Introduction of emission inventory and VOCs emissions from stationary sources

Jun-ichi Kurokawa
Asia Center for Air Pollution Research, Japan
The Network Center of EANET

Outline

1. Introduction of Emission Inventory

2. Methodology to develop Emission Inventory

3. Methodology to estimate VOCs emissions from Stationary Sources

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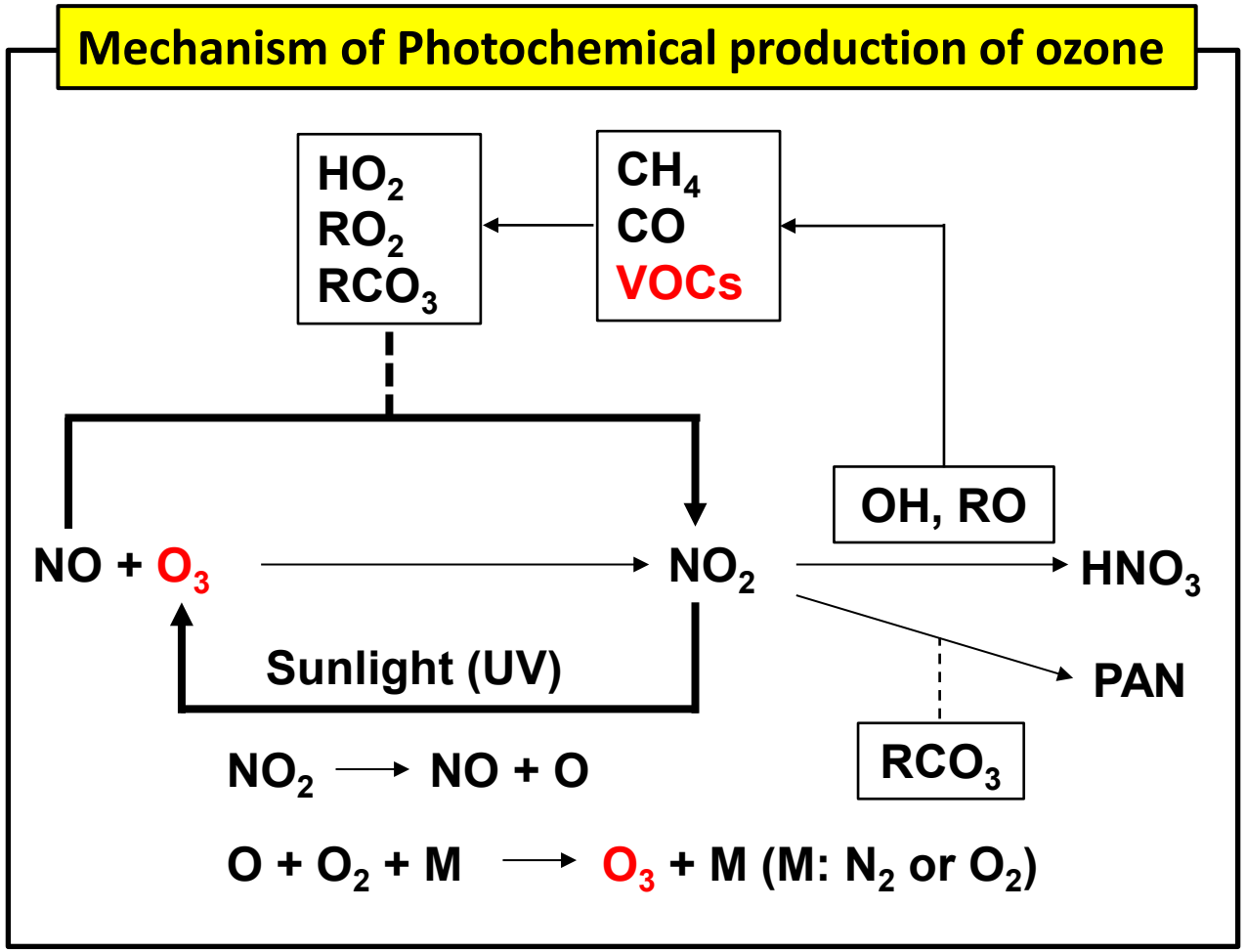
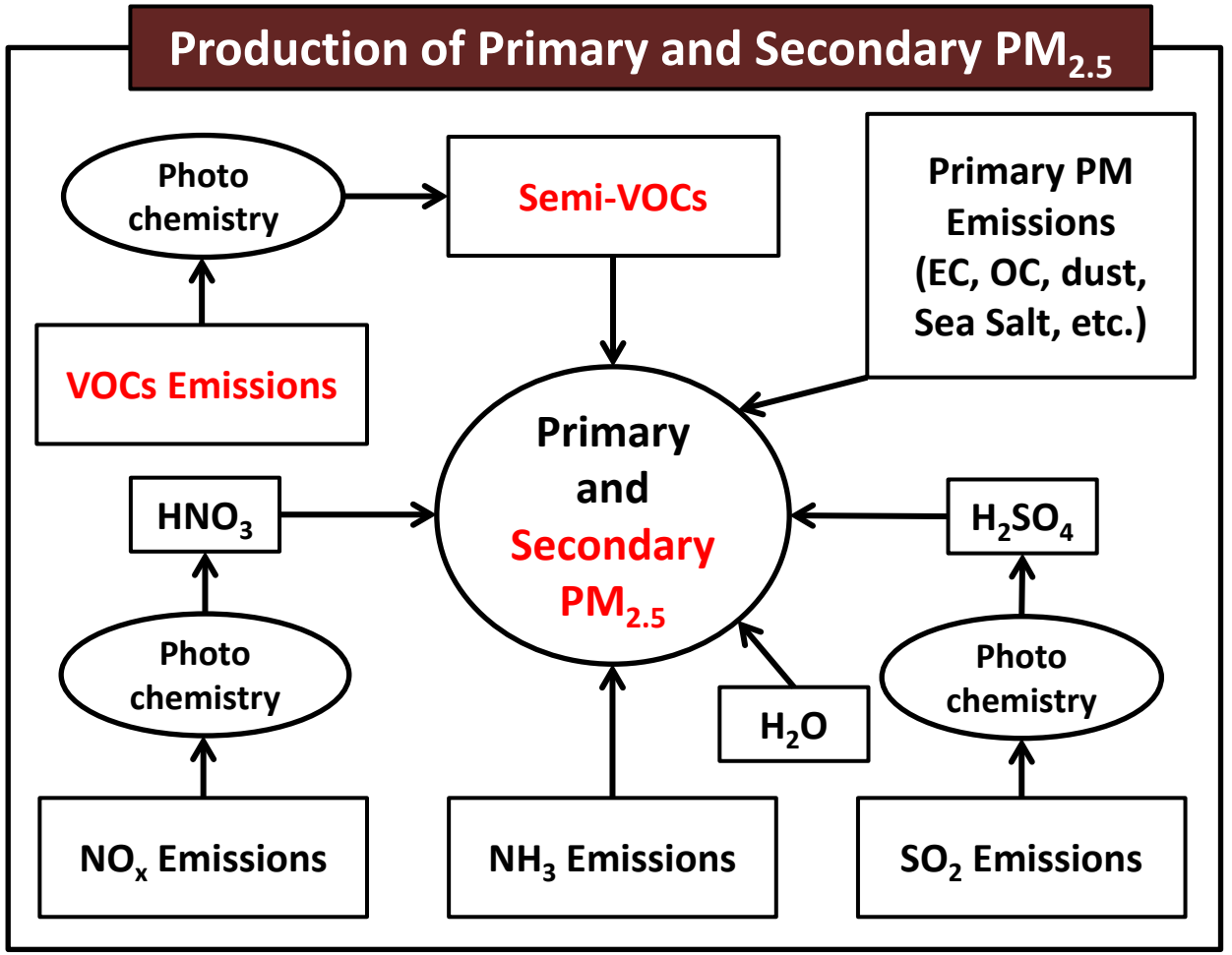
Why are VOCs important for air quality management?





- Volatile Organic Compounds (VOCs) are a group of organic chemicals that have a high vapor pressure and comprise various components with different chemical characteristics.
- In addition to toxic effects of some VOCs, considering atmospheric environmental problems in EANET participating countries, important roles of VOCs are precursors of ozone and secondary $PM_{2.5}$.

Necessity of Air Quality Management

Population Increase and Economic Growth

- Increasing energy demands for power generation, industry, transport etc.
- Growing agricultural activities such as production of crops and livestock.
- Lower priority for air pollution problems.

Worsening Air Pollution

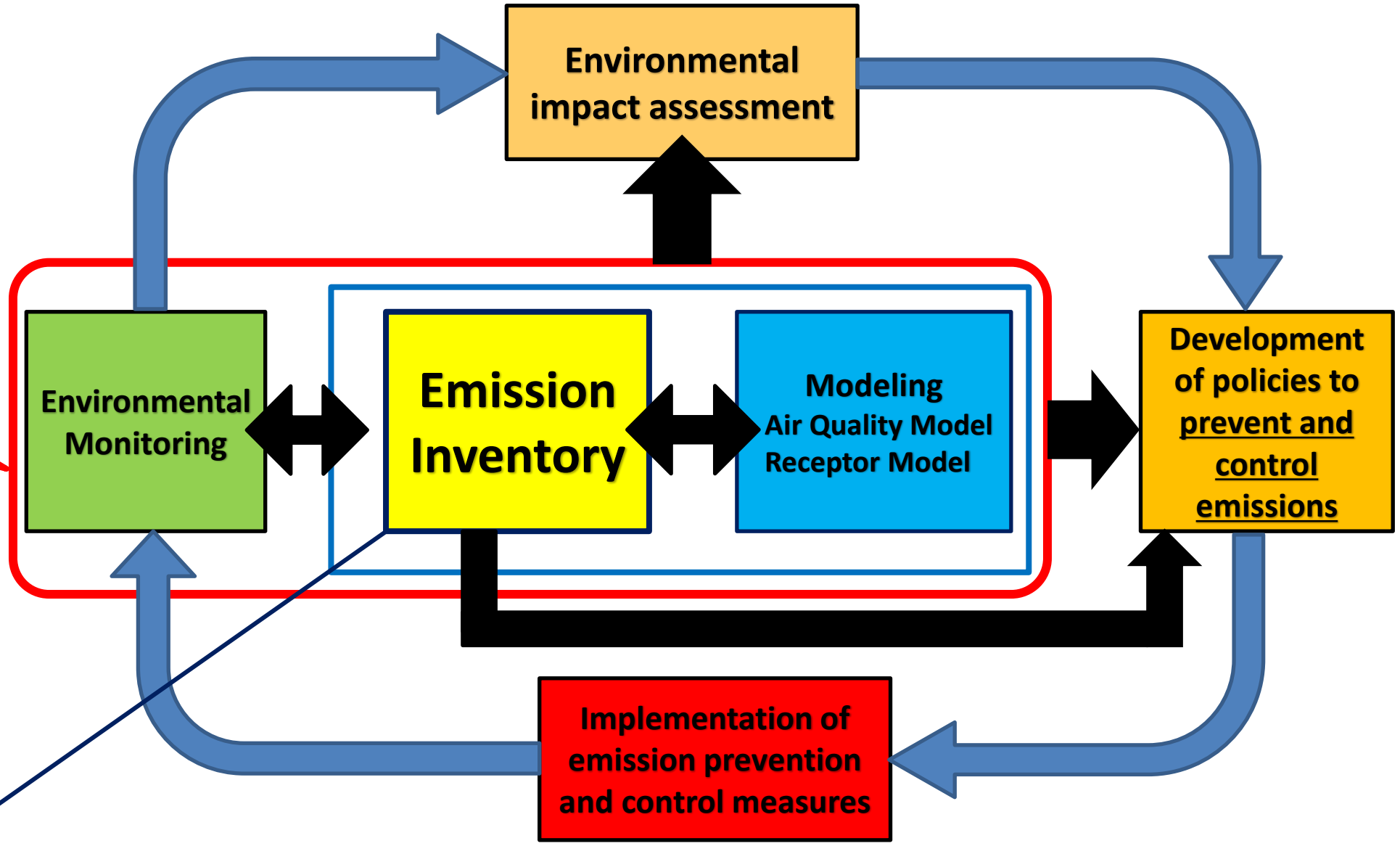
- Increasing adverse effects of air pollutants on human health, ecosystem, etc.
- Complaints from citizens to government and companies about air pollution.
- Higher priority for air pollution controls.

Air Quality Management

- Understanding the status of air pollution and considering priorities and effectiveness of emission control measures.
- Implementation of the control measures and assessment of the effects.
- Maintaining the improved air quality and acting against new problems including climate change.

Framework of Atmospheric Environment Management

Monitoring, emission inventory, and modeling are fundamental components for understanding the state of atmospheric environment that are used for policy making as well as environmental impact assessment



Emission inventory itself and related information including that with air quality models are essential for development of policies to prevent and control emissions

Two types of Emission Inventory

Emission inventory is data set of emission amounts of air pollutants from their sources in target region and period.

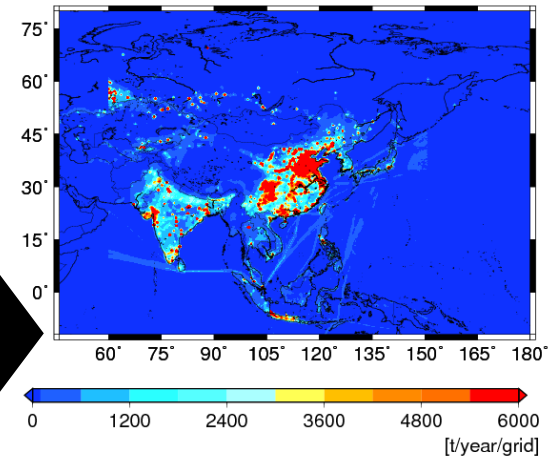
1. List of emissions from detailed sources in some administrative regions

SO2 [t/year]	2007	2008	2009	2010
1A1a_Electricity	1.1180E+05	1.0516E+05	8.7023E+04	1.1995E+05
1A1bc_Other-transformation	8.0001E+04	7.6085E+04	6.8720E+04	8.5502E+04
1A2a_Ind-Comb-Iron-steel	6.3541E+04	5.7620E+04	5.0148E+04	1.0782E+05
1A2b_Ind-Comb-Non-ferrous-metals	3.2111E+03	3.3404E+03	2.9191E+03	4.4002E+03
1A2c_Ind-Comb-Chemicals	5.3460E+04	5.1864E+04	4.5583E+04	5.7643E+04
1A2d_Ind-Comb-Pulp-paper	3.3764E+04	3.1585E+04	2.6185E+04	2.6466E+04
1A2e_Ind-Comb-Food-tobacco	6.4320E+03	8.7938E+03	7.3161E+03	6.4855E+03
1A2f_Ind-Comb-Non-metalic-minerals	4.9241E+04	5.0354E+04	4.3323E+04	4.8654E+04
1A2g_Ind-Comb-Construction	4.7216E+02	4.1463E+02	2.8737E+02	3.5191E+02
1A2g_Ind-Comb-transpequip	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1A2g_Ind-Comb-machinery	2.0796E+03	8.7746E+02	7.4672E+02	1.7001E+03
1A2g_Ind-Comb-mining-quarying	2.5574E+02	2.4088E+02	1.9968E+02	2.7619E+02
1A2g_Ind-Comb-wood-products	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1A2g_Ind-Comb-textile-leather	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1A2g_Ind-Comb-other	4.2602E+04	4.2768E+04	4.2616E+04	1.1919E+05
1A3ai_International-aviation	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1A3aii_Domestic-aviation	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1A3b_Road	1.2519E+03	1.2131E+03	1.1879E+03	1.0855E+03
1A3c_Rail	1.9067E+01	1.9361E+01	1.8968E+01	1.8379E+01
1A3di_International-shipping	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1A3dii_Domestic-naviation (shipping)	9.6735E+04	8.7238E+04	9.4692E+04	9.9941E+04
1A3eii_Other-transp	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1A4a_Commercial-institutional	8.9607E+03	8.3232E+03	8.0518E+03	7.6123E+03
1A4b_Residential	5.6456E+02	5.2867E+02	5.1321E+02	5.5695E+02
1A4c_Agriculture-forestry-fishing	1.2255E+04	1.0837E+04	1.0055E+04	9.8447E+03
1A5_Other-unspecified	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

- Major sources contributing to air pollution can be identified.
- Effects of control measures can be examined and priority of them can be considered.

2. Gridded data of emissions from major aggregated categories in some area

LON	LAT	JAN	FEB	MAR	APR	MAY	JUN
156.50	76.75	1.22E-03	1.14E-03	1.23E-03	1.17E-03	1.23E-03	1.18E-03
156.75	76.75	2.07E-05	1.94E-05	2.08E-05	1.99E-05	2.08E-05	2.00E-05
138.00	76.00	1.61E-03	1.51E-03	1.62E-03	1.55E-03	1.62E-03	1.56E-03
138.25	76.00	6.27E-03	5.86E-03	6.30E-03	6.02E-03	6.30E-03	6.05E-03
138.50	76.00	9.81E-03	9.18E-03	9.86E-03	9.43E-03	9.86E-03	9.47E-03
138.75	76.00	1.13E-02	1.06E-02	1.13E-02	1.08E-02	1.13E-02	1.09E-02
139.00	76.00	7.68E-03	7.19E-03	7.72E-03	7.38E-03	7.72E-03	7.42E-03
139.25	76.00	3.42E-03	3.20E-03	3.44E-03	3.29E-03	3.44E-03	3.30E-03
139.50	76.00	4.45E-04	4.17E-04	4.48E-04	4.28E-04	4.48E-04	4.30E-04
141.00	76.00	3.53E-03	3.30E-03	3.55E-03	3.39E-03	3.55E-03	3.40E-03
141.25	76.00	3.35E-03	3.13E-03	3.37E-03	3.22E-03	3.37E-03	3.23E-03
141.50	76.00	5.99E-03	5.61E-03	6.03E-03	5.76E-03	6.03E-03	5.79E-03
141.75	76.00	5.19E-03	4.86E-03	5.22E-03	4.99E-03	5.22E-03	5.01E-03
142.00	76.00	7.81E-04	7.31E-04	7.86E-04	7.51E-04	7.86E-04	7.54E-04
135.50	75.75	1.05E-03	9.86E-04	1.06E-03	1.01E-03	1.06E-03	1.02E-03
135.75	75.75	1.36E-03	1.28E-03	1.37E-03	1.31E-03	1.37E-03	1.32E
137.00	75.75	3.52E-05	3.29E-05	3.53E-05	3.38E-05	3.54E-05	3.39E
137.25	75.75	1.63E-03	1.52E-03	1.64E-03	1.56E-03	1.64E-03	1.57E
137.50	75.75	1.17E-02	1.10E-02	1.18E-02	1.13E-02	1.18E-02	1.13E-02
137.75	75.75	1.47E-02	1.38E-02	1.48E-02	1.42E-02	1.48E-02	1.42E-02
138.00	75.75	1.49E-02	1.39E-02	1.50E-02	1.43E-02	1.50E-02	1.44E-02
138.25	75.75	1.49E-02	1.39E-02	1.50E-02	1.43E-02	1.50E-02	1.44E-02



- Spatial distribution and trends of air pollutants emissions in whole target area can be evaluated.
- Input of Air Quality Model
  - Contribution from different emission categories, effects of control measures, and source-receptor relationship can be examined.

- Understanding emission amounts and their trends from detailed source categories as fundamental information to consider air quality issues
- Considering effective and feasible measures to reduce emissions

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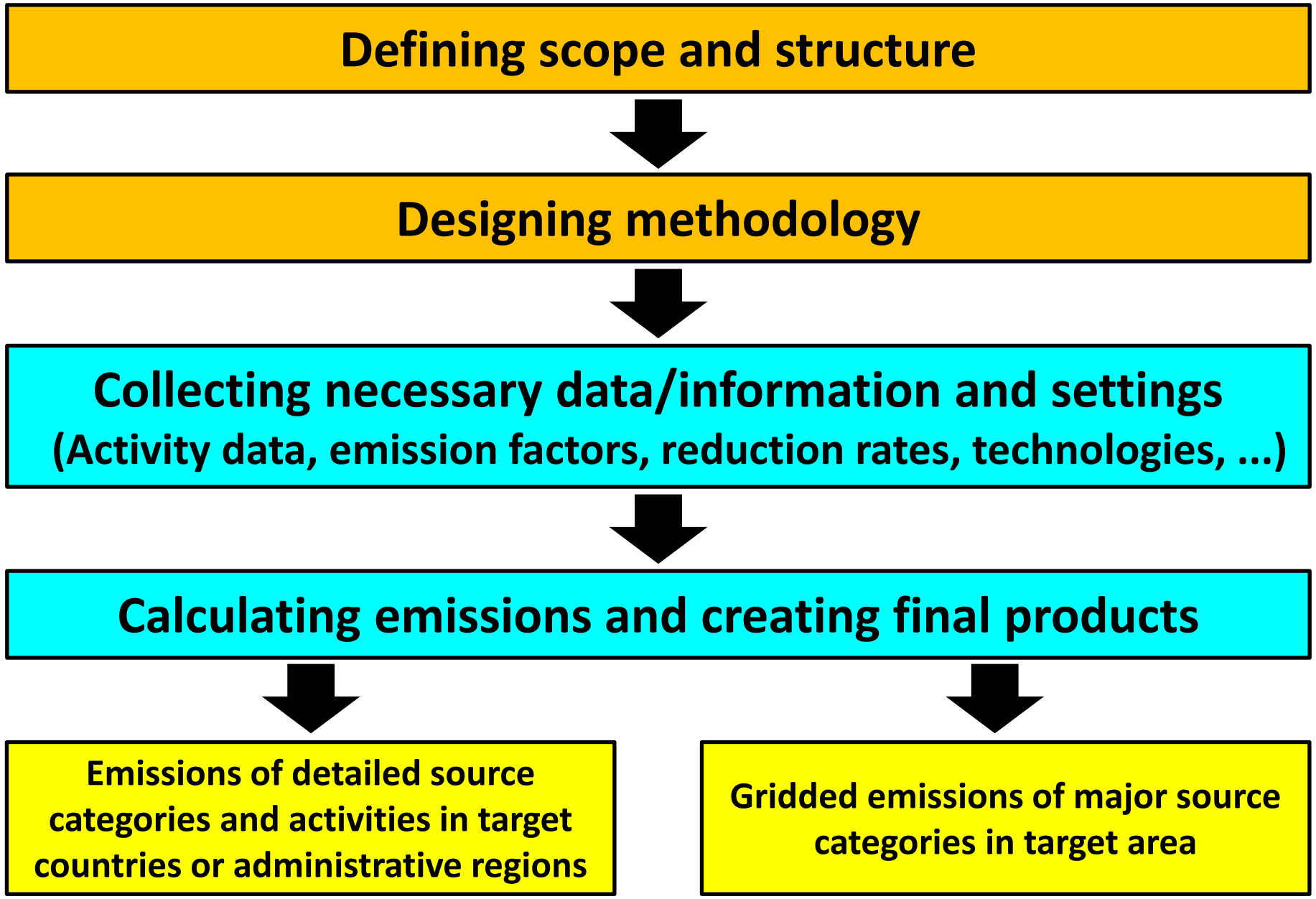
2. **Methodology to develop Emission Inventory**

3. Methodology to estimate VOCs emissions from Stationary Sources

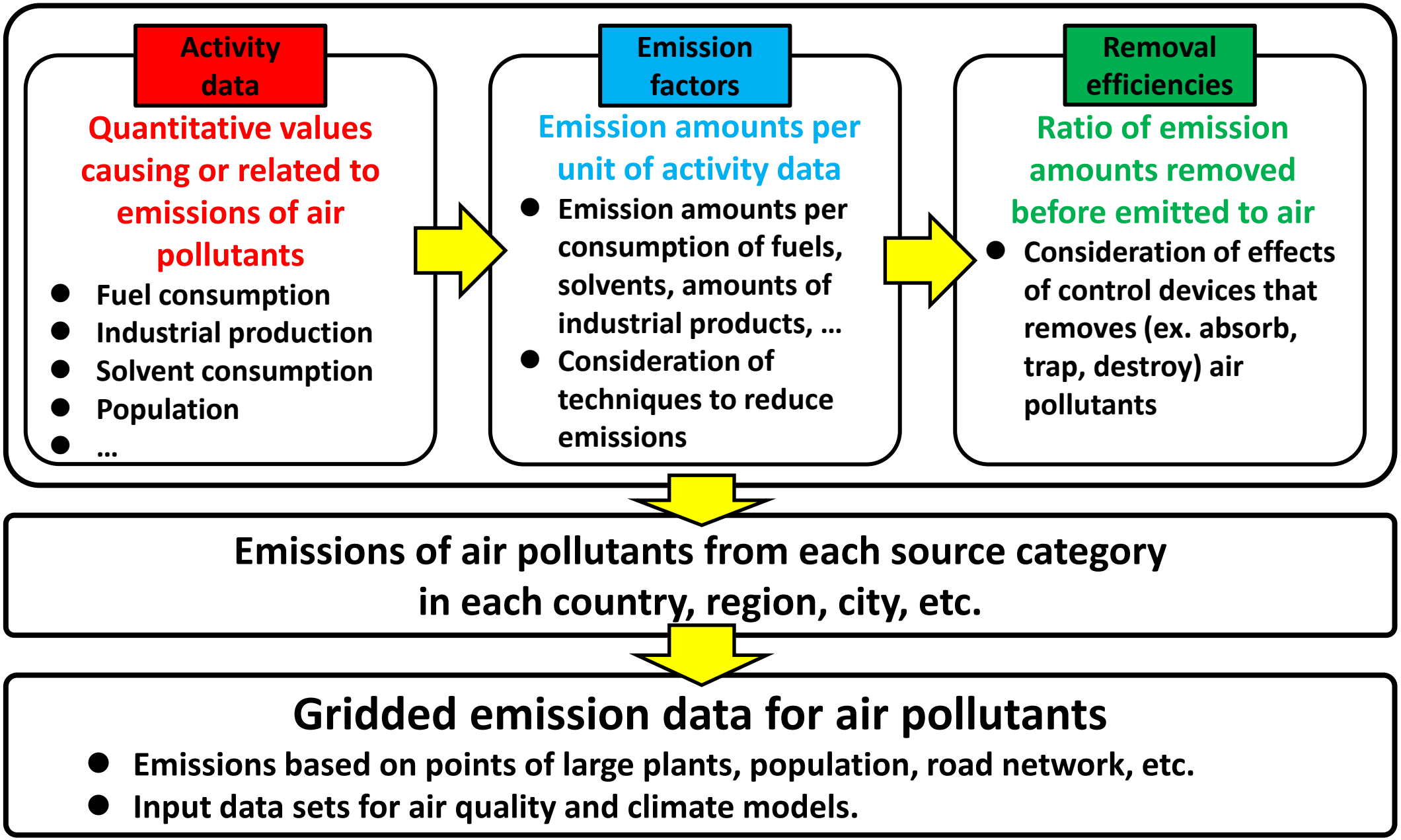
Process flow of developing Emission Inventory



Scope and structure of Emission Inventory

Item	Description for targets (Ex.)
Species	SO_2, NO_x, CO, VOCs (Total, Component Species), NH_3 PM_{10}, $PM_{2.5}$, BC, OC (Primary PM species)
Years	2015, 2010-2015, 1990-2015, 1850-2015, ...
Areas	Global, Asia, Japan, Niigata
Sources	Fuel Combustion: Power plants, Industry, Road transport, Other Transport, Residential, Commercial and Public services, … Non-Fuel Combustion: Fugitive emission, Industrial process, Solvent use, Agriculture, Vegetation fires and forestry, Waste, ... Natural: Volcano, Vegetation, Soil, Natural Dust, ...
Horizontal resolution	Country, Administrative regions Points, 0.5°x0.5°, 0.25°x0.25°, 0.1°x0.1°, ...
Temporal resolution	Annual, Monthly Weekly, Diurnal

Basic ideas to develop Emission Inventory



Designing methodology

$$EM_{i,j,y} = A_{i,j,y} \times EF_{i,j,y} \times (1-R_{i,j,y})$$

i Activity types
j Sectors
y Target years

Activity Rates	Emission Factors	Removal Ratios
Default Approach		
Consumption, etc. in each sector from national or international statistics	Averaged EF for each sector assumed from available manuals.	Averaged R for each sector assumed from available manuals.
Technology Specific Approach		
● Consumption, etc. in each plant/unit ● Consumption, etc. in each technology in each sector	● EF for equipment in each plant/unit ● EF for each technology and ratios of introduced control	● R for equipment in each plant/unit ● R for each technology and penetration rates in each sector

Default Approach : No detailed information or rough estimation is enough
Technology Specific Approach : Detailed information is available or should be surveyed
-> Effects of control measures can be evaluated and examined.

Development of gridded emissions

Emissions in cities/regions/countries

Emissions from each plant (Point sources)

Emissions from Area sources (Non-point sources)

Residential sector

Emissions from urban area

Emissions from rural area

Emissions from road vehicles

Longitude & latitude of each plant

Default proxy data
Ex. Total Population distribution

Urban population distribution

Rural population distribution

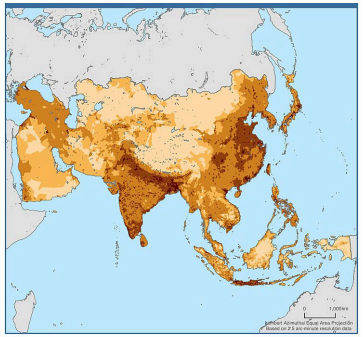
Road network distribution

Gridded emissions

Vertical distribution

Monthly, weekly, diurnal variation

Air quality model/Climate model



12	15	11
22	20	5
8	7	3

Population map

R(i,j)

0.12	0.15	0.11
0.21	0.19	0.05
0.08	0.07	0.03

$$EM(i,j) = EM(Total) \times [R(i,j)/\Sigma_{i,j}R(i,j)]$$

Allocate total emission amounts to grid cells using the proxies (such as population distribution)as weighting factors

Emission Inventory and Air Quality Model

Emissions are just flux of species and to evaluate atmospheric environment (concentrations of air pollutants and their effects) in different emission structures, simulations by air quality model are essential.

- There are over ten thousands VOCs component species with different chemical characteristics.
- There are several chemical mechanisms of VOCs for air quality mode.
- Speciation of VOCs are difficult but important for VOCs emission inventory.

Gridded Emission Inventory
(Usually unable to be used on an "as-is basis")

↓

Convert Emission Inventory to "model-ready input data"

- Speciation of VOCs and PM species based on chemical mechanism and target species of air quality model
- Conversion of coordinate system from that of Emission Inventory (Longitude/Latitude) to that of air quality model (Lambert etc.)

↓

Air Quality Model

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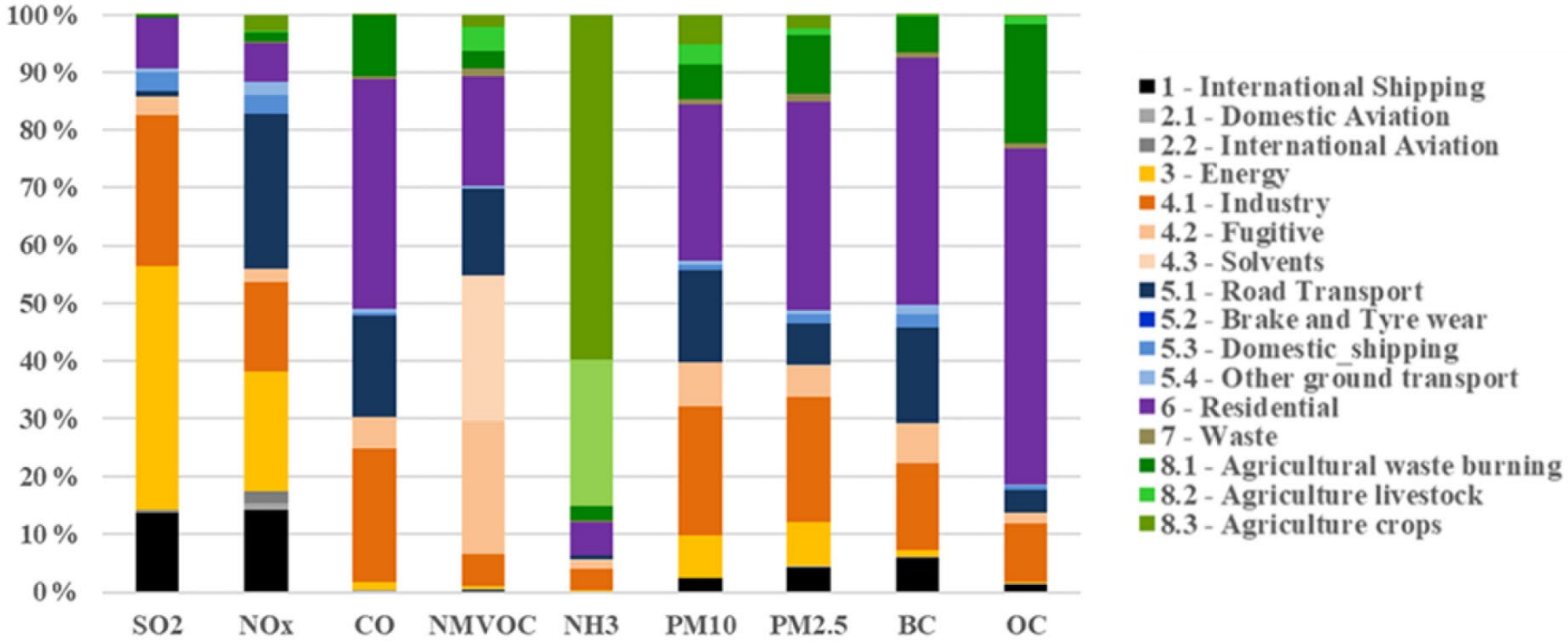
3. **Methodology to estimate VOCs emissions from Stationary Sources**

Defining scope and structure on VOCs emission inventories



Sectoral breakdown (ratio) of air pollutant emissions from global emission inventory (HTAP_v3*) for the year 2018.
Crippa et al., Earth Syst. Sci. Data, 15, 2667-2694, 2023 (https://doi.org/10.5194/essd-15-2667-2023)
***Global emission inventory for Task Force on Hemispheric Transport of Air Pollution (TF-HTAP) Phase III**

- **Major emission sources of VOCs are Solvents, Fugitive, Residential, Road Transport, Industry, etc.**
- **Contributions from evaporative emissions are large compared to those from combustion emissions that are major sources for SO_2, NO_x, CO, and primary PM species.**

Sector categories for VOCs emission inventories

Fuel Combustion

- Fossil fuel combustion
- Biofuel combustion

Ref. EANET Emission Inventory Webinar Workshop in 2023
https://www.eanet.asia/advancing-emission-inventory-management-for-combustion-sources-insights-from-the-eanet-workshop

Fugitive Sources

- Gas extraction/handling/distribution
- Oil extraction/handling/distribution
- Petroleum Refineries
- Coal mining/handling
- Charcoal production
- Coke production
- Service stations
- …

Solvent Use

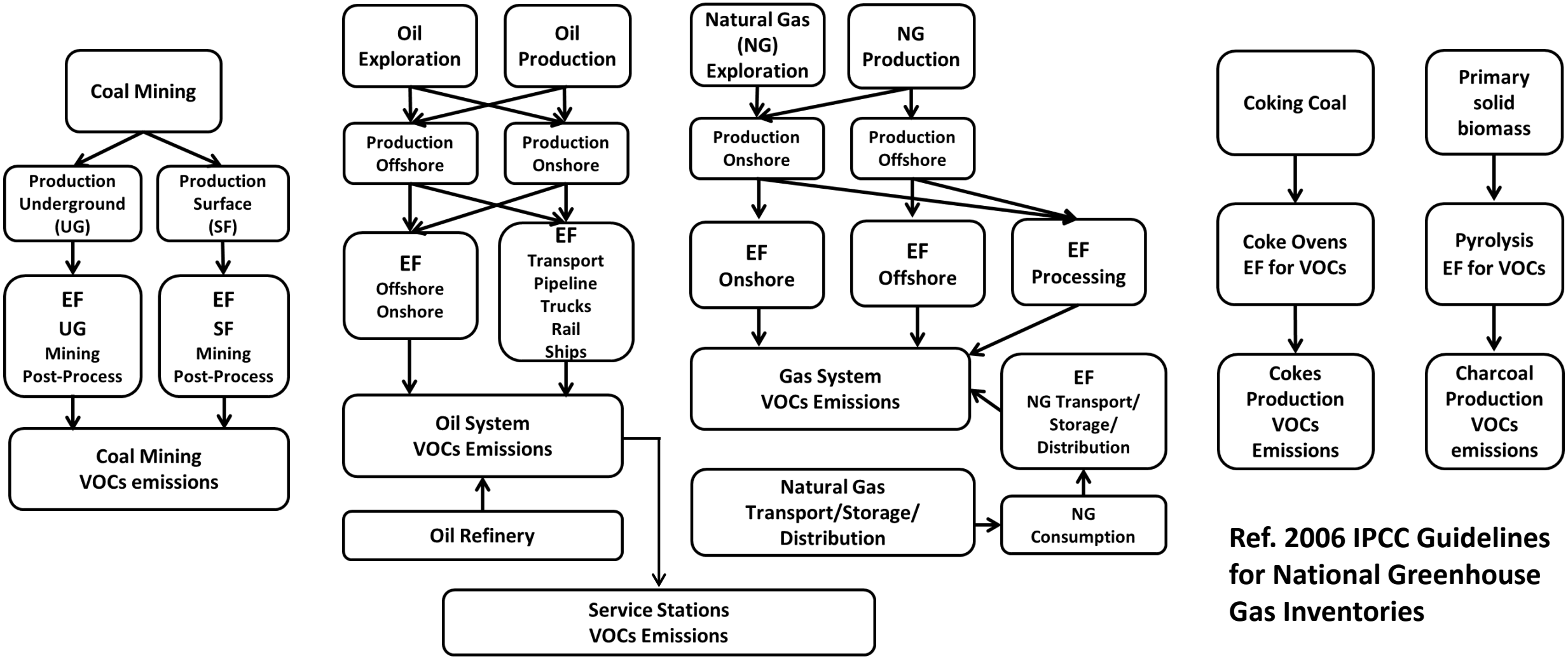
- Paint application
- Degreasing operations
- Dry cleaning
- Domestic use of solvents
- Vehicle treatment
- Printing (packing, offset printing, screen printing, etc.)
- Preservation of wood
- Application of adhesives
- Chemical product manufacturing/processing/storage
- …

Others

- Production of food, beverage, pulp and paper, asphalt, etc.
- Agricultural waste burning, manure management, etc.
- Natural sources especially for biogenic VOCs.
- …

Define sector categories especially considering major emission sources of target area.

Example of Fugitive VOCs emissions



Ref. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

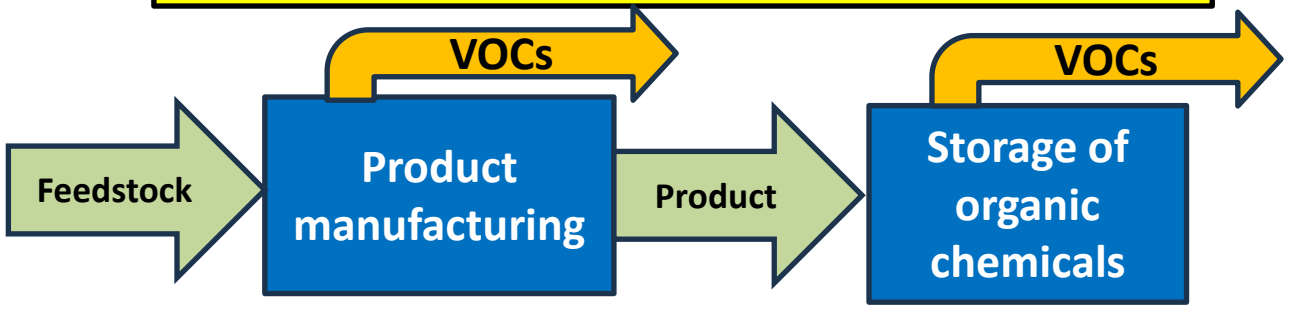
- **Fugitive emissions are from non-combustion activities related to mainly fossil fuels.**
- **Processes of fugitive emissions from Coal, Oil, and Natural Gas are basically the same as for methane that are described in IPCC Guideline for GHGs emissions. IPCC plans to prepare the similar Guideline for Short-Lived Climate Forcers (SLFCs) that includes SO_2, NO_x, CO, NH_3, BC, OC and VOCs (plans to be published in 2027).**

Example of VOCs emissions from Solvent Use

Paint application

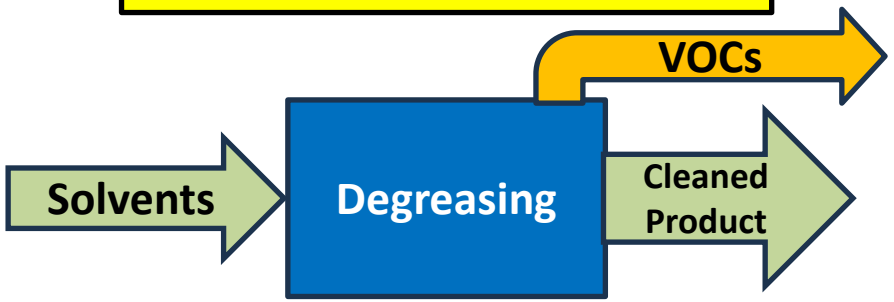
- Automobile manufacture, Vehicle refinishing
- Building and construction
- Domestic use
- Other industrial paint applications
- …

Chemical product manufacturing/processing/storage



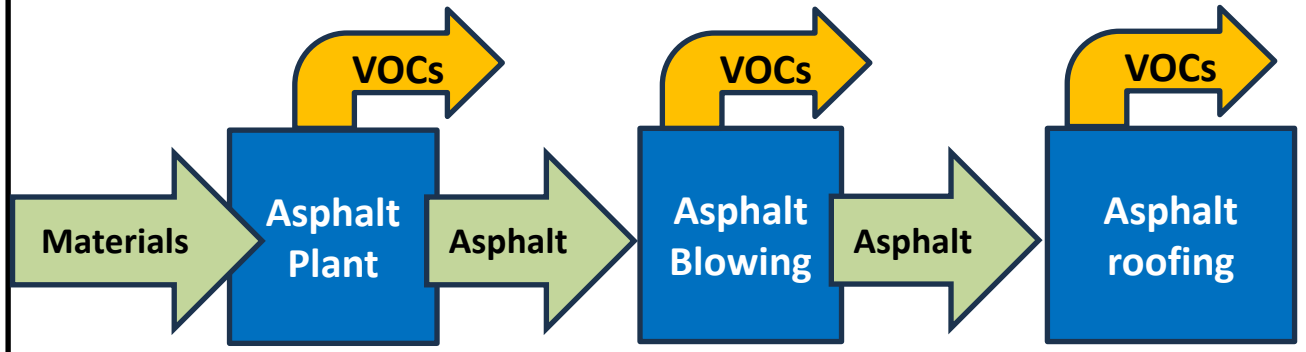
- Processing (Polyester, Polyvinylchloride, Polyurethane foam, Polystyrene foam, Synthetic rubber, etc.)
- Manufacturing (Paints, Inks, Adhesives, etc.)
- Textile finishing, Leather tanning, etc.
- …

Degreasing operations



- Degreasing is a process for cleaning products from water-insoluble substances

Production and use of asphalt

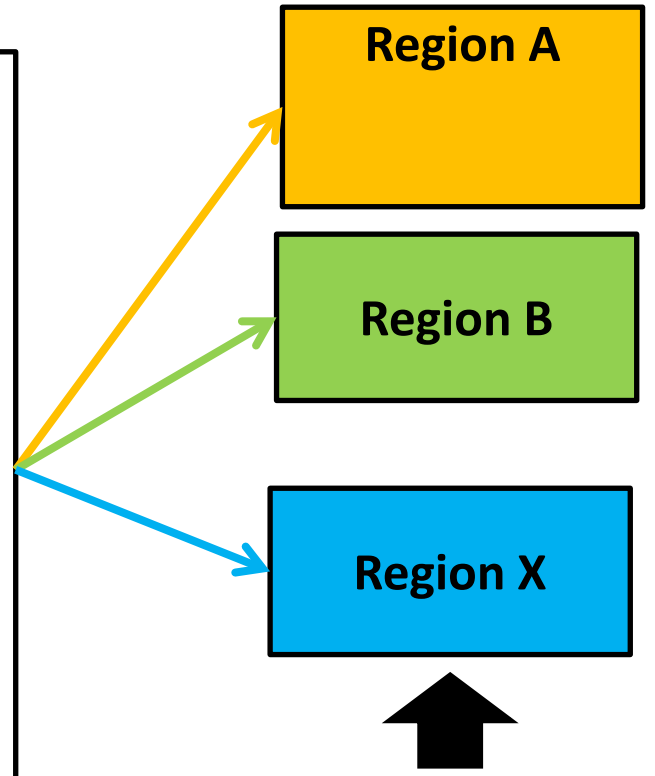


Ref. EMEP/EEA air pollutant emission inventory guidebook

Collecting and distributing activity data

National data

- Specify or assume activity amounts for all detailed sector categories
- Fuel consumption and production for fuel combustion and fugitive emissions from extraction, production, processing, distribution, etc.
- Production amounts of industrial products.
- Production and consumption of solvent materials and related data and to assume consumption and its trend of solvent materials.
  - Assuming consumption based on amounts of made, sold, imported solvents.
  - Data and information of emission controls for solvent use such as types of solvents and how solvents are treated.
- Data in national total should be distributed to each region (and plant) in the same format if necessary data and information is available.



- National Statistics
- International Statistics (IEA Energy Balances, UNdata, etc.)
- Related literatures (local reports, scientific papers, etc.)
- Survey of related industries (website, reports, questionnaire, etc.)

- Regional Statistics
- Proxy data to distribute national total activity data to each region such as production amounts, population, GDP, etc. in each region.

Collecting and setting emission factors and Removal Efficiencies (EF/R)

$$EM_{i,j,y} = A_{i,j,y} \times EF_{i,j,y} \times (1-R_{i,j,y})$$

i Activity types
j Sectors
y Target years

Collecting data

- **Emission factors and removal efficiencies in each defined activity type and sector category**
- Default EFs (including effect of R) for $A_{i,j}$ if technology information is not available.
- EFs/R for technologies:
  - Paint use: EFs for water-based paint, UV paint, etc.
  - Degreasing, etc.: EFs for low-solvent degreaser (solvent materials), R for applying carbon absorption, etc.
  - …

- Information of technologies including regulations for (i,j) in target countries
  - Literature survey
  - Questionnaire for target sectors

- Database for EFs
  - Emission inventory manuals (ex. AP-42, EMEP/EEA, IPCC, ABC Manual)
  - Scientific papers and local literature

Setting EF/R

- Selection of default EFs/R suitable for target countries
- It is preferable to set EFs/R based on technology information for target countries:
  - EFs/R for technologies installed in each country
  - Averaged EFs/R for $A_{i,j}$ considering ratios of technologies used in (i,j) or distribution of $A_{i,j}$ to each technology
- It must be noted that ratios of technologies vary by target years.

Speciation of total VOCs emissions to components

Total VOCs emissions in each sector category and activity type

Speciation factors

- SPECIATE (USEPA)
- Survey reports of each country
- Scientific papers for specific sectors
- …

Emissions of VOCs component species (Ex. GEIA 25 NMVOC groups)

Alkanols (alcohols)	$C_nH_{2n+1}OH$
Ethane	C_2H_6
Propane	C_3H_8
Butanes	C_4H_{10}
Pentanes	C_5H_{12}
Hexanes and higher alkanes	C_nH_{2n+2} $(n \geq 6)$
Ethene (ethylene)	C_2H_4
Propene	C_3H_6
Ethyne (acetylene)	C_2H_2
Isoprenes	C_5H_8
Monoterpenes	$C_{10}H_{16}$
Other alk(adi)enes/alkynes (olefines)	C_nH_{2n-2}
Benzene (benzol)	C_6H_6
Methylbenzene (toluene)	C_7H_8
Dimethylbenzenes (xylenes)	$C_6H_4(CH_3)_2$
Trimethylbenzenes	$C_6H_3(CH_3)_3$
Other aromatics	C_nH_{2n-6}
Esters	R-C(=O)O-R'
Ethers (alkoxy alkanes)	R-O-R'
Chlorinated hydrocarbons	CH_3Cl
Methanal (formaldehyde)	CH_2O
Other alkanals (aldehyedes)	R-CHO
Alkanones (ketones)	R-C(=O)-R'
Acids (alkanoic)	R-C_nH_nCOOH
Other NMVOCs (HCFCs, nitriles, etc.)	NA

VOCs emissions for Chemical mechanisms for air quality models

- SAPRC (Statewide Air Pollution Research Center) chemical mechanism: VOCs are classified according to chemical characteristics
- CBM (Carbon Bond Mechanism): VOCs are classified according to molecular carbon bond structure.
- …

Air Quality Models (CMAQ, WRF-Chem, etc.)

Calculating emissions and creating final products

Actual works necessary to create Emission Inventory

- Prepare or develop systems to calculate emissions and create final products, namely Emission Inventory.
  - Use publicly available systems (Ex. The ABCs Emission Inventory Manual Excel Workbook. http://www.rrcap.ait.ac.th/abc/Pages/Emission-Inventory.aspx)
  - Develop original systems using programing languages (Ex. Fortran, Python, C, etc.) and/or Excel-based systems including utilizing publicly available systems
- Create input data (activity data, emission factors, removal efficiencies, ratios of technologies, other necessary data, parameters and information) in the required format of the systems.
- Conduct calculations and create Emission Inventory using the systems

Utilize the data and information of Emission Inventory

References for methodologies to develop Emission Inventory

Manuals

- EMEP/EEA air pollutant emission inventory guidebook 2023 (https://www.eea.europa.eu/publications/emep-eea-guidebook-2023)
- AP-42: Compilation of Air Pollutant Emissions Factors (https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors)
- Atmospheric Brown Clouds (ABC) Emission Inventory Manual (http://wedocs.unep.org/handle/20.500.11822/21482)
- 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html)

Scientific papers

- Scientific papers of emission inventories in Asian countries are useful not only for understanding the status of air pollutants emissions but also for learning methodology to estimate emissions and how to analyze the results.
  - Atmospheric Chemistry and Physics (https://www.atmospheric-chemistry-and-physics.net/)
  - Earth System Science Data (https://www.earth-system-science-data.net/)
  - Atmospheric Environment (https://www.journals.elsevier.com/atmospheric-environment)
  - Environmental Science & Technology (https://pubs.acs.org/journal/esthag)
  - … … ⇒ Google Scholar

Thank you for your attention!