The EANET Emission Inventory Webinar Workshop on Combustion Sources, 11 December 2023

Emission Inventory for Transportation Sector

DR. DIDIN AGUSTIAN PERMADI
National Institute of Technology, Bandung, Indonesia
didin@itenas.ac.id
https://www.researchgate.net/profile/Didin-Agustian

Outline of presentation

01 Sources coverage under transportation sector

02 Emission calculation methodology

03 Type of activity data and emission factors

04 Case studies and summary

itenas
Institut Teknologi Nasional

EANET

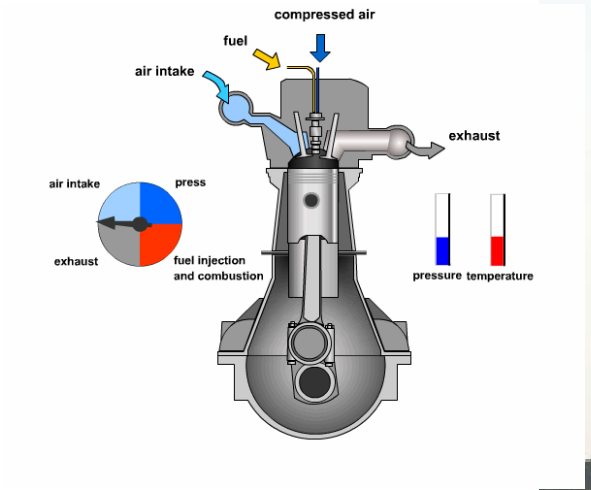
What sources covered under transport sector?

1. **On-road mobile source**
2. **Civil aviation**
3. **Shipping**
4. Railway
5. Other machineries

