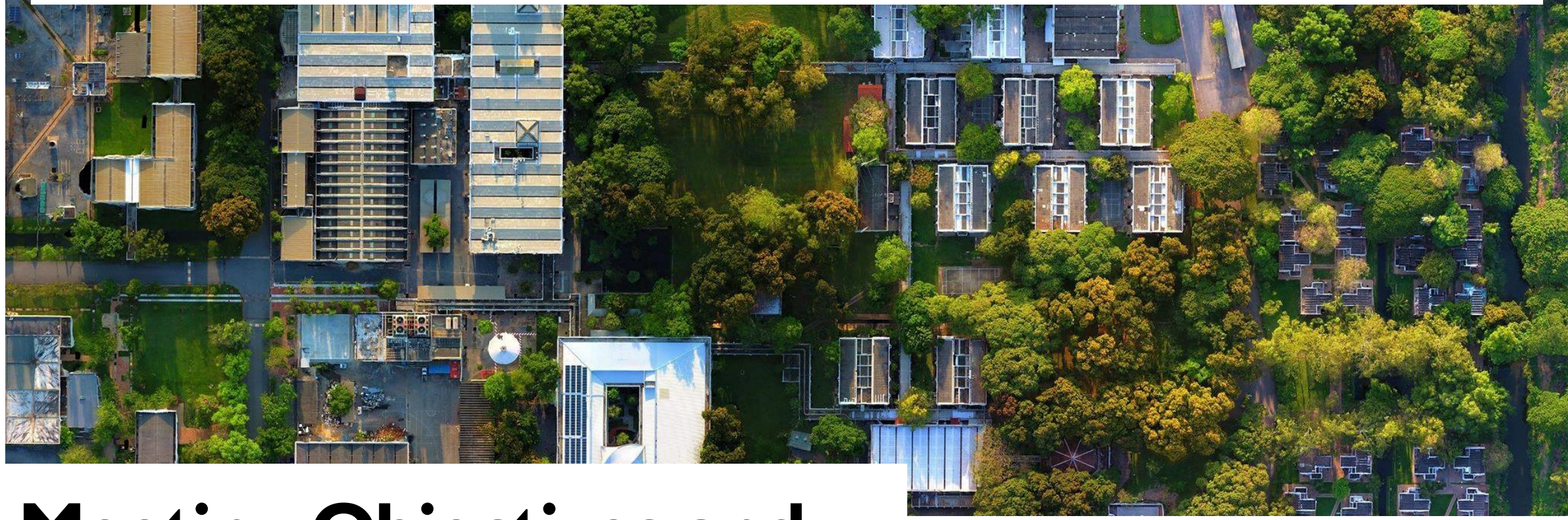
National Air Quality Awareness Raising Workshop And Stakeholder Mapping For Clean Air Plan Development

27-28 August 2024
Luang Prabang, Lao PDR



Meeting Objectives and Participant Introduction

Ekbordin Winijkul, PhD
Environmental Engineering and Management
Asian Institute of Technology
ekbordinw@ait.asia

Overview of the Project

- The development of clean air plan in Lao PDR to be initiated by NRERI
  - UNEP supports the stakeholder mapping activity to help identify key stakeholders, assess their interests and needs, and analyze their potential contribution to the clean air plan's viability.

- The stakeholder mapping helps identify opportunities for city-to-city cooperation and potential common urban air quality mitigation measures within urban airsheds in Lao PDR.

- This awareness-raising workshop
  - Initial step towards providing a better understanding of the current situation regarding data and information related to air pollution in Lao PDR
  - Seeking solutions for improved air quality management among government agencies and other key stakeholders.
  - Co-Organizers: MoNRE/NRERI, AIT, UNEP, UNESCAP

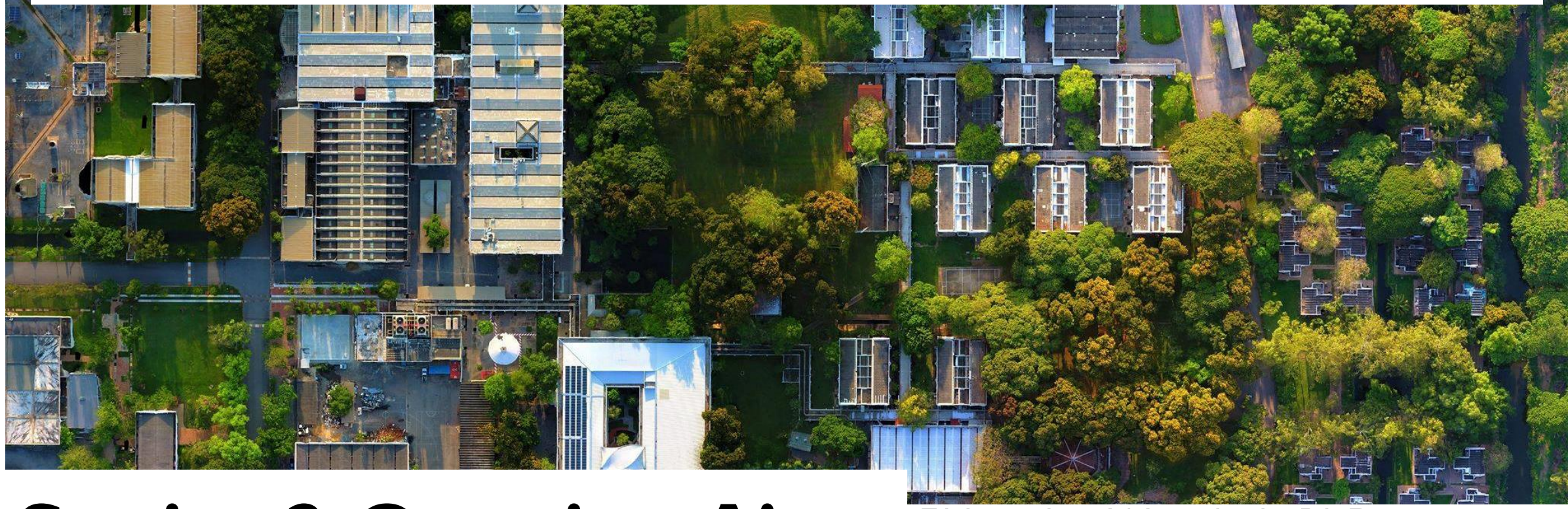
Meeting Objectives

This workshop aims to empower and raise awareness of the key stakeholders in Lao PDR with the knowledge and tools necessary to tackle air pollution effectively.

1. Increase Understanding: Enhance the knowledge of government officials and stakeholders about the sources, impacts, and current status of air pollution in Lao PDR.
2. Promote Best Practices: Share best practices and successful strategies from other countries on reducing air pollution.
3. Engage Stakeholders: Facilitate collaboration between government agencies in addressing air pollution.

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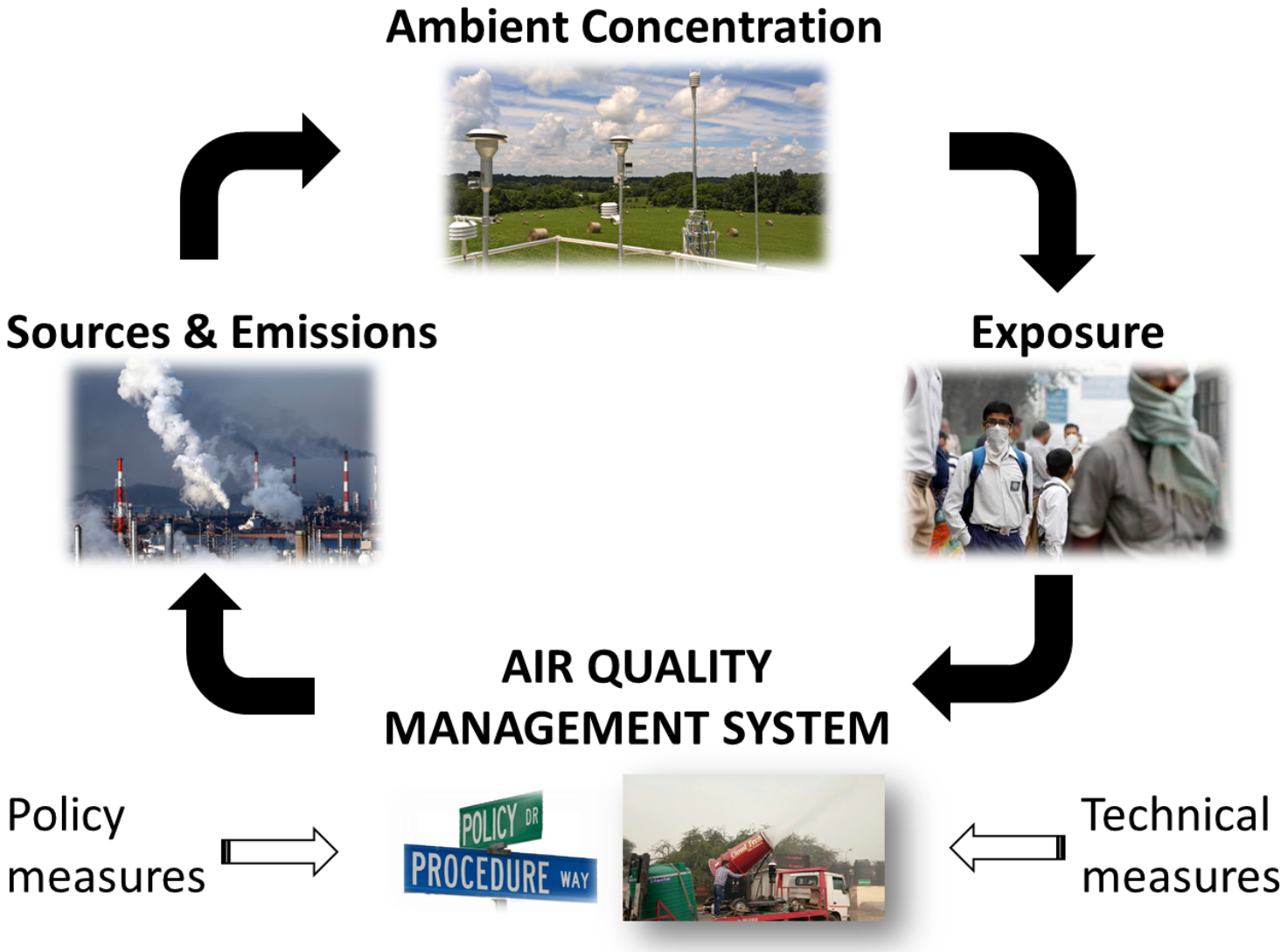
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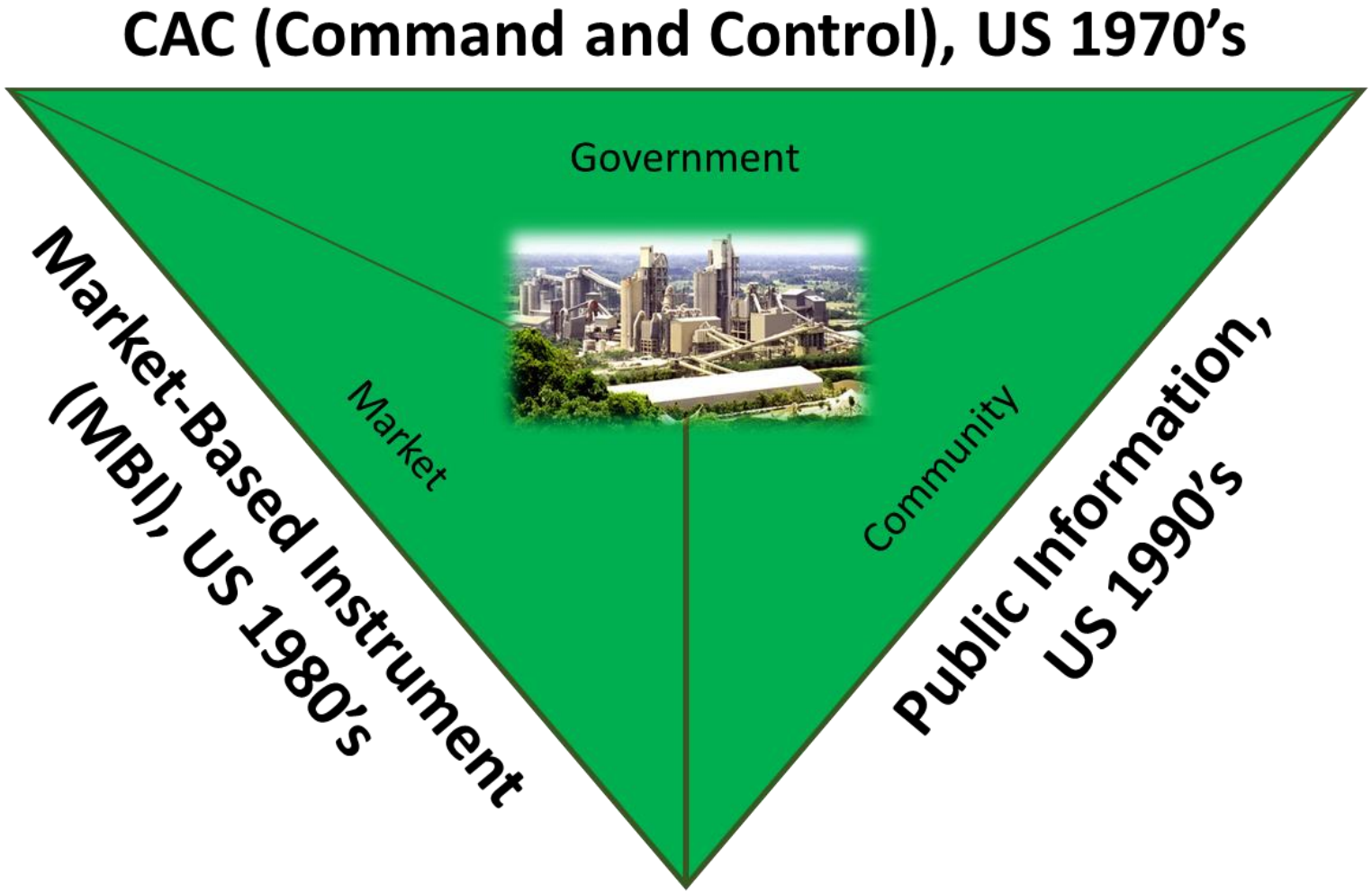
Session 2: Overview: Air Quality Management

Ekbordin Winijkul, PhD
Environmental Engineering and Management
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ekbordinw@ait.asia

Integrated Approach to set Air Quality Management



Actors of AQM and Approaches



Disseminate AQ data: Air Quality Index (AQI)

- A tool for air quality scientists to communicate with the public
- It is calculated based on concentration of each pollutant compared to the ranges of index of that pollutant
- AQI will be calculated for all six (6) pollutants in Thailand
- The highest AQI will be used to represent AQI at that location

- Formula:

$$AQI = \frac{I_H - I_L}{X_H - X_L}(X - X_L) + I_L$$

  - X = Pollutant concentration
  - X_H, X_L = Highest and lowest conc. of pollutant in that class
  - I_H, I_L = Highest and lowest index of pollutant in that class

AQI ** Example: Thailand's case **	Meaning	$PM_{2.5}$ ($\mu g/m^3$) 24-hr average	O_3 (ppb) 8-hr average
0 – 25	Excellent	0 -15.0	0 – 35
26 – 50	Satisfactory	15.1 – 25.0	36 – 50
51 – 100	Moderate	25.1 – 37.5	51 – 70
101 – 200	Unhealthy	37.6 – 75.0	71 – 120
≥ 201	Very Unhealthy	≥ 75.1	≥ 121

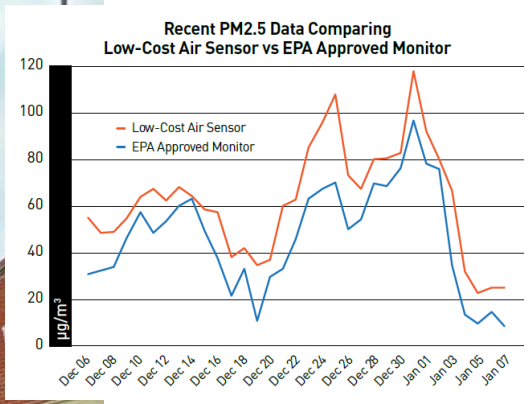
Example of Public Awareness Raising: USEPA Flag Program

- USEPA Flag Program
  - Uses brightly colored flags - simple, intuitive means of informing people about daily air quality
  - A colored flag is flown according to the air-quality forecast for the day
  - Flag program uses an Air Quality Index (AQI) for PM2.5 to inform public about outdoor air quality

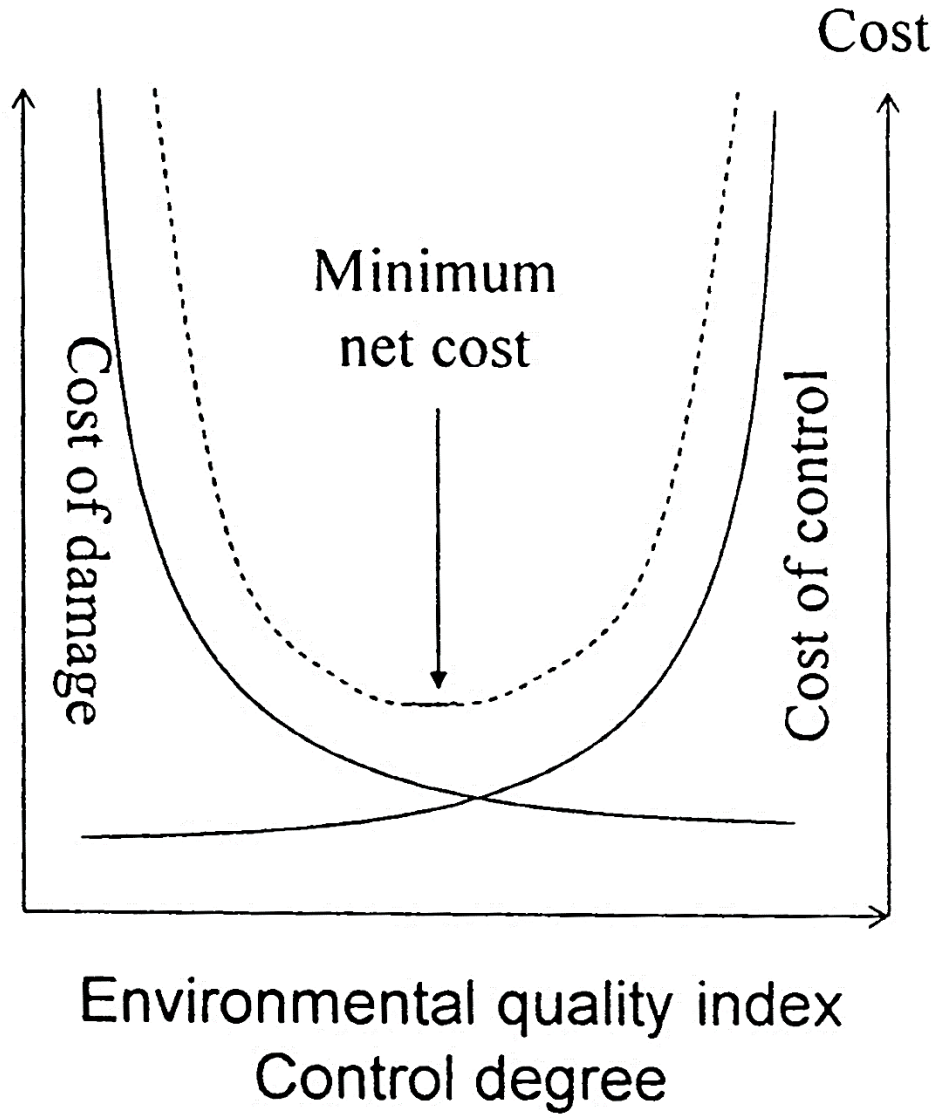
- Why at school?
  - An inexpensive, visible way to help protect children, a group vulnerable to effects of air pollution
  - Helps teachers, students and the public understand what actions they can take to help protect their health
  - During periods of unhealthy air, schools can direct children to modify their activities

Air Quality Index	Outdoor Activity Guidance
green GOOD	Great day to be active outside!
yellow MODERATE	Good day to be active outside! Students who are unusually sensitive to air pollution could have symptoms.*
orange UNHEALTHY FOR SENSITIVE GROUPS	It's OK to be active outside, especially for **short activities** such as recess and physical education (PE). For **longer activities** such as athletic practice, take more breaks and do less intense activities. Watch for symptoms and take action as needed.* Students with asthma should follow their asthma action plans and keep their quick-relief medicine handy.
red UNHEALTHY	For **all outdoor activities**, take more breaks and do less intense activities. Consider moving **longer or more intense activities** indoors or rescheduling them to another day or time. Watch for symptoms and take action as needed.* Students with asthma should follow their asthma action plans and keep their quick-relief medicine handy.
purple VERY UNHEALTHY	Move **all activities** indoors or reschedule them to another day.





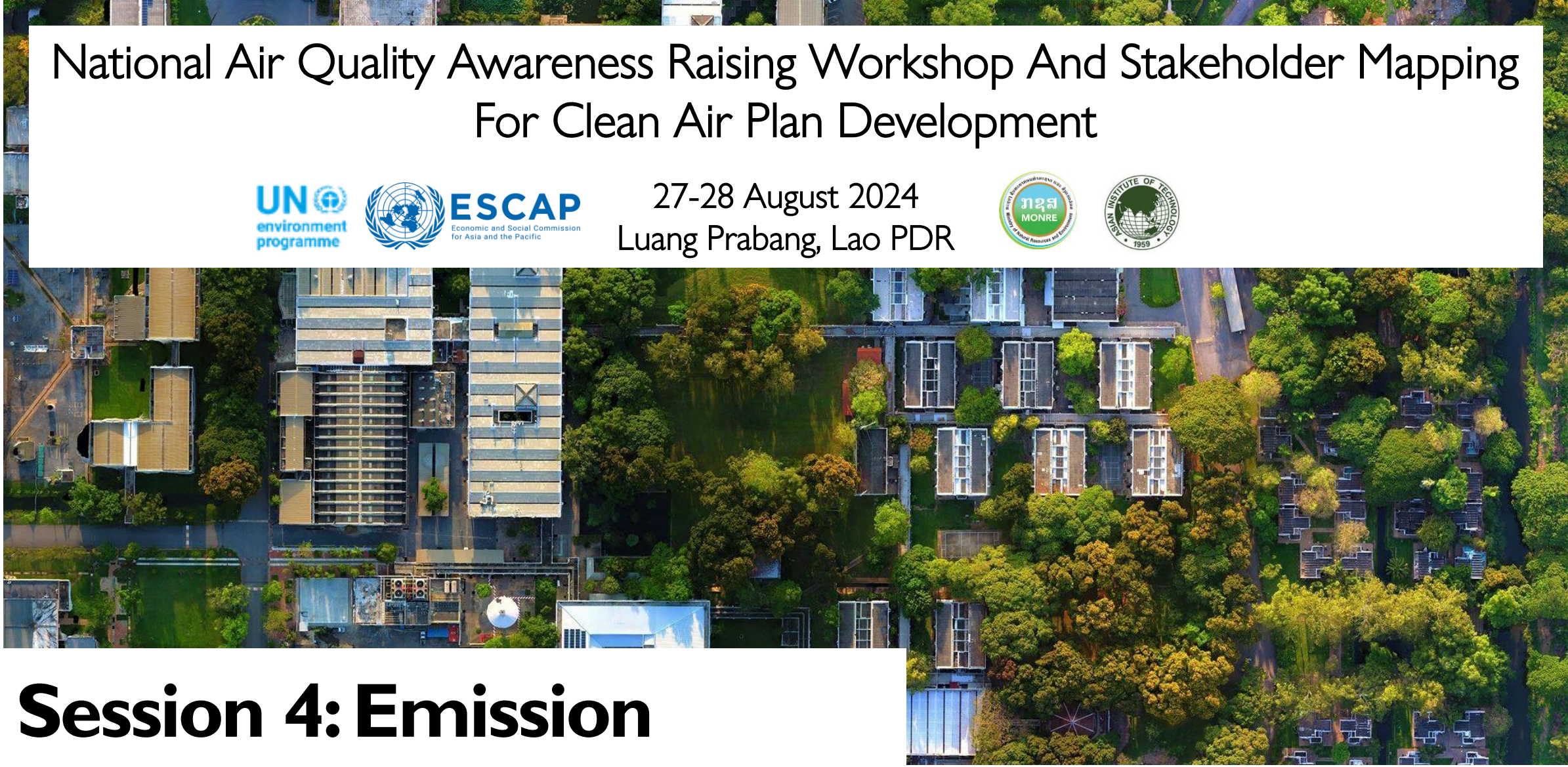
Economical Aspects of Air Quality Management



- Damage cost:
  - Health care
  - Morbidity/Mortality
  - Crop loss/damage
  - Property damage
  - Environmental degradation
- Benefit = inverse Damage
- Damage cost + Control Cost = Net cost
- Min. net cost = Optimum Control Degree
- Problem: intangible cost (?)

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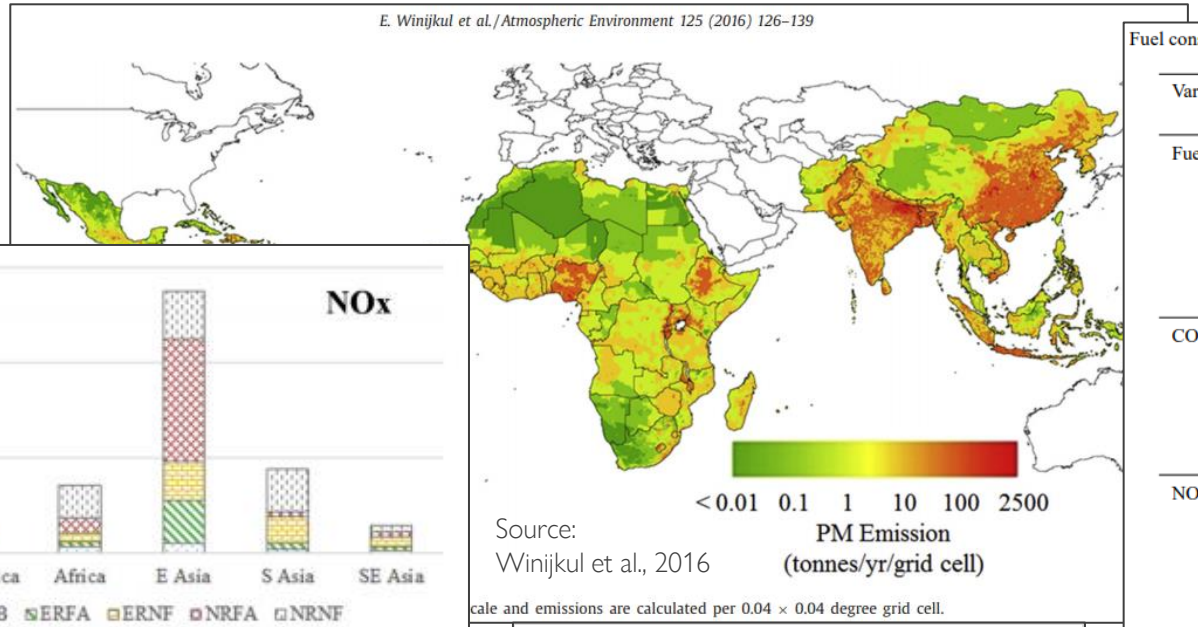


Session 4: Emission Inventory Development (Part 1)

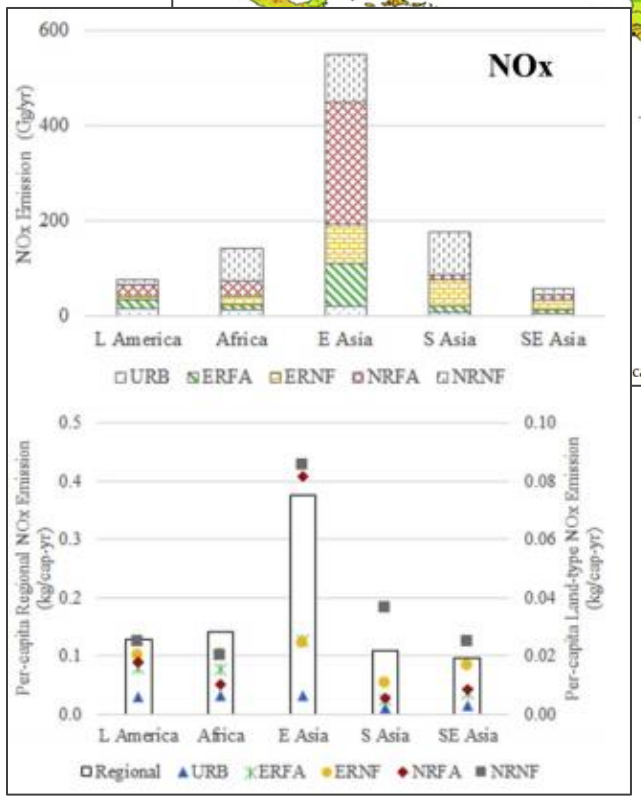
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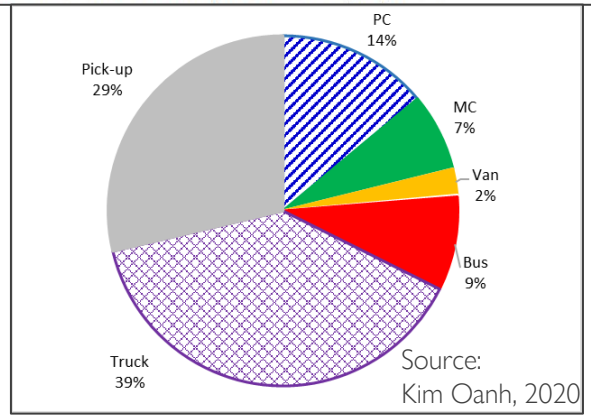
I. Emission inventory

Comprehensive listing by sources of air pollutant emissions in a geographic area during a specific time period



Source: Winijkul et al., 2016





Source: Kim Oanh, 2020

Fuel consumption (unit: Pg year^{-1}) and emissions (unit: Tg year^{-1}) from different transport modes in year 2010, 2030, and 2050.

Variable	Mode	2010	2030				2050			
			A1B	A2	B1	B2	A1B	A2	B1	B2
Fuel[a]	On-road[b]	1.7	2.71	2.05	2.1	1.86	2.84	2.38	1.93	1.53
	Non-road	0.25	0.35	0.28	0.29	0.31	0.37	0.27	0.25	0.26
	Shipping	0.25	0.37	0.33	0.36	0.35	0.55	0.42	0.49	0.46
	Aviation	0.24	0.44	0.38	0.36	0.37	0.77	0.47	0.43	0.44
	Rail	0.03	0.09	0.06	0.08	0.07	0.17	0.09	0.14	0.13
	Total	2.47	3.97	3.1	3.19	2.96	4.69	3.62	3.23	2.82
	Total (EJ year^{-1})[c]	107	171	134	138	128	203	157	139	122
CO	On-road[b]	97.4	72.8	53.8	58.8	51.2	93	63.2	65.1	45.3
	Non-road	35.9	59.9	43.2	49	48.8	69.1	45.4	46.4	44.9
	Shipping	1.19	1.77	1.57	1.69	1.64	2.59	1.96	2.31	2.17
	Aviation	1.92	2.33	1.98	1.92	1.93	2.64	1.61	1.47	1.5
	Rail	0.35	0.84	0.56	0.73	0.73	1.08	0.57	0.89	0.79
	Total	137	138	101	112	104	168	113	116	95
NO_x	On-road[b]	25.2	18.1	13.7	14.7	13.3	21.9	14.9	15.3	11.1
	Non-road	10.1	6.58	5.7	5.87	5.87	3.84	2.9	2.86	2.91
	Shipping	16.2	20.4	18.1	19.4	18.9	27.3	20.7	24.3	22.8
	Aviation	3.02	4.95	4.42	3.85	4.14	7.5	5.4	3.4	4.4
	Rail	1.59	3.48	2.32	3.05	3.04	4.52	2.33	3.65	3.33
	Total	56.1	53.5	44.2	46.9	45.2	65.1	46.2	49.5	44.5
THC	On-road[b]	12.1	8.77	6.52	7.09	6.3	11.4	7.66	7.96	5.65
	Non-road	4.87	6.7	4.85	5.57	5.56	8.11	5.19	5.48	5.36
	Shipping	1.26	1.8	1.6	1.72	1.68	2.56	1.94	2.28	2.14
	Aviation	0.3	0.29	0.24	0.24	0.24	0.25	0.16	0.14	0.14
	Rail	0.25	0.64	0.43	0.56	0.56	0.73	0.39	0.6	0.54
	Total	18.8	18.2	13.6	15.2	14.3	23.1	15.3	16.5	13.8
PM	On-road[b]	1.49	1.05	0.83	0.88	0.8	1.26	0.82	0.89	0.62
	Non-road	1.28	0.99	0.83	0.87	0.87	0.75	0.51	0.53	0.52
	Shipping	1.38	1.96	1.74	1.87	1.82	2.77	2.1	2.47	2.32
	Aviation	0.006	0.011	0.009	0.009	0.009	0.019	0.012	0.011	0.011
	Rail	0.21	0.35	0.23	0.3	0.31	0.15	0.08	0.13	0.1
	Total	4.37	4.36	3.62	3.93	3.8	4.94	3.53	4.02	3.58

[a] Fuel for on- and non-road, shipping, and aviation is oil; that for rail is oil and coal.
[b] For on-road vehicles, the historical fuel use from IEA is until 2005, in order to make the results consistent with Yan et al. (2011). The values shown here are from the A1B scenario.
[c] The net calorific values of gasoline, diesel, and coal used in this paper are 44.0 MJ kg^{-1}, 42.6 MJ kg^{-1}, and 21.2 MJ kg^{-1}, respectively.

Purposes of Emission Inventory

- GOAL is to obtain systematic information on:
  - Category and distribution of sources
  - Amounts and types of pollutants emitted
- Why emission inventories?
  - Identify major sources to identify cost-effective control strategies, permitting, emissions fees, etc.
  - Tracking emissions over time
  - Input for modelling
  - Input to design monitoring program
  - Public information

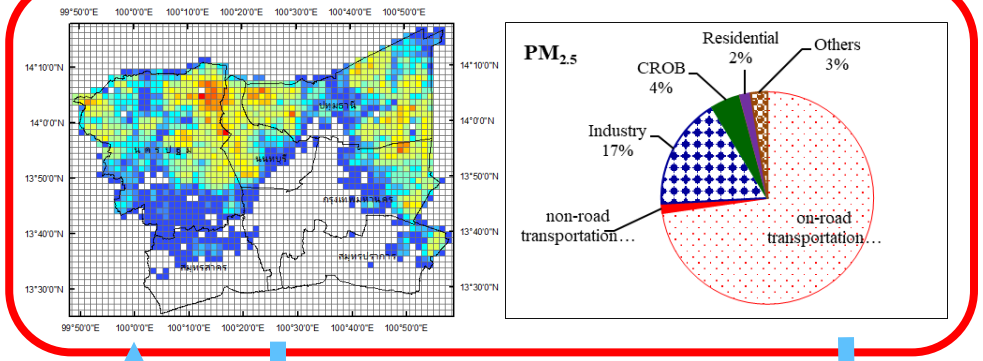
General Features of Emissions in Developing Countries

- Mobile sources contribute over 60-80% of urban air pollution
  - Fast increase of vehicle fleets, slow increase of road coverage --> traffic jam & air pollution
  - Long life of vehicles, slow turn-over of fleet, many old vehicles w/o control equipment
  - Slow intrusion rates of Euro engines, fuel quality and fuel alternatives: unleaded gasoline, CNG, LPG, biodiesel, etc.
- Cooking emission (solid fuels: fuelwood, crop residue, dung, coal)
- Open burning (forest, solid waste, crop residues, etc.)
- Small and medium industries (technology issues, etc.)

2. Emission Inventory in Air Quality Management

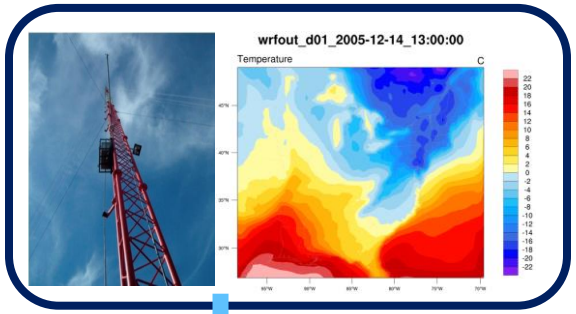


Air Quality Monitoring

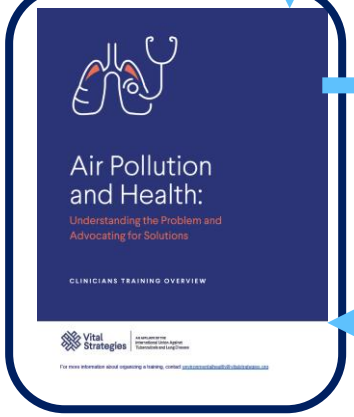


Emission Inventory

Meteorological data

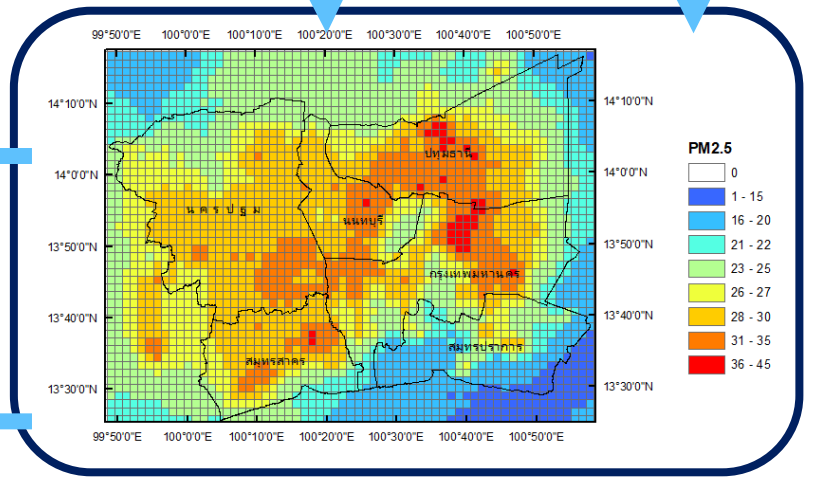


Impact Assessment





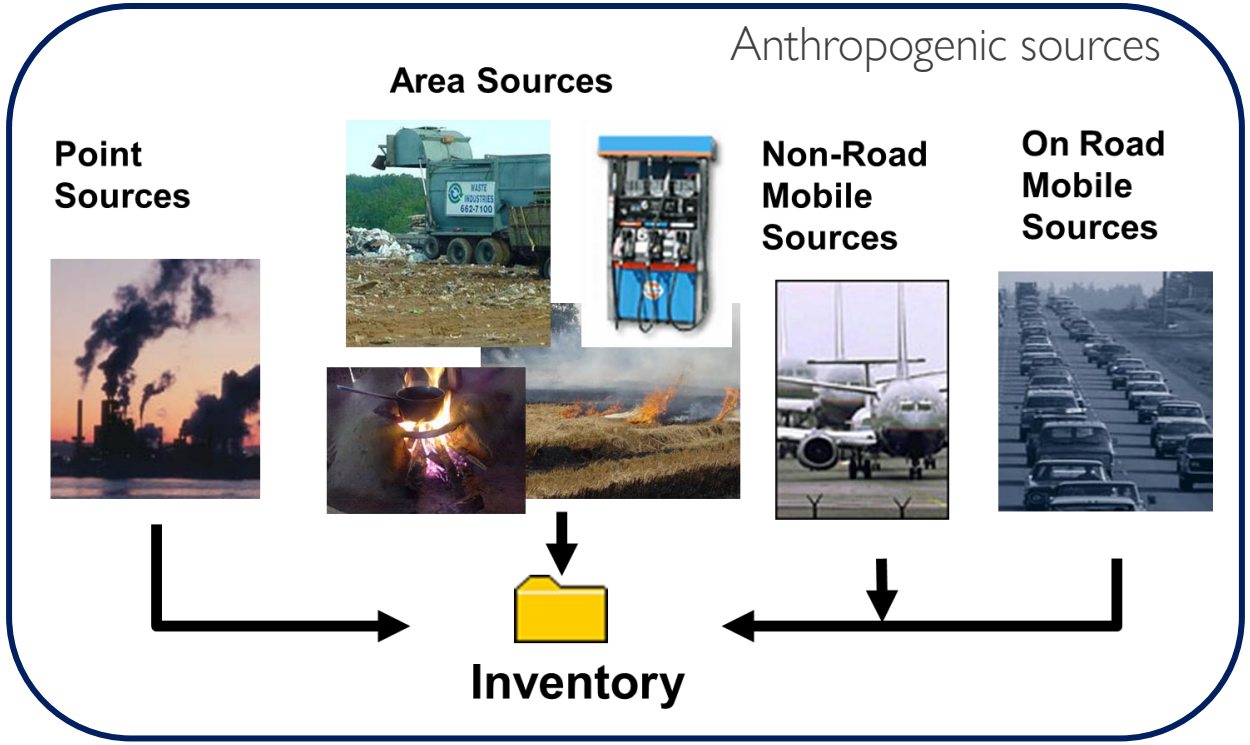
Air Quality Management



Air Quality Modeling

3. Source Categories: Point, Area and Mobile

- *Stationary Point Sources* are non-moving, fixed-site emitters, e.g. industrial combustion processes, stacks of boilers in power plants or manufacturing processes

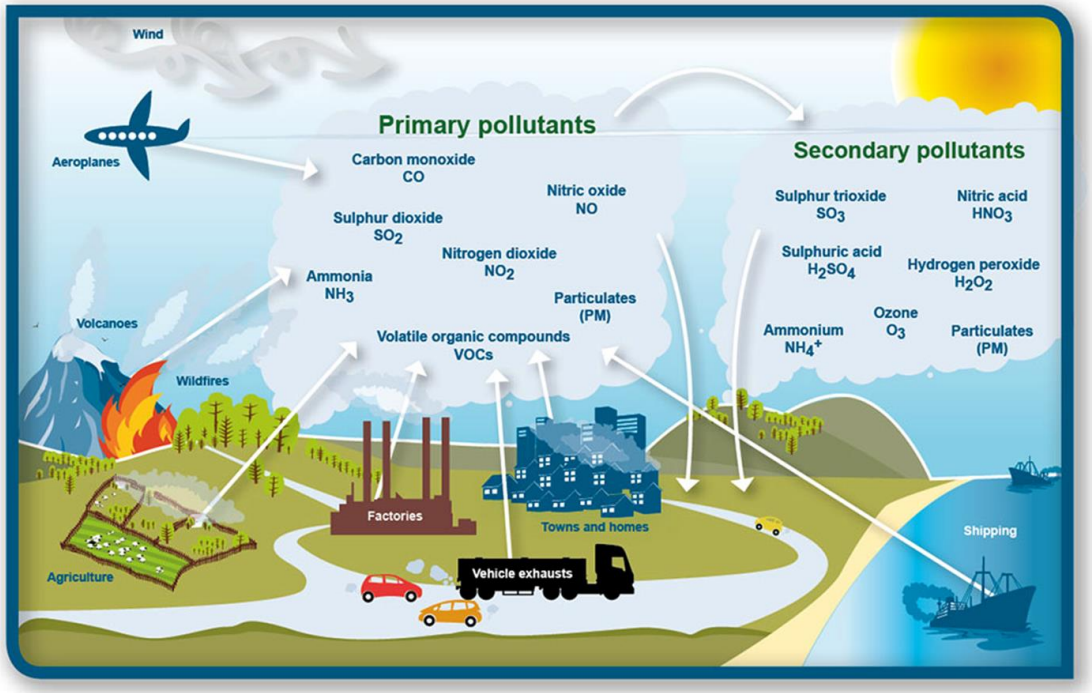


- *Stationary Non-point sources (Area source)* where emissions may be from multiple point sources over an area, i.e., forest fires and crop residue open burning

- *Mobile sources* comprise of a wide variety of vehicles, engines, and equipment that emit air pollutants and move, or can be moved from one place to another
  - On-road mobile sources: vehicle on roads
  - Non-road mobile sources: machineries used for construction, agriculture, non-road transportation, recreation, etc.

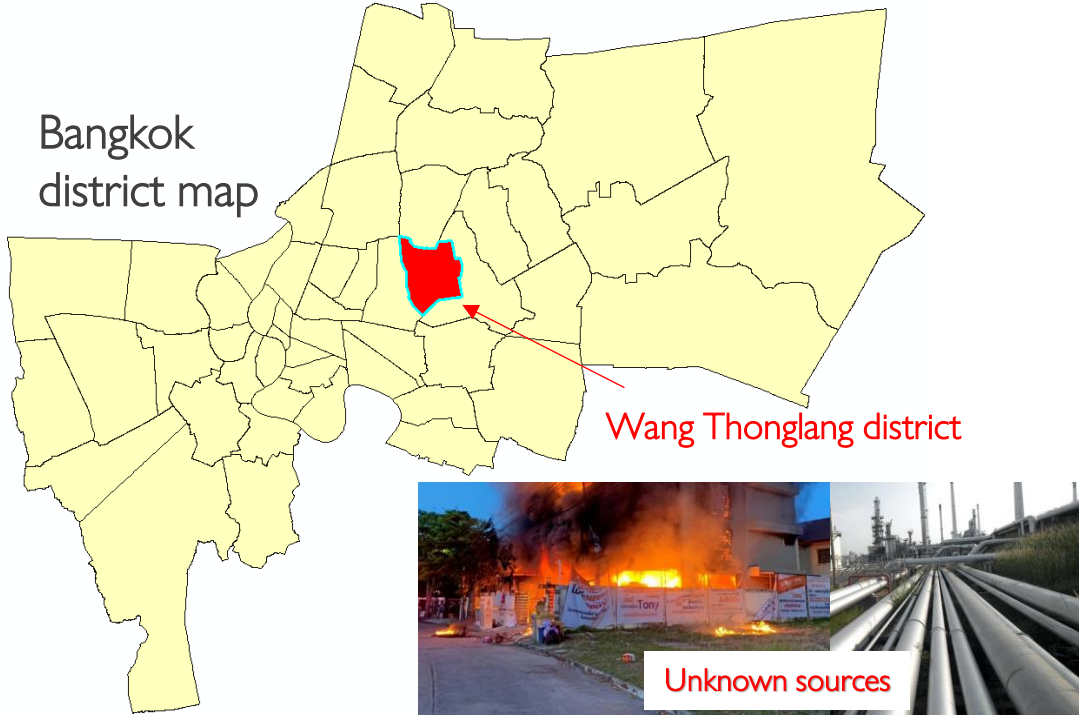
4. Limitations of Emission Inventory

- Primary: directly emitted from sources
- Secondary: formed in atmosphere



**** Only primary pollutants can be quantified in an emission inventory**

- Sources are limited to the defined study area
- Sources are known



**** EI does not include emission outside of the study area & cannot identify unknown emission sources**

5. Pollutants from Different Sources

Air Pollutants: PM VS Gases

- Particulate Matter (PM):
  - Solid or liquid, ranging from the largest gas molecules to above 100 μm
  - Size: $\mathbf{TSP}$, $\mathbf{PM_{10}}$, $\mathbf{PM_{2.5}}$, ultrafine, nanoparticles, etc.

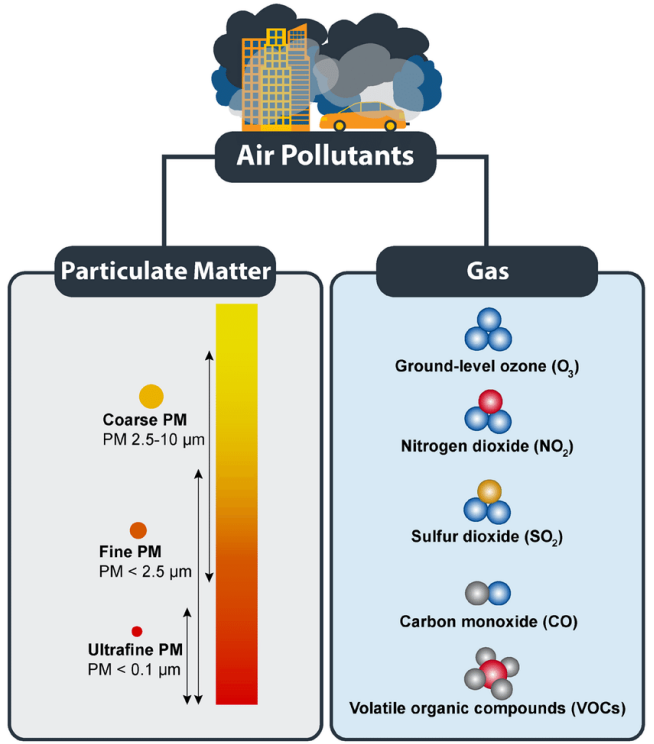


Figure credit: Sompornrattanaphan et al., 2020

- Gaseous pollutants (CO, NO_x, SO_2, VOC, etc.) contribute above 90% of man-made pollutants by mass

Emission Sources

Anthropogenic Sources

- Point sources
- Mobile sources
- Area sources

Natural Sources

- Biogenic sources
- Geogenic sources

6. Approaches and Tiers for Conventional EI

- **Bottom-up:** Collection of specific information of "activity data" of individual sources, processes, activities and their levels, and estimates of emission factors (**higher Tier data**)

- **Top-down:** National- or regional-level emission estimates allocated to a domain based on activity data of surrogate parameters such as population, employment, energy consumption, resource use, vehicle number etc. (**lower Tier: Tier 1 data)**

- A combination of these approaches is normally used

Top-Down VS. Bottom-Up Approaches

Top-Down Approach

- Methodology
  - Use emission factors and high level (national) activity data (e.g., emission factor x national coal consumption) to estimate emissions
  - National- or regional-level emission estimates scaled to the inventory domain based on surrogate data (geographic, demographic, economic data)
- Typically used when
  - Local data are not available
  - Too high cost to gather local information
- **Advantages:** Requires minimum resources
- **Disadvantages:** Low accuracy, high uncertainty

Bottom-Up Approach

- Methodology
  - Uses source-specific data (for point sources) and category-specific data at the most refined spatial level (for nonpoint and mobile sources)
  - Emission estimates for individual sources (and source categories) are summed up to obtain domain-level inventory
- Typically used when
  - Source/category-specific activity or emissions data are available
  - End-use of EI justifies high cost of collecting site-specific data
- **Advantage:** Produce more accurate emission estimates
- **Disadvantage:** Requires more resources to collect site-specific information than a top-down approach

7. EI Design: Major Preparation Activities

- Identification of EI manager and EI compiler
- Identify key air pollution issues
- Selection of air pollutants and sources
- Selection of inventory domain and base year
- Selection of temporal resolution e.g., hourly or daily or annual
- Designing reporting document of EI

EI Design: Major Preparation Activities

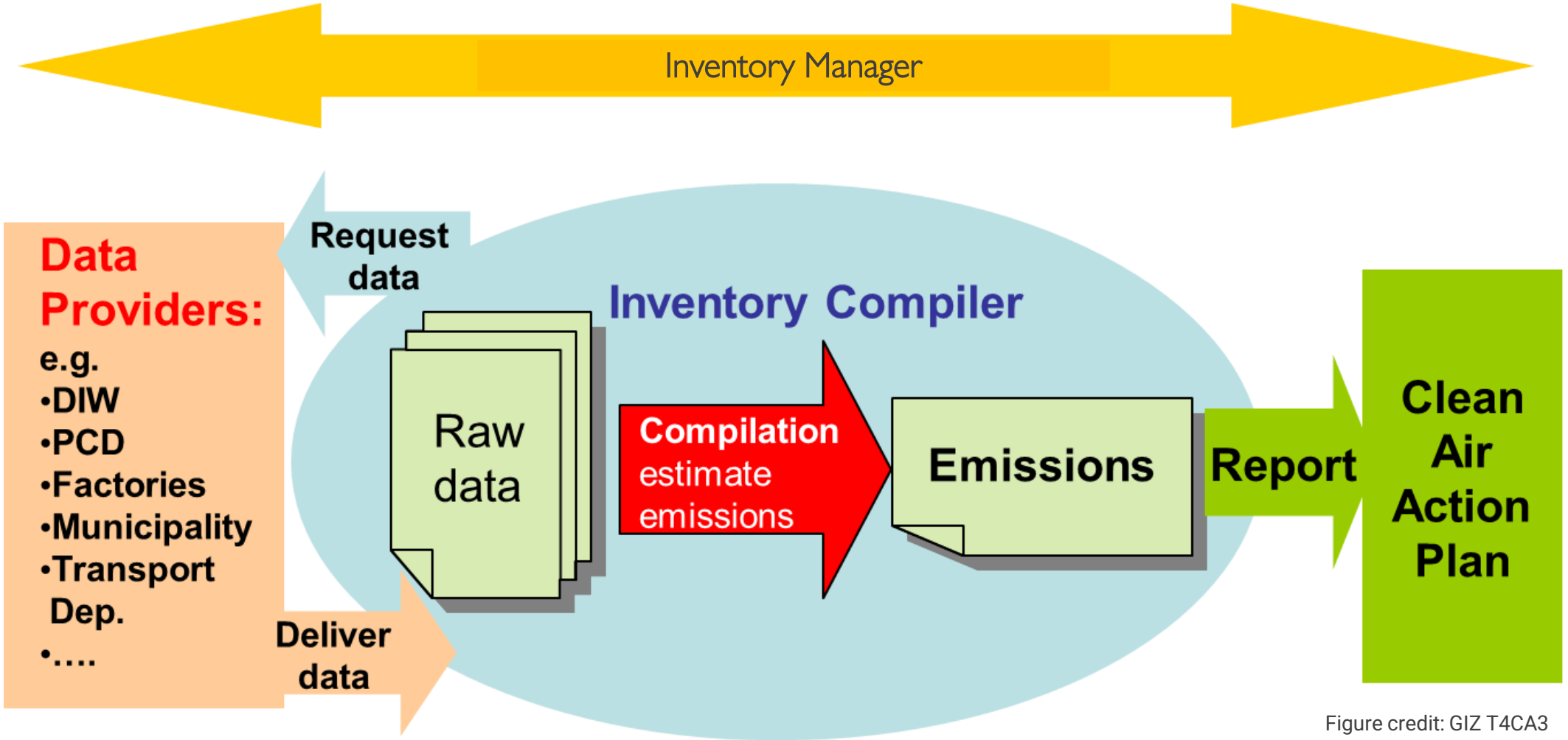
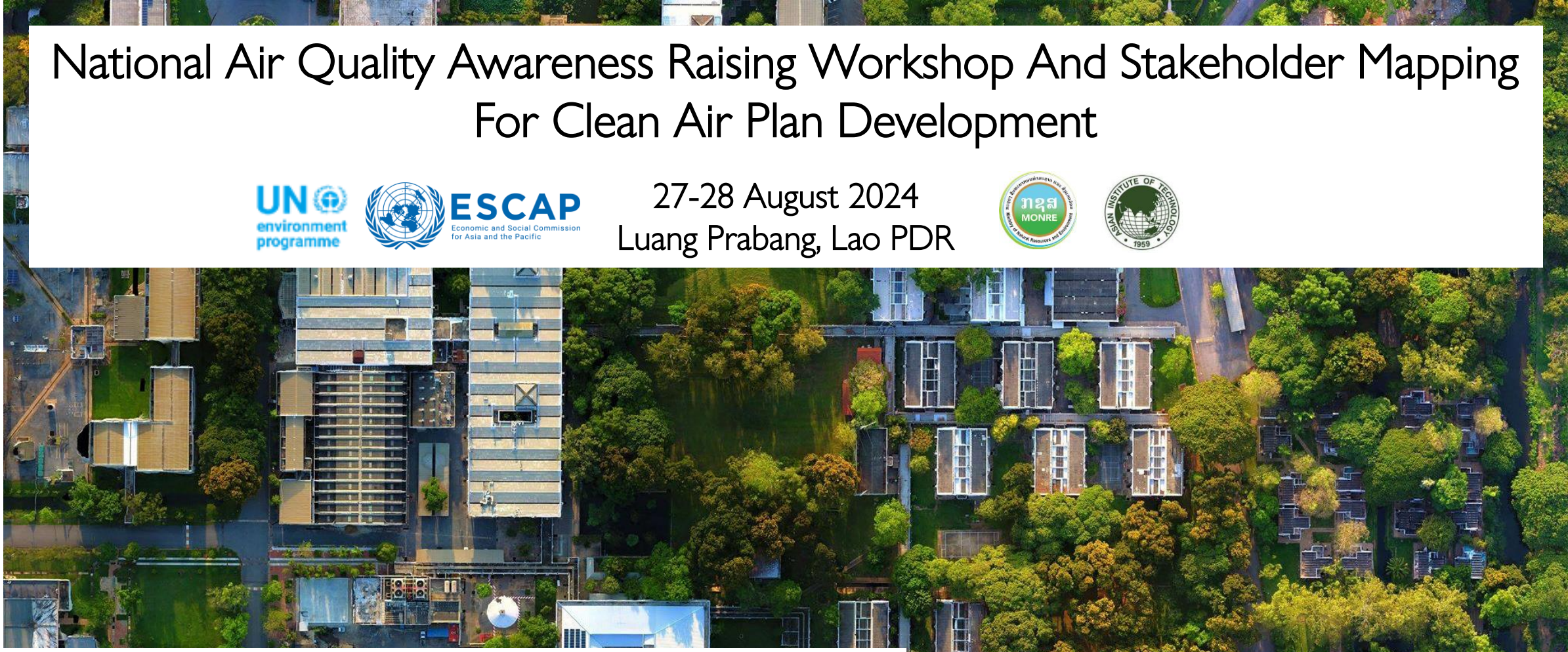


Figure credit: GIZ T4CA3

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Session 4: Emission Inventory Development (Part 2)

Ekbordin Winijkul, PhD
Environmental Engineering and Management
Asian Institute of Technology
ekbordinw@ait.asia

8. Basic Formula for Emission Factor Method

Emission = Emission Factor x Activity Data

EF (emissions factor) is the rate of emissions released from a source per activity unit, e.g.:

- Kg SO_2 /ton coal burned
- Kg CO /km travelled by car
- Kg PM_{10} /ton cement produced

Activity data: amount of activity per a time period of EI, e.g.:

- Amount of coal burned/year
- Total distance travelled: km/ year
- Amount cement produced: ton/year

Basic Formula for Material Balance Method

Input of materials = output of materials

This method is normally used for SO_2 emission (using S content of fuel), PM emission (based on Ash content of fuel) and CO/CO_2 emissions (using C content of fuel)

$$\mathbf{EF_{SO2} = 2 \times \left(\frac{S_{fuel}}{100}\right) \times \left(\frac{100 - \alpha_s}{100}\right) \times 1000}$$

EF_{SO2}: uncontrolled EF (kg/ton fuel)

S fuel: sulfur content by weight, %

α_s: percent of S retention in ash, % (about 5% for coal)

Basic Formula for CEM Method (Stack Emission)

Emission Rate = conc. (mg/Nm^3) x flowrate (Nm^3/hr)

$$E_i = \frac{h \times Q_0 \times C_{i0} \times N}{10^9}$$

Ei: annual emission rate of pollutant *i* (tonnes/year);

h: number of operation hours per day

Q_0 : Emission flow rate of the source (Nm^3/h);

C_{i0}: Average emission concentration of pollutant *i* (mg/Nm^3);

N : Actual days the point source is in operation (day), (excluding days that a plant is shut down)

9. Data Requirement

Point Source





Area Source



Mobile Source

Methodologies (Tiers of Emission Inventory)

- **Tier 1:** Less detailed inventory with default emission factors with top-down approach
- **Tier 2:** More detailed inventory of sources (usually with different technologies)
- **Tier 3:** Most detailed inventory of sources with bottom-up approach

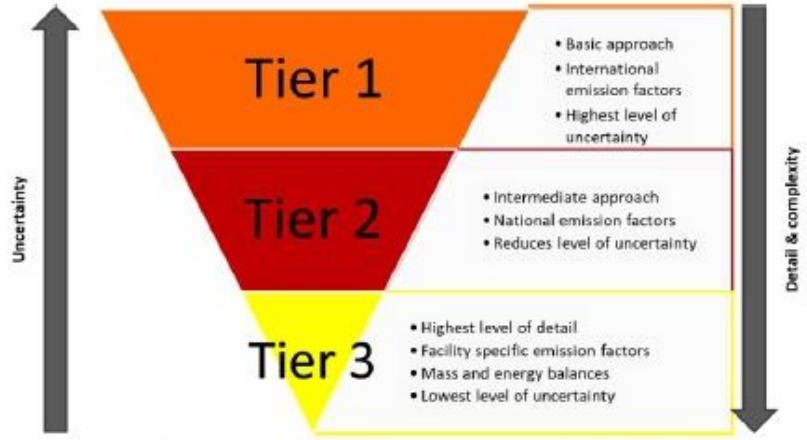


Figure 1: Different calculation methods [31]

Figure credit: Booysen et al., 2018

Stationary Point Sources: Data for Tiered EI

Tier	Type of activity data required	Activity data sources	EF required
Tier 1	Consumption for different fuel types	National statistics, International Energy Agency	Default EF based on fuel type
Tier 2	Fuel type and combustion technology	Primary survey of the plant, Environmental Impact Assessment (EIA) document	Technology specific EF
Tier 3	Facility specific data (i.e. **Continuous Emission Monitoring system**)	Pollutant release and transfer registry (PRTR) report, plant technical report/environmental monitoring	Emission calculation using stream/flue gas data (flow rate, temperature, concentration of pollutants)

Summary Activity Data for Mobile Sources

Tier	Type of activity data required	Activity data sources	EF required
Tier 1	Fuel type and fuel consumption	National statistics, International Energy Agency	Bulk EFs in g/kg of fuel consumed
Tier 2	Number of vehicles, vehicle kilometer travelled (VKT), average speed	Research (secondary literature), primary survey, statistics	g/km (laboratory measurement based on average speed)
Tier 3	Number of vehicles, VKT, instantaneous speed (acceleration), engine technology	Primary survey and statistics	g/km per type of engine technology, EFs are often generated from **the vehicle emission model**

Summary Activity Data for Area Sources

Sources	Emission tier (1-2)	Activity data
Combustion source		
Domestic and commercial combustion	1: fuel type	Fuel consumption
	2: fuel type and combustion technology	Fuel consumption and type of cookstove (i.e. improved cookstove, gasifier)
Industrial combustion	1: fuel type	Fuel consumption
	2: fuel type and combustion technology	Fuel consumption and type of boiler and generator
Biomass open burning	1: biomass fuel type	Fraction of burning, crop production, residue to product ratio, burning efficiency
	2: Forest fire E modeling	Land cover, global fire hotspot
Non-combustion source		
Fuel station	1: fuel based	Fuel sold volume, Reid vapour pressure (RVP), temperature
Fuel storage	1: bulk emission method – fuel based	Volume of fuel storage in the tank
	2: emission model (i.e. TANKS)	Volume of fuel, roof type, tank type, depth of the tank, temperature of fuel, etc.
Biogenic emission	1: Gunther method	Land cover, leaf area index (LAI), temperature
	2: Emission modeling (i.e. BEIS, MEGAN)	Land cover, LAI, temperature, Photosynthetically Active Radiation (PSAR)

Examples of Emission Factors for Different Tiers

Thermal Powerplant Emission Factors (Point Sources)

Fuel type	Combustion technology	S, % w/w	Ash, %, w/w	Uncontrolled EF for SO_2			Uncontrolled EF for NOx			Uncontrolled EF $PM_{2.5}$	
				WHO, kg/ton	EMEP, g/GJ	AP-42 kg/ton	WHO , kg/ton	EMEP, g/GJ	AP-42, kg/ton	EMEP, g/GJ	AP-42, kg/ton
Fuel oil (FO)	Normal firing	2.2	0.3	19.9 S	495.0	19.2S	13.20	142.0	5.75	19.30	(1.1S+0.39)/1.4
	Tangential firing	2.2	0.3			19.2S			3.90		(1.1S+0.39)/1.5
	Distillate oil fired	2.2	0.3			17.1S			2.40		0.17
Waste oil (industrial oil, automotive oil)	Boilers	0.5	0.3		495.0	18.0 S		142.0	2.33	19.30	5.3A
	Atomizing burners	0.5	0.3			14.3S			2.13		5.3A
Anthracite coal	Pulverized coal furnace	3.0	5.0	19 S		19.5S	9.00		9.00		0.6A
	Fluidized bed combustion (FBC)	3.0	5.0		820.0	1.45		82.5	0.90	5.20	0.3A
	Stoker-fired	3.0	5.0			19.5S			4.50		0.3A

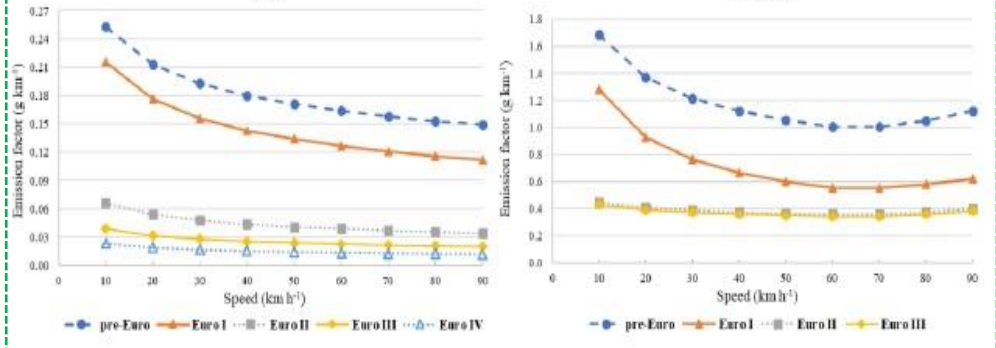
WHO: Tier 1

US EPA, EMEP: Tier 2

Onroad Emission Factors (Mobile Sources)

Source: Thailand PCD, 2019

Tier 3



Tier 1

PC EF = 0.01 g/kg-fuel

Tier 2

Source: Kim Oanh, 2020

SOURCE SECTOR : 1
1. TRANSPORTATION
1.1. Road
1.1.2. Running emisison
Back

Vehicles Category	Sub-category	N: $PM_{2.5}$ emission factor (g/km) (Suggested values) Low	Central	High	(Put your values) Low	Central	High
PC	Gasoline Pre Euro		0.033			0.033	
	Gasoline Euro 1		0.014			0.014	
	Gasoline Euro 2		0.005			0.005	
	Gasoline Euro 3		0.002			0.002	
	Gasoline Euro 4		0.002			0.002	
	Gasoline Euro 5		0.002			0.002	
	Gasoline Euro 6		0.002			0.002	
	CNG		0.001			0.001	
	LPG Pre-Euro		0.007			0.007	
	LPG Euro 1		-			-	
	LPG Euro 2		-			-	
	LPG Euro 3		-			-	
	LPG Euro 4		-			-	
	Diesel Pre-Euro		0.706			0.706	
	Diesel Euro 1		0.313			0.313	
	Diesel Euro 2		0.165			0.165	
	Diesel Euro 3		0.077			0.077	
	Diesel Euro 4		0.052			0.052	
	Diesel Euro 5		0.005			0.005	
	Diesel Euro 6		0.005			0.005	
	Gasohol Pre-Euro		0.011			0.011	
	Gasohol Euro 1		0.005			0.005	
	Gasohol Euro 2		0.005			0.005	
	Gasohol Euro 3		0.005			0.005	
	Gasohol Euro 4		0.005			0.005	
	Gasohol Euro 5		0.005			0.005	
	Gasohol Euro 6		0.005			0.005	

Residential Emission Factors (Area Source)

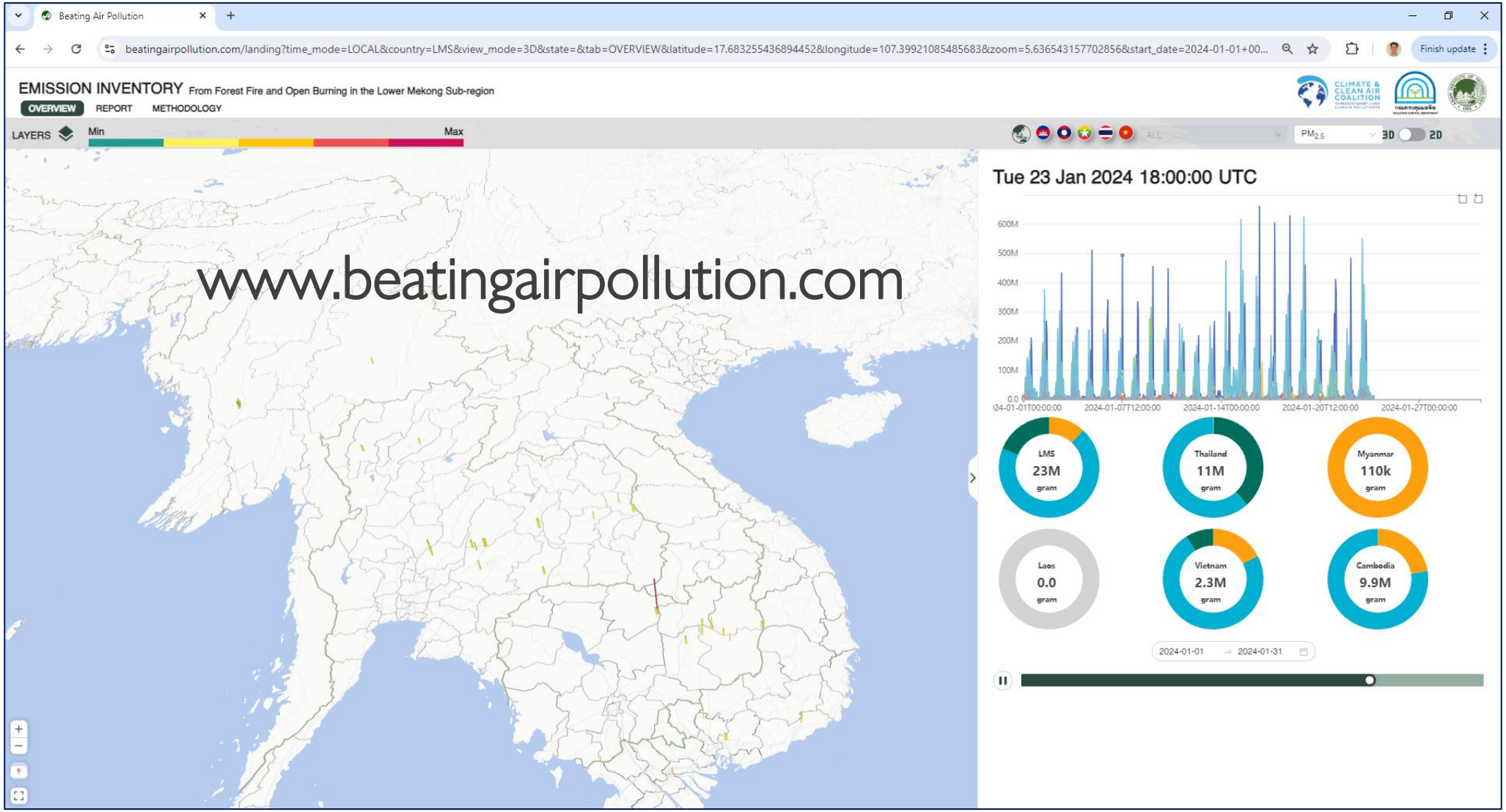
Fuel	Efficiency (%)	Emission Factor (g/kg)[2]							
		CO	CO2	NOx	PM	BC	OC	CH4	NMHC
Cooking/ Water Heating[1]									
Natural Gas[3]	75[4]	0	3440	0.6	0.2	0.0[5]	0.0[5]	0.0	0.2
Derived Coal[3]	35[6]	59	2710	0.4	4.5[7]	0.1[8]	2.4[8]	0.0	0.0
Anthracite Coal	35[6]	162	2248	0.9	1.1[9]	0.0[10]	0.1[10]	5.2	2.1
All Other Coal	35[6]	162	2248	0.9	12.0[11]	4.1	5.9	5.2	2.1
LPG[3]	65[6]	19	3060	0.1	0.0	0.0[5]	0.0[5]	0.3	6.2
Charcoal[13]	25[14]	168[15]	2384	0.3	1.5[16]	0.2	0.5	9.2	6.8
Fuelwood[17]	30[18]	47	1583	0.5	3.8	1.2	2.1	7.7	10.6
Fuelwood - Fan[19]	40[20]	15	829	0.5	0.5	0.1	0.3	7.7	1.6
Agri Waste[23]	20[24]	52[24]	1352	0.7	3.6[24]	0.4	1.4	3.8	12.6
Dung	25[25]	36[25]	1020	0.7	5.1[25]	1.2	3.8	11.7	21.0
Heating[1]									
Fuelwood[21]	70[22]	48	1583	0.6	2.3	0.4	0.6	7.6	10.6
Lighting[1]									
Kerosene[12]	-	3	3085	0.6	13.0	9.0	0.5	0.4	8.8

Tier 2

Tier 1

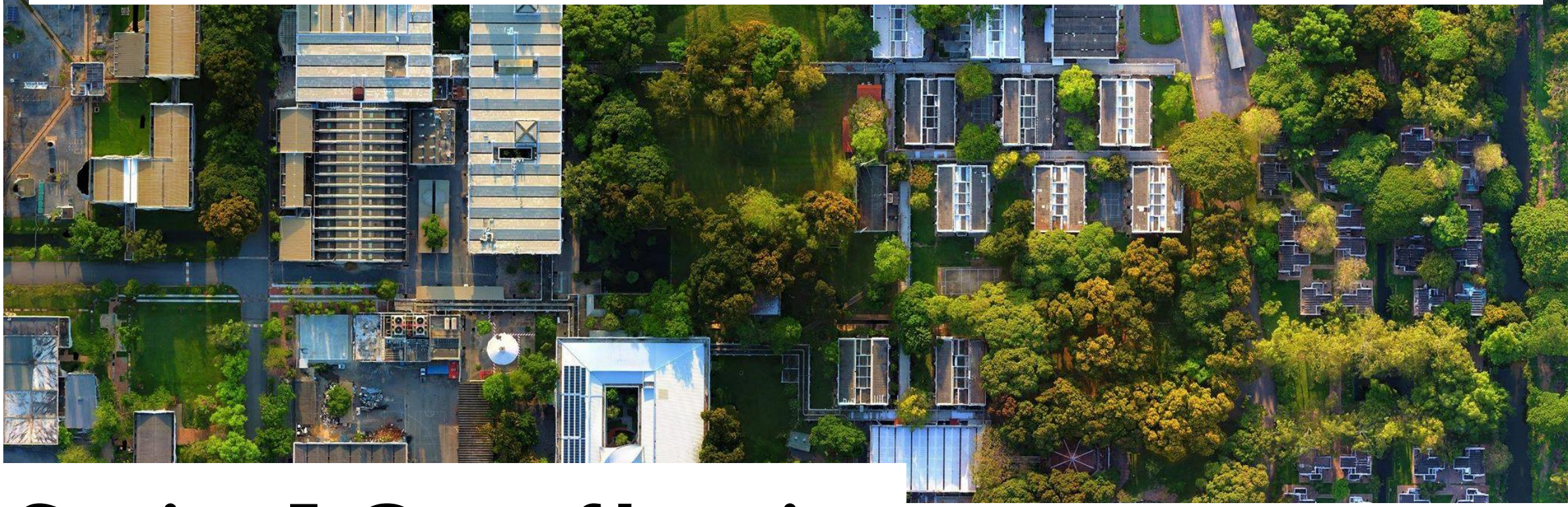
Source: Winijkul et al., 2016

Demonstration of Emission Inventory for LMS



National Air Quality Awareness Raising Workshop And Stakeholder Mapping For Clean Air Plan Development

27-28 August 2024
Luang Prabang, Lao PDR



Session 5: Cost of Inaction on Air Pollution

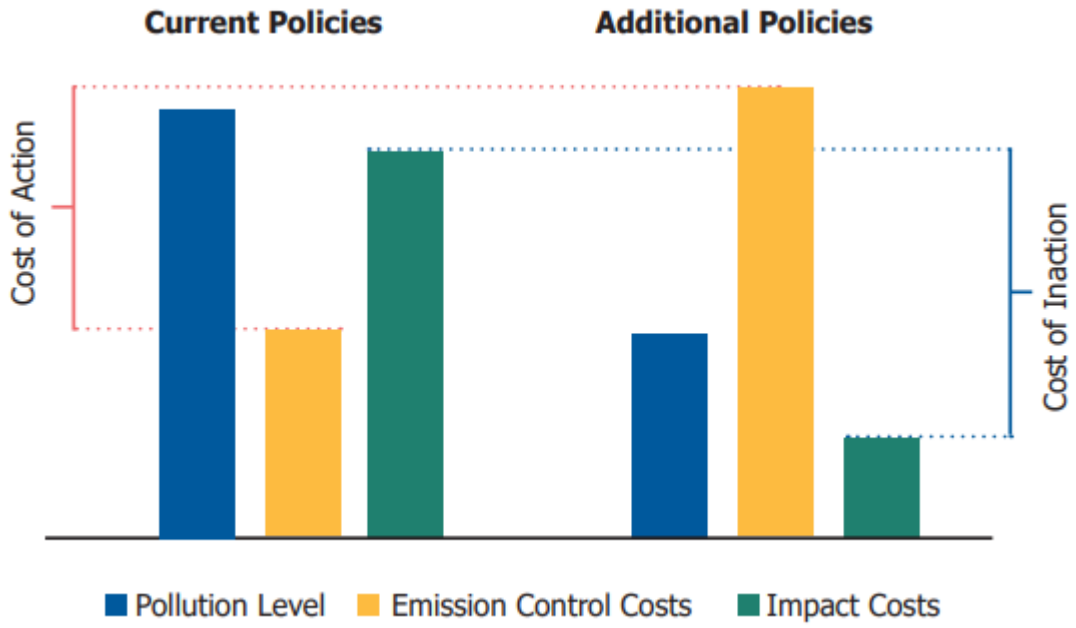
Ekbordin Winijkul, PhD
Environmental Engineering and Management
Asian Institute of Technology
ekbordinw@ait.asia

Definition of the Cost of Inaction

- The 'cost of inaction' is defined as the total damage cost
  - remain without policy intervention
  - Or, conversely, can be avoided by taking action

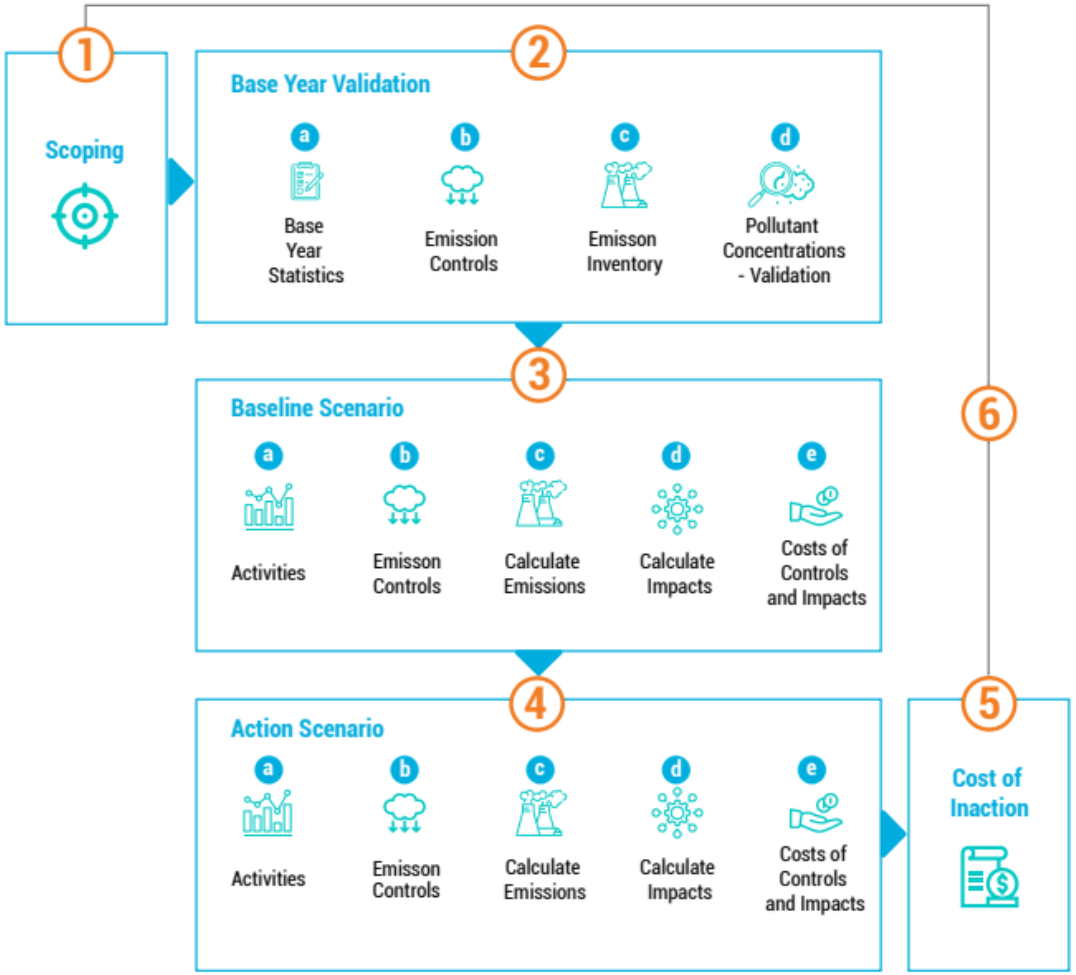
- The cost is related to the key impacts that are associated with air pollution and their total damage costs.
  - health costs, lost labour days, mortality costs, declining crop yields, ecosystem impacts, material damage, impact on tourism, noise, visibility, traffic accidents and congestion.

- A simplified, conceptual representation of the approach is shown on the right.



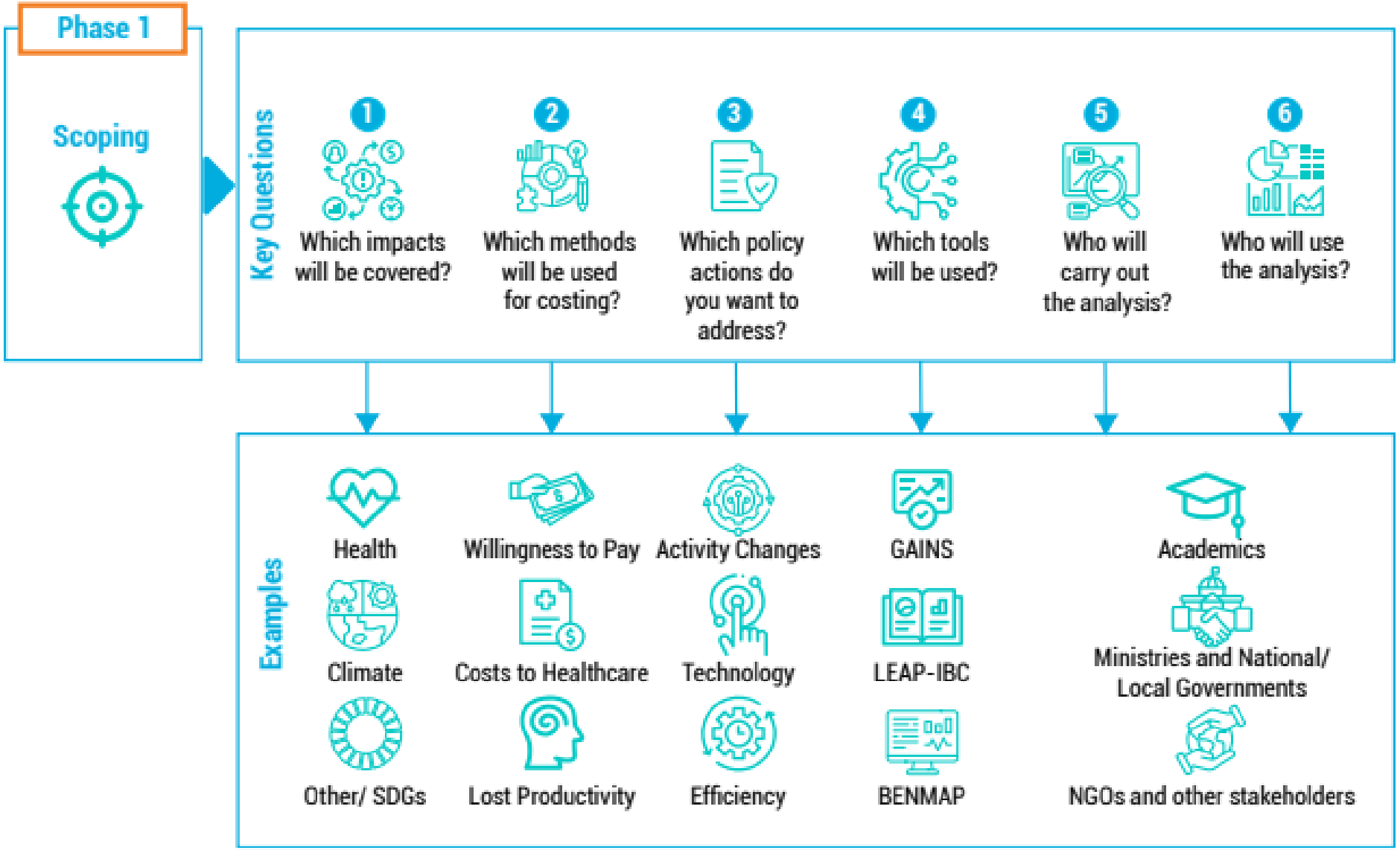
The key principle is the comparison of two different scenarios for a given target year: a Current Policies scenario, representing the implications of current legislation (assuming no further policy action), is compared to an alternative Additional Policies scenario in which a bundle of new measures to curb pollution, reduce GHG emissions, and address SDGs are implemented.

Assessment the Costs of Inaction

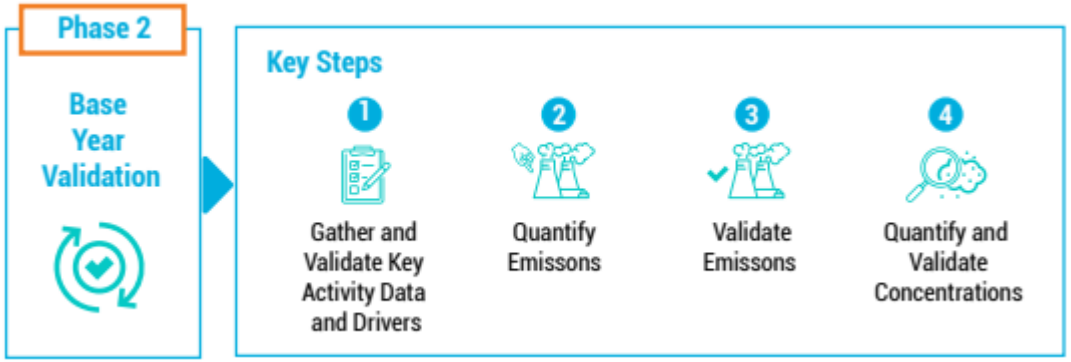


1. Scoping of the assessment: co-designing the assessment with stakeholders
2. Base year validation
3. Baseline scenario development and assessment
4. Alternative policy scenario development and assessment
5. Establishment of differences in costs and impacts

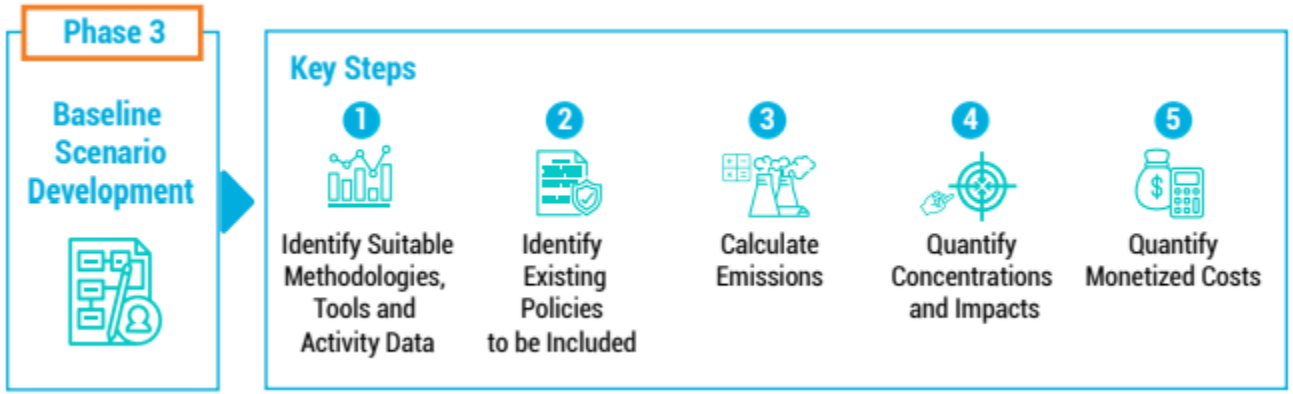
Phase 1: Determine the Scope of the Analysis



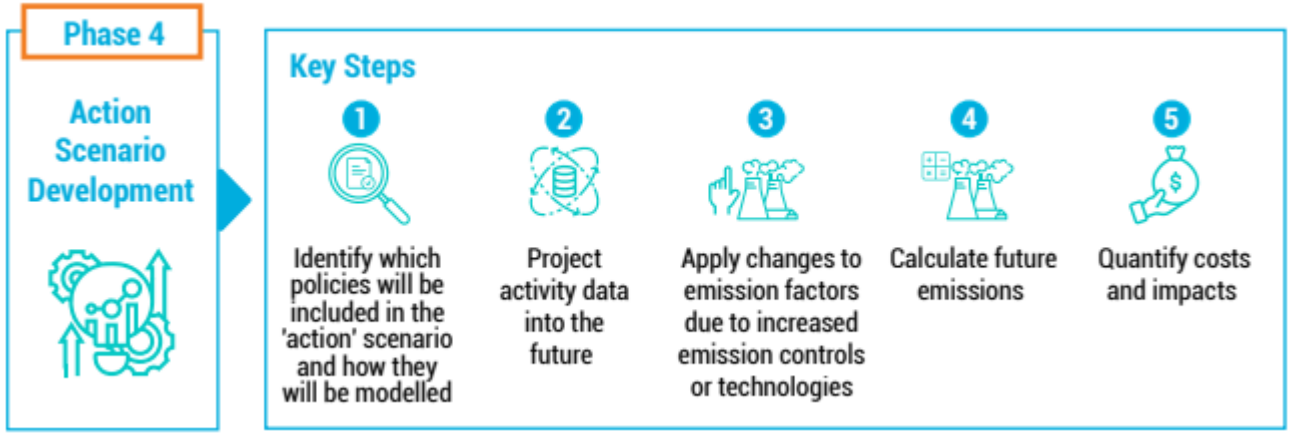
Phase 2: Quantify and Validate Emissions in the Base Year



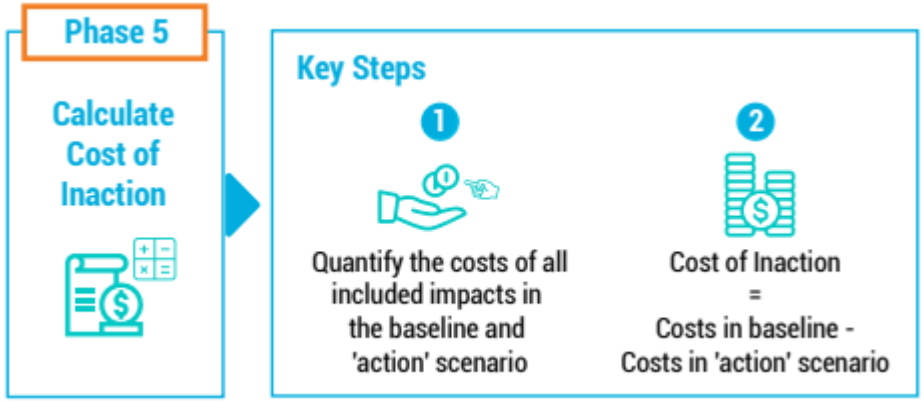
Phase 3: Development of a Baseline Scenario



Phase 4: Development of an Alternative Action Scenario



Phase 5: Cost of Inaction as Difference



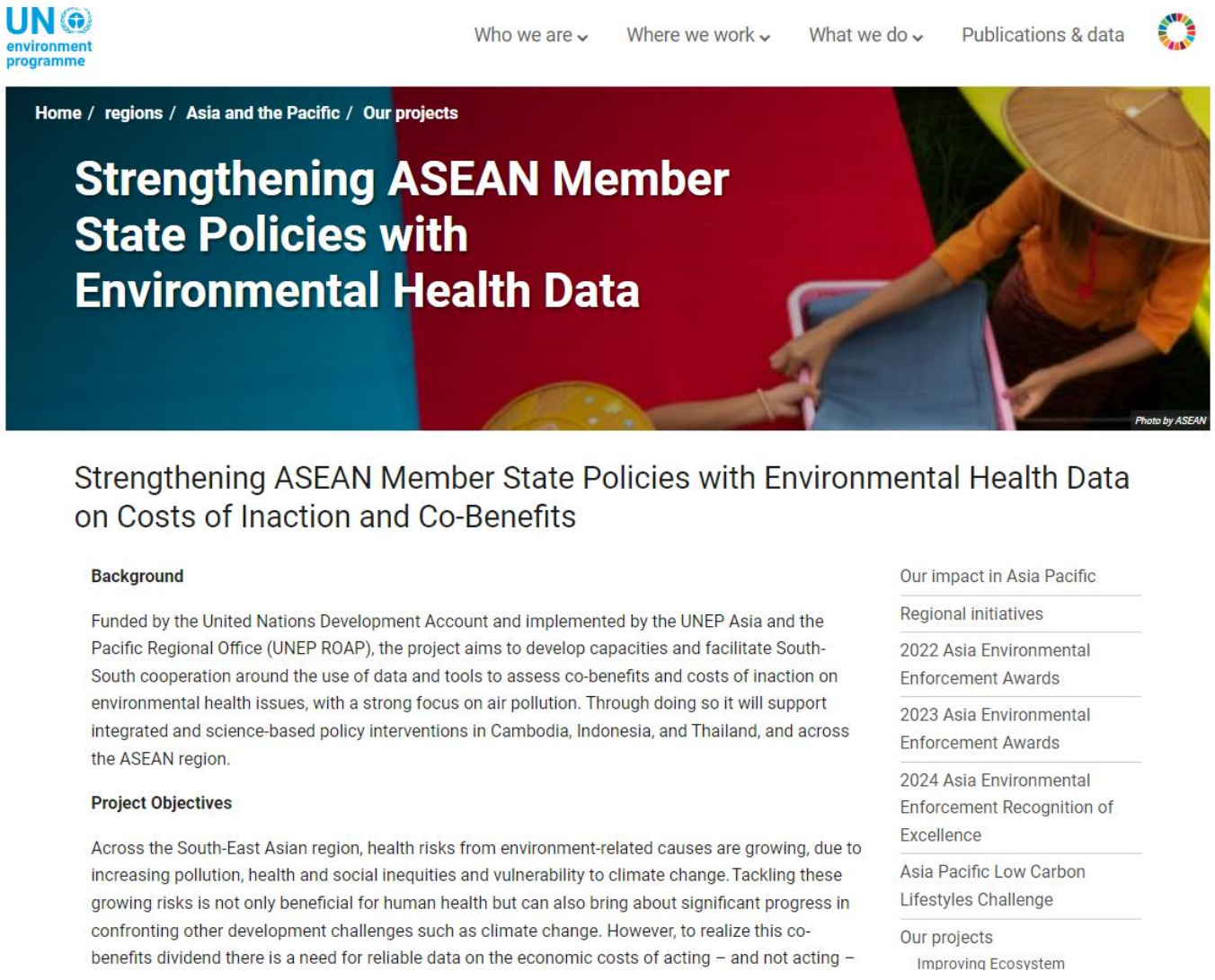
Phase 6: Iterate and Refine

Good Practices & Challenges

- Communication
- Co-design and consultation
- Institutional Development
- Capacity Building
- Equity and Inclusivity

- Quality of data/Lack of local data
- Limited disaggregation of data
- Limited coverage of effect
- Limited assessment capacity
- Lack of alignment between assessment and national-scale decision making processes

More Information – Cost of Inaction of Tackling Air Pollution





https://www.unep.org/regions/asia-and-pacific/our-projects/strengthening-asean-member-state-policies-environmental