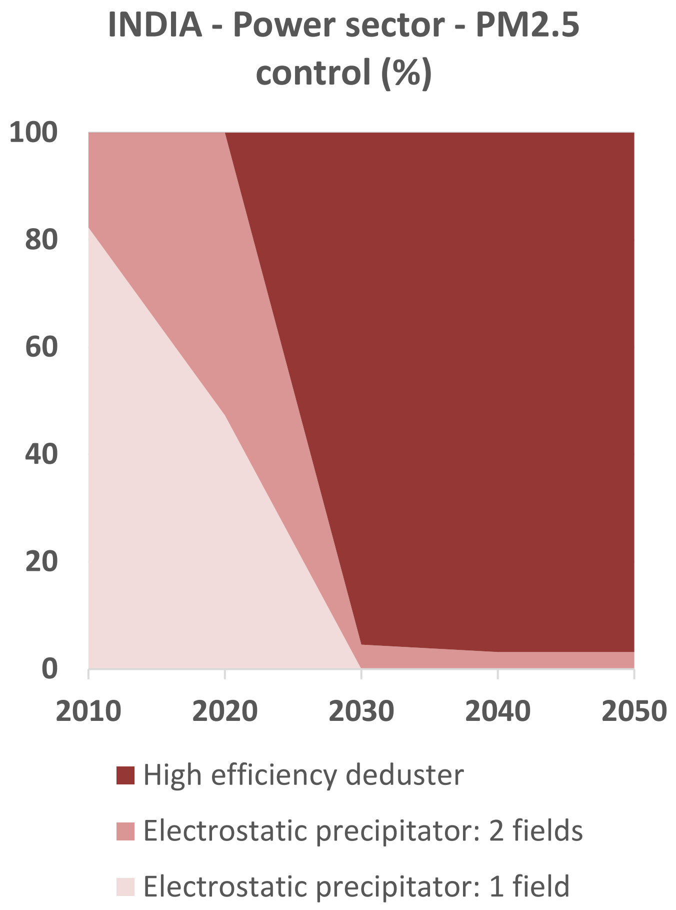
Driver : Value added from service sector

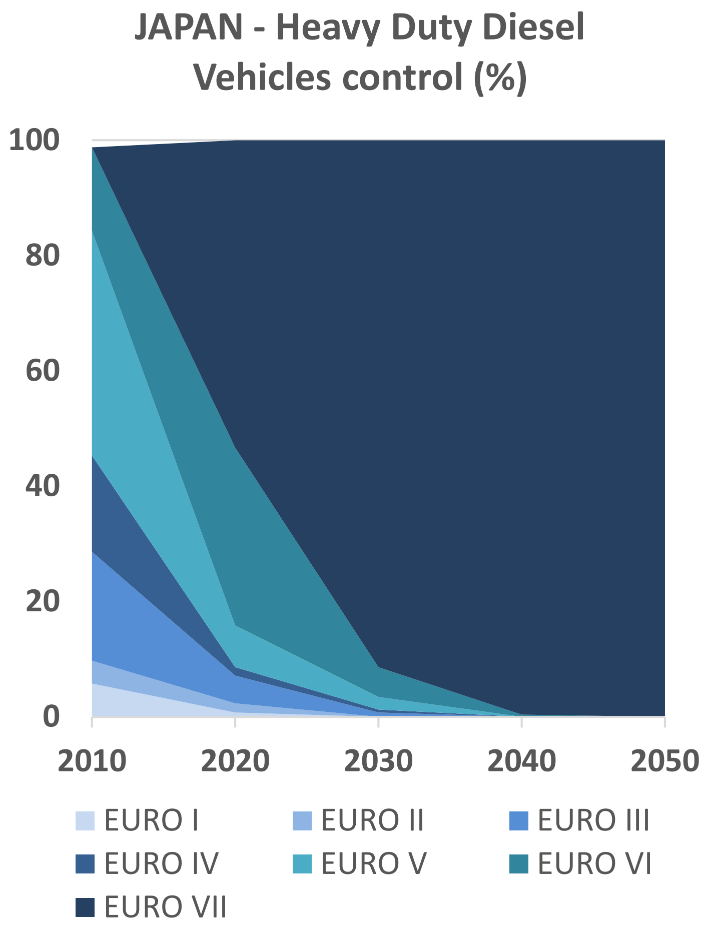


GAINS Control Strategy

Application rates of abatement measures: % of capacity/activity







What is a GAINS control strategy?

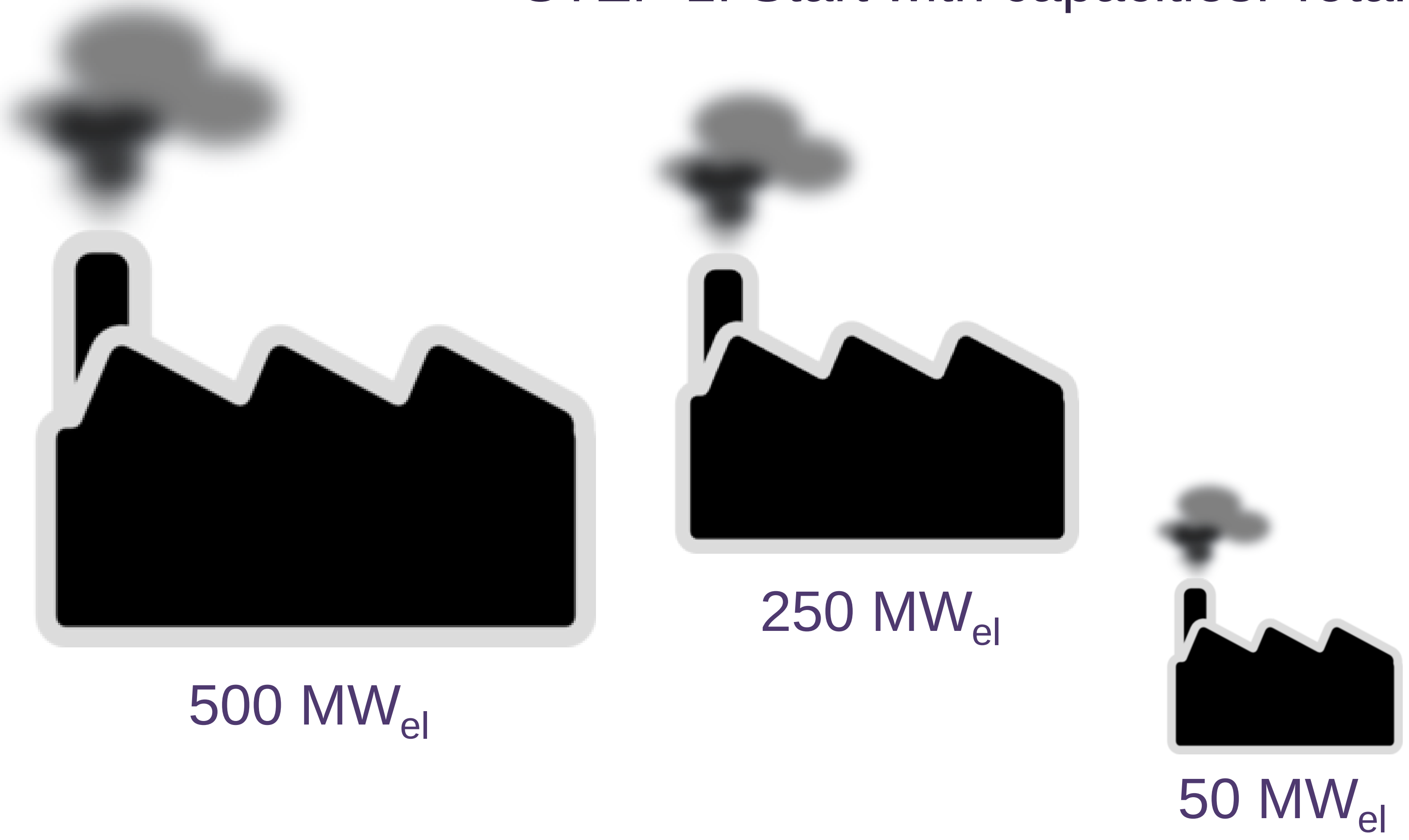
- A set of numbers (weighted averages) that tell you for each emission source to what extent which control technology is being applied
  - ➢ Represents what kind of technologies are used
  - ➢ Represents what policies are planned or implemented, and how this changes over time

- For each technology: value is between 0% and 100%

- Sum over <u>all</u> technologies (incl. ‘no control’) = 100%
  - o Total activity is either controlled or not
  - o % is always relative to activity
  - o For power plants activity means energy input

How do I calculate a control strategy?
Example: Coal-fired power plants

STEP 1: Start with capacities: Total = 800 MW_{el}



How do I calculate a control strategy?

Step 2: Calculate fuel input per year, using

- Operating hours per year
- Conversion efficiency

500 MW_{el}

4,000 hours/yr, 35% efficiency
20.6 PJ/yr = 69%

250 MW_{el}

2,000 hours/yr, 30% efficiency
6.0 PJ/yr = 20%

50 MW_{el}

6,000 hours/yr, 32% efficiency
3.4PJ/yr = 11%

How do I calculate a control strategy?

Step 3: Determine control technology in operation

20.6 PJ/yr = 69%

e.g. flue gas desulfurization

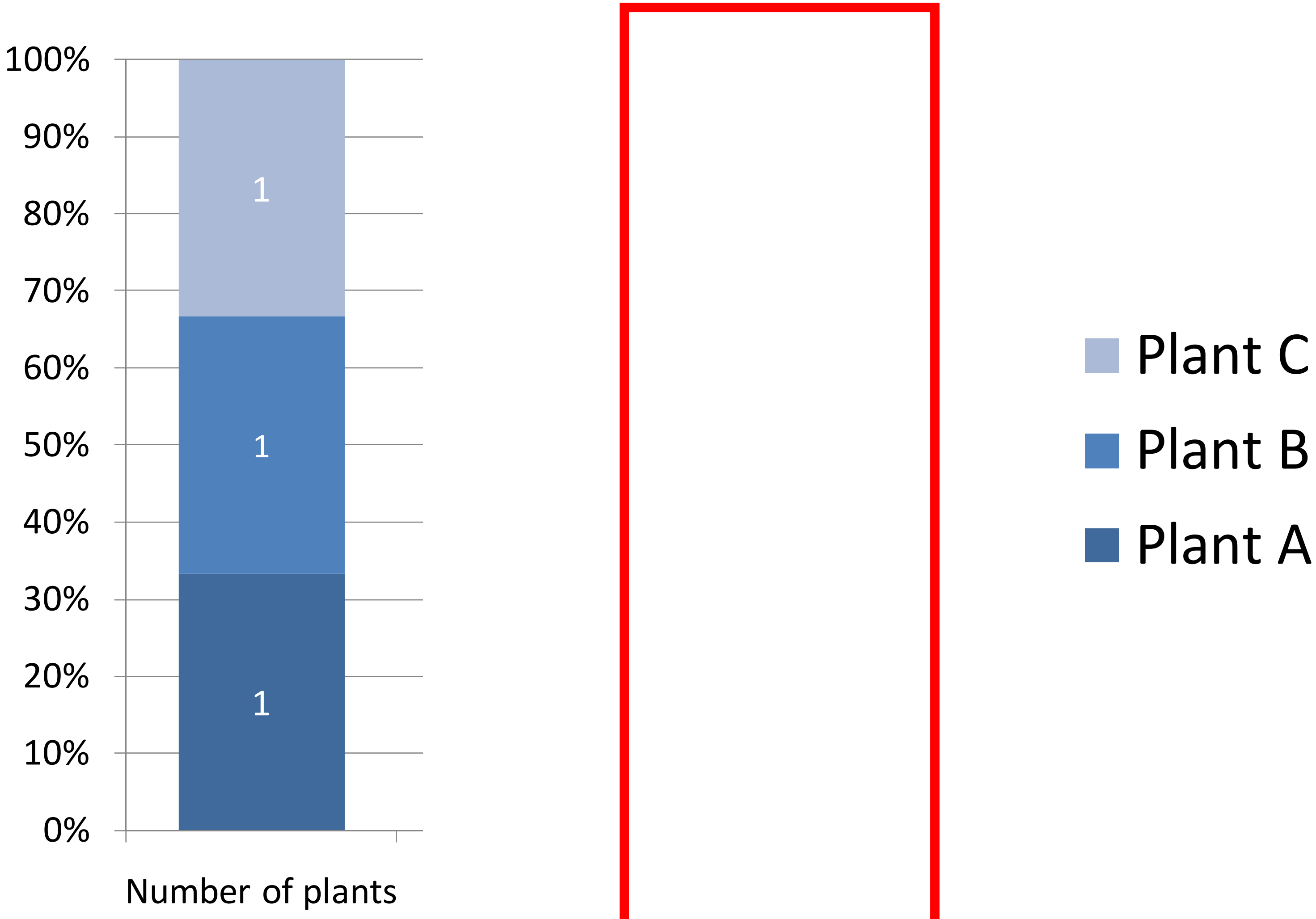
6.0 PJ/yr = 20%

e.g. lime stone injection

3.4PJ/yr = 11%

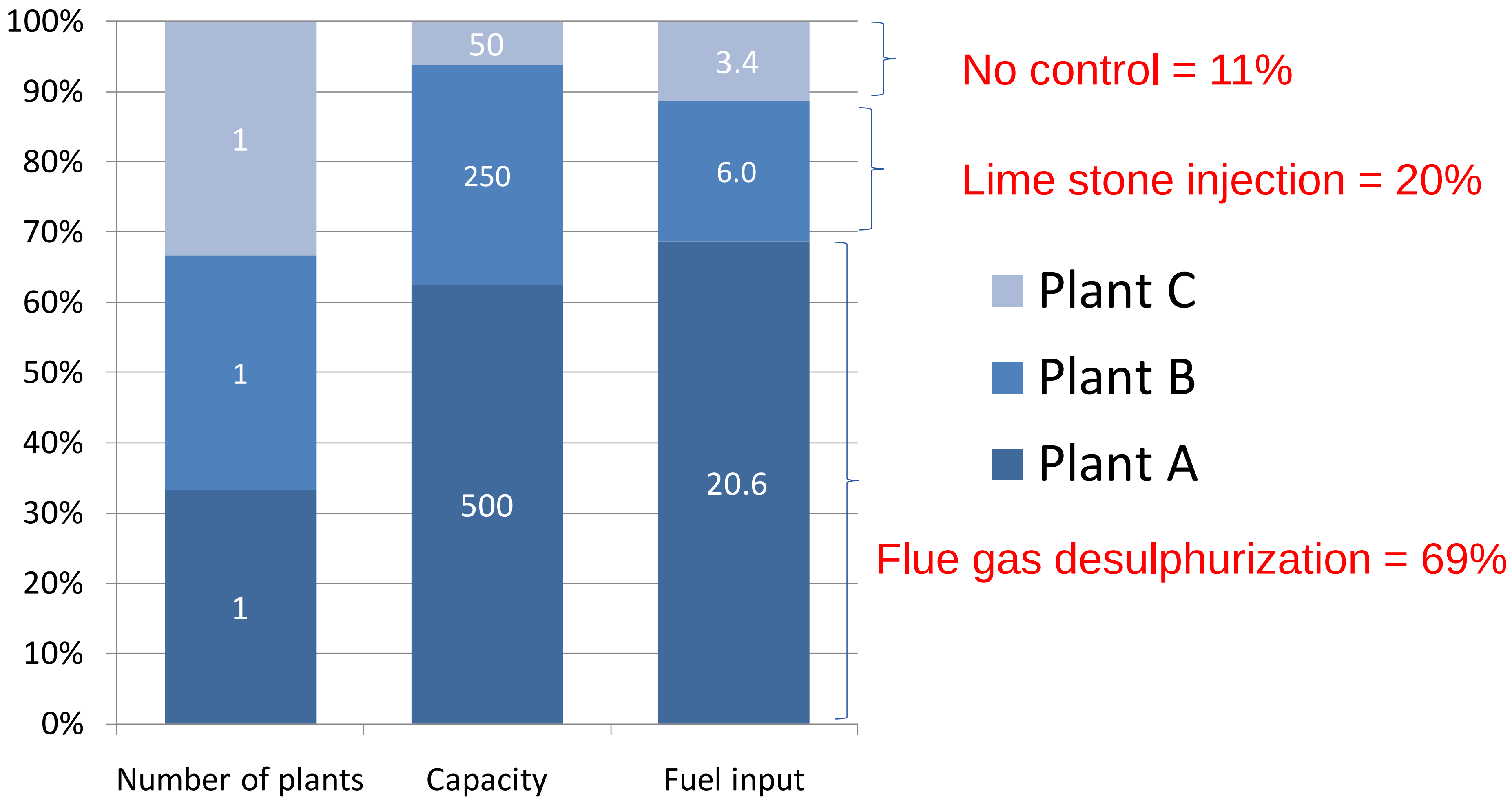
e.g. no control

How do I calculate a control strategy?



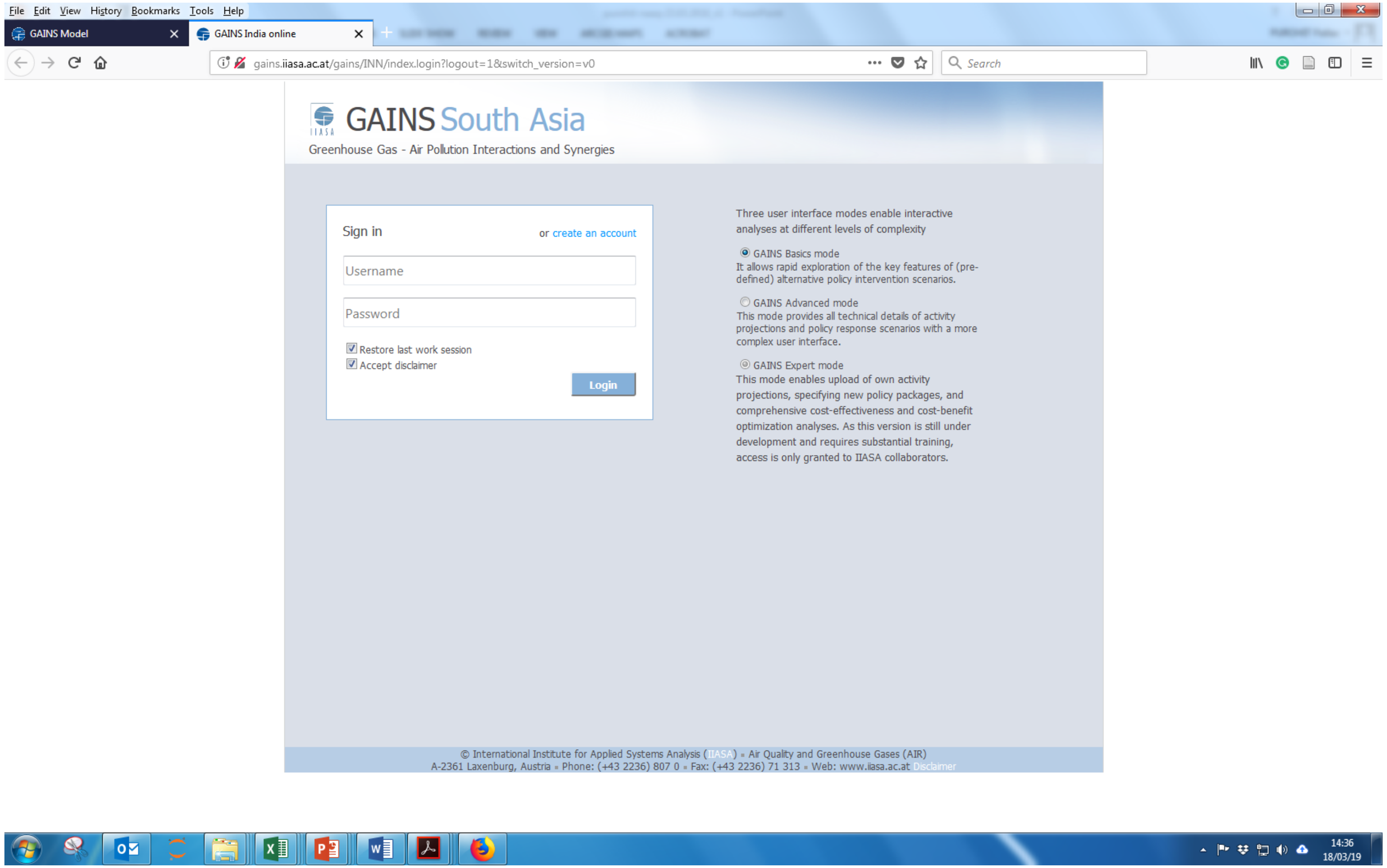
Apply control strategy here

How do I calculate a control strategy?



The GAINS tool is available online to explore cost-effective strategies that maximize multiple benefits

Access on the Internet:
http://gains.iiasa.ac.at



Thank you!

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