itenas
Institut Teknologi Nasional

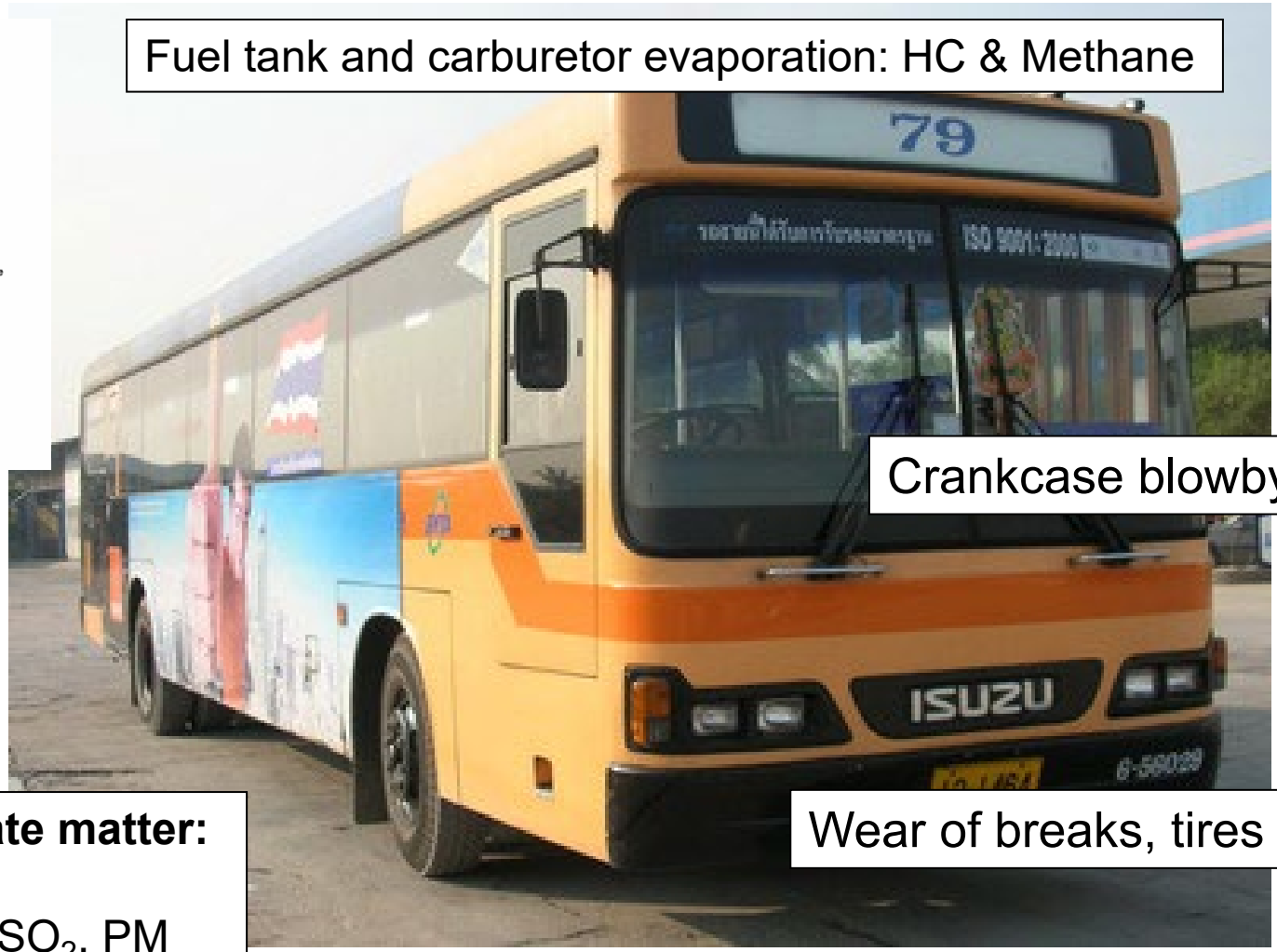
EANET

(i) On-road mobile source



1. Intake/induction stroke
2. Compression stroke
3. Power stroke
4. Exhaust stroke

Fuel tank and carburetor evaporation: HC & Methane



Crankcase blowby: HC

Wear of breaks, tires (PM) etc

Exhaust gas and particulate matter:
- GHGs: CO_2, CH_4, N_2O
- Air pollutants: CO, NOx, SO_2, PM
- Air toxics: benzene, toluene, xylene

itenas
Institut Teknologi Nasional

EANET

Traffic Emission in Asia: Consideration

- **01** Second-hand and long-life vehicles, low I&M, no emission control: high emissions
- **02** Wide range of vehicle technologies: from pre-Euro to Euro4/Euro 5
- **03** Severe congestions: slow movement ➔ high emissions
- **04** Fast increases of vehicle fleets: need to update EI more frequently than other sources
- **07** Both on-road and non-road emissions are important
- **06** Current situation: improvement in vehicle technologies and fuel quality, alternative fuels available

itenas
Institut Teknologi Nasional

EANET

Why do we need emission estimation?

What quantities of air pollutants are emitted in a specific area for on-road mobile transport?

Which type of vehicles are the largest emitters of the pollutants?

What types of emissions from which vehicles are currently controlled and how well are they controlled?

itenas
Institut Teknologi Nasional

EANET

Emission calculation methodology

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 can be generated from the vehicle emission model

How to measure emission factors?

Laboratory chassis dynamometer testing:

- Simulates load and inertia of vehicle running on road ➔ representative driving cycle for the location
- Sampling exhaust gas by a constant volume sampler (CVS) with flow measurement ➔ emission factors

On road monitoring system: PEMS and sniffer

Remote sensing: measure absorption of UV/IR by emission from passing-by vehicle

Reverse modeling:

- Tunnel methods (tunnel is an airshed ➔ estimate on road emission of vehicle-mix
- Reverse line source modeling using roadside monitoring data

Emission modeling: US EPA, Europe models

Tier 1: emission calculation using bulk EF

$$Em_{i,j,k} = \sum_{j} Fc_{j,k} \times EF_{i,j,k}$$

where,

j = Type of vehicle

$Em_{i,j}$ = Emission of pollutant i from vehicle type j and fuel k

Fc_j = Fuel consumption of vehicle type j fuel k

$EF_{i,j}$ = EF of pollutant i for vehicle type j and fuel k

- This method uses fuel consumption (taken from sales statistic or calculated from total VKT using fuel economy)
- This equation requires the fuel consumption/sales statistics to be split by vehicle category

Example of bulk emission factors (EMEP-EEA, 2013)

Fuel type	Category	CO	NOx	NMVOC	CH_4	PM
Gasoline	Gasoline PC	550	27	63	1.7	0.88
	Gasoline LDV	360	29	59	1.24	0.88
	Motorcycle	730	2.7	530	5.2	28
Diesel	Diesel LDV	18	16	4.6	0.08	2.2
	Diesel HDV	36	42	8	0.25	8.4
	Diesel PC	12	11	3	0.13	2.2
LPG	General	67.5	17.7	29.5	2.9	-
CNG	General	36.1	19	4.5	4.7	-

Bulk EF does not consider vehicle technologies (Pre-Euro, Euro1,2 etc.)

Higher Tiers: traffic emission calculation

Running emissions: NV * EF * VKT

NV - number of vehicles,

Running EF, g/km

VTK – vehicle km traveled per vehicle, km/veh/yr

Start-up emissions = NV x EF_{st} x N-start

NV - number of vehicles

Start-up EF_{st}: g/start

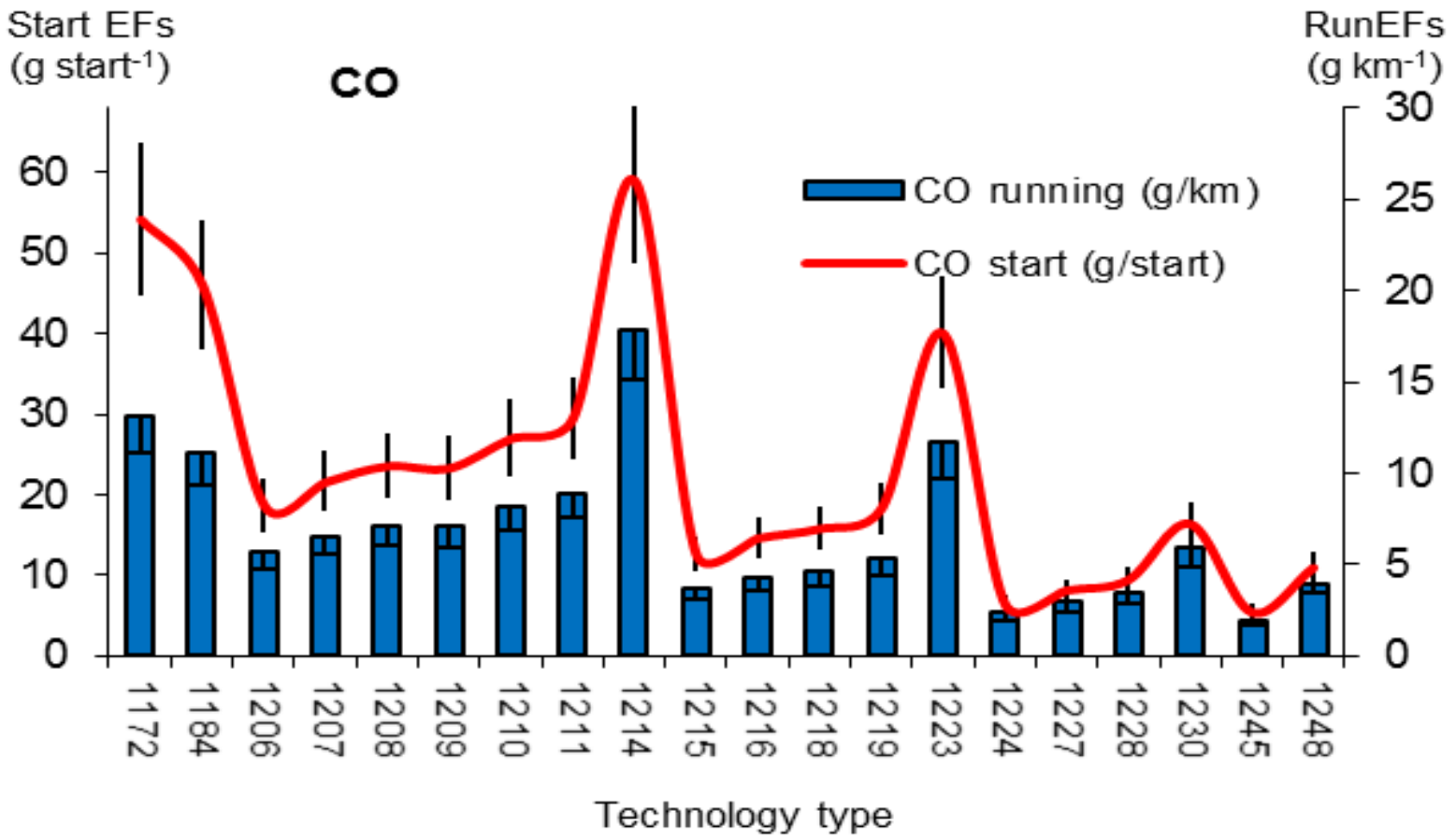
N-start: number of starts per vehicle, km/veh/yr

Total emissions = Running + Start-up

itenas
Institut Teknologi Nasional

EANET

Start and running emission factors



Source: Kim Oanh et al., 2012

On-road transport emission models

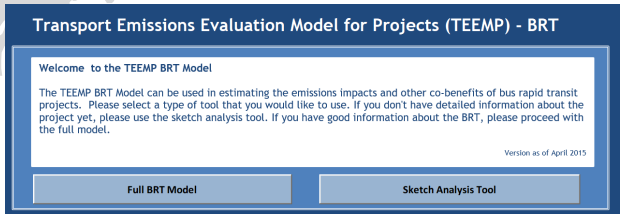
MOtor Vehicle Emission Simulator (MOVES)

GAINS Online
Greenhouse Gas - Air Pollution Interactions and Synergies

- Moves
- IVE

- Copert
- Mobilev
- GAINS

TEEMP



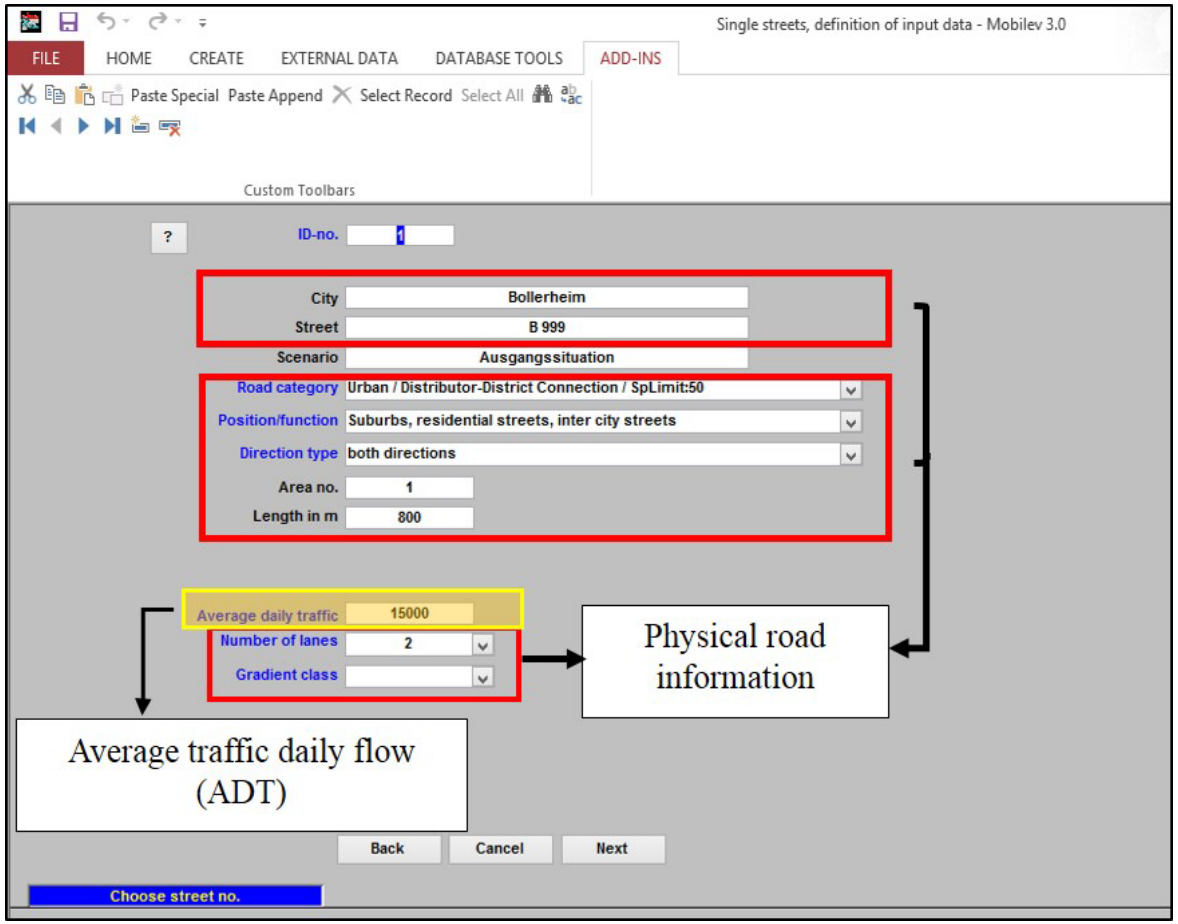
copert

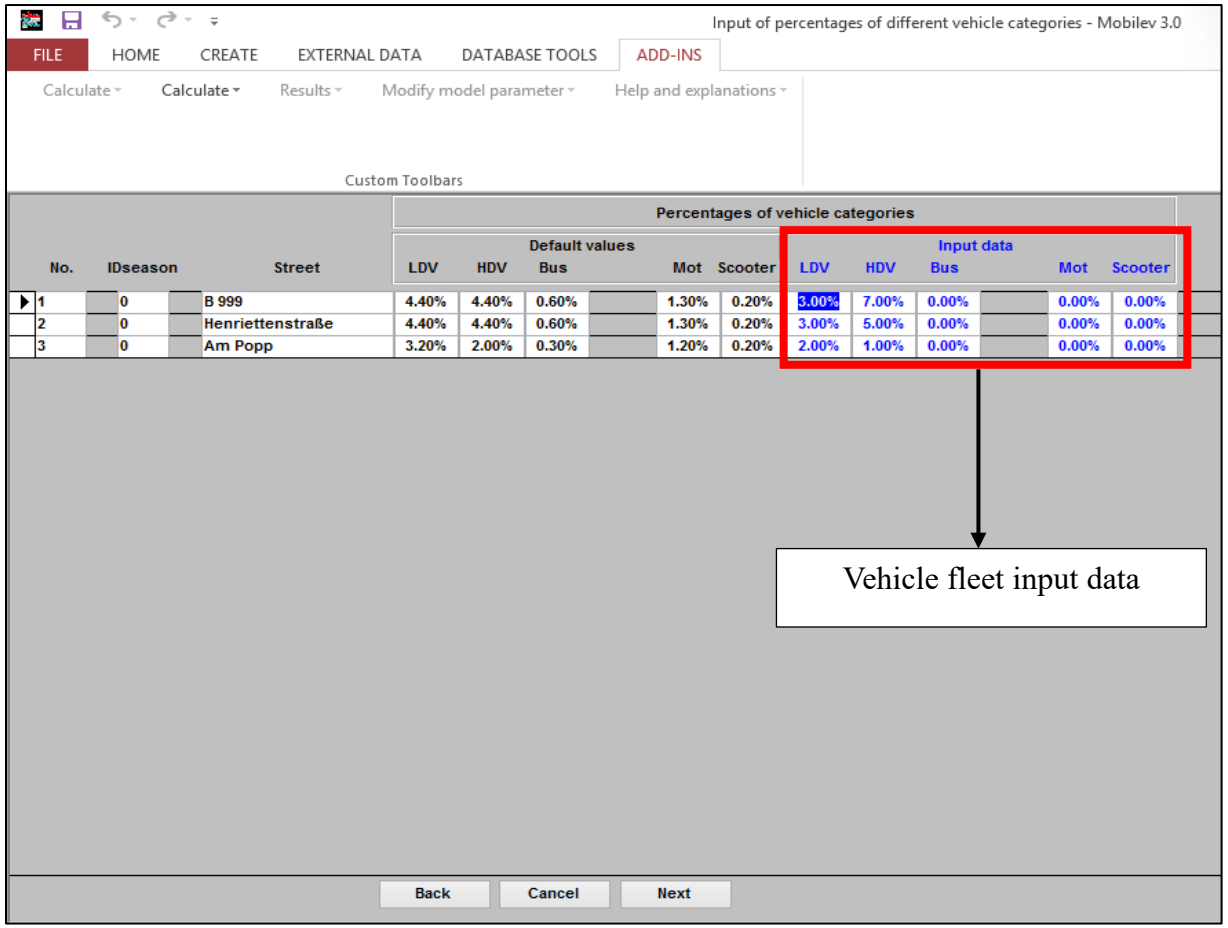
International Vehicle Emissions Model

itenas
Institut Teknologi Nasional

EANET

Mobilev



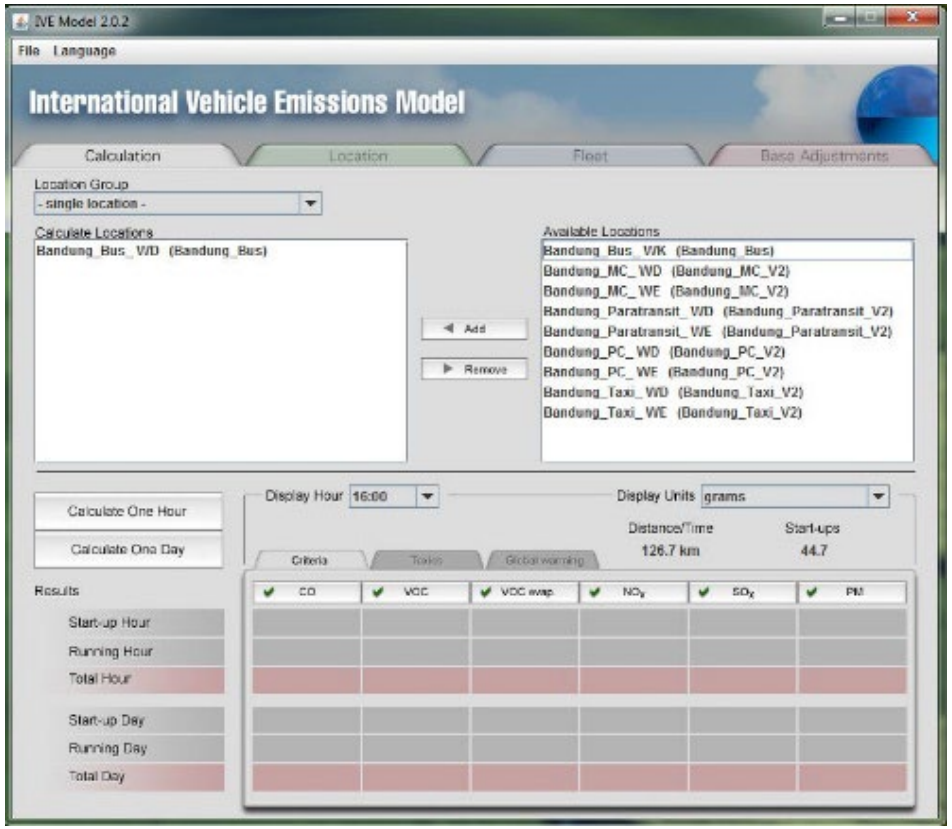


itenas
Institut Teknologi Nasional

EANET

International Vehicle Emission Model (IVE)

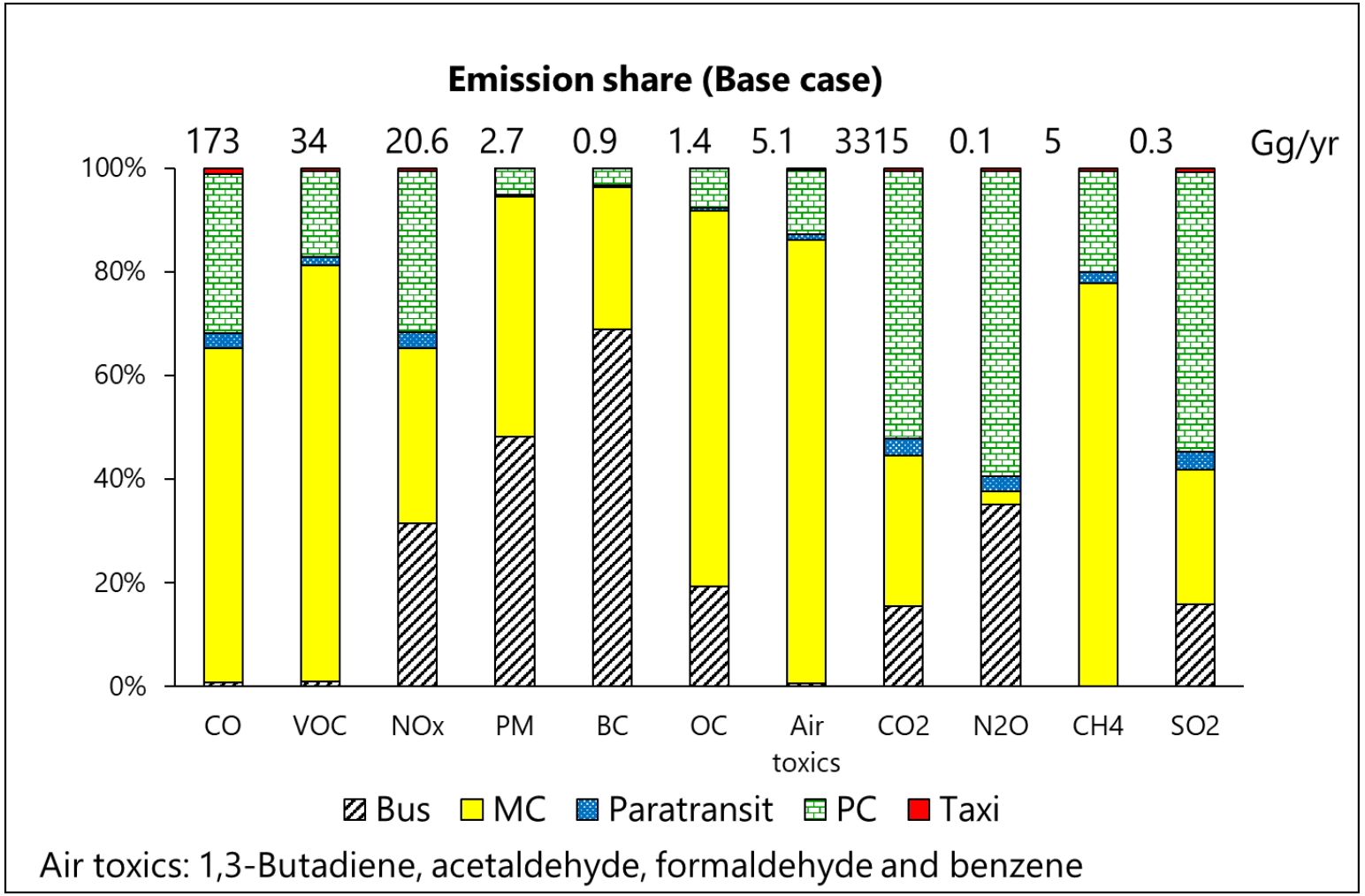
- IVE: by University of California at Riverside, Center for Environmental Research and Technology (CE-CERT) of GSSR and the International Sustainable System Research Center (ISSRC) ➔ Website: http://www.issrc.org/ive/
- Suitable for developing countries: many technology indexes, from pre-Euro to Euro5
- Main features of IVE modeling:
  - Use Vehicle Specific Power (VSP) for exhaust emission determination
  - Incorporate VSP bin distribution and start patterns
  - Incorporate environmental variables (altitude, road grade, and temperature, moisture content etc.) and fuel characteristics
- Challenge: intensive survey to collect local data and technology index matching for input files



itenas
Institut Teknologi Nasional

EANET

Example of IVE model implemented for developing city (Bandung, Indonesia)

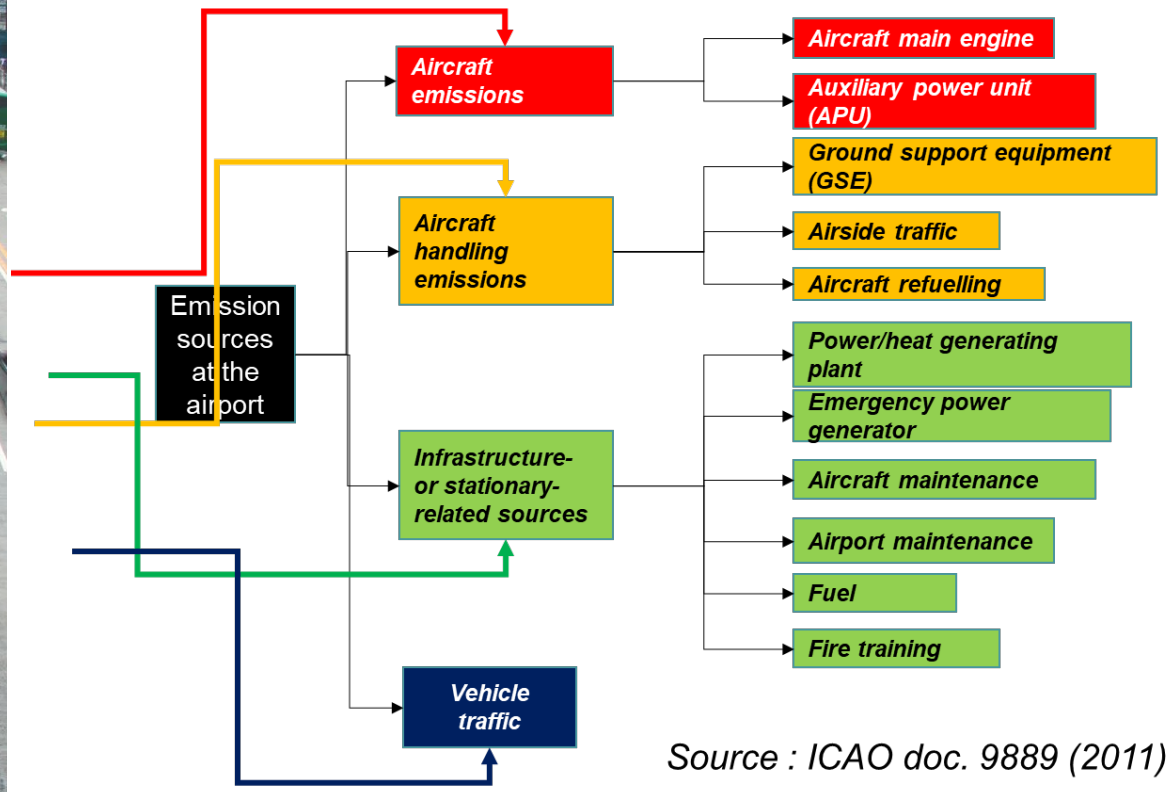


Source: Kimoanh et al. (2018)

(ii) Civil aviation

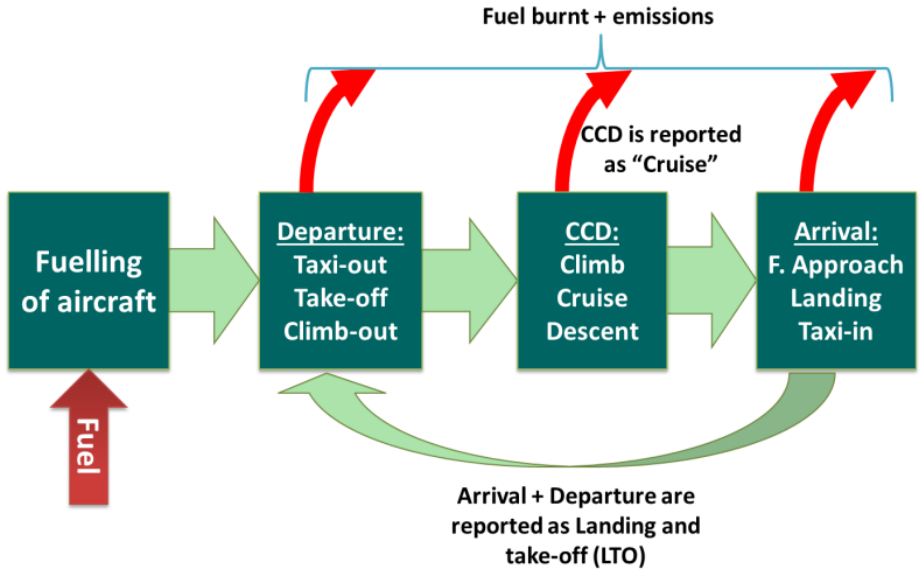
Scope of activity

Airport emissions



Source : ICAO doc. 9889 (2011)

Cruising emissions



Source: EMEP/EEA (2023)

Inventory methodology

Tier	Activity	Data and tools used
Tier 1	Fuel sales sub-divided into domestic and international usage Total LTO numbers for domestic and international	Use average fleet mix (i.e. generic aircraft EFs) and average factors for LTO and CCD
Tier 2	Fuel sales sub-divided into domestic and international use, as for Tier 1 LTO numbers for domestic and international, per aircraft type	Use of aircraft-specific LTO EFs and average EFs for CCD
Tier 3	Data for each flight containing aircraft type and flight distance, sub-divided into domestic and international	Tier 3A: Use specific aircraft type/engine data from the spreadsheet accompanying this chapter, available from the 2023 *EMEP/EEA air pollutant emission inventory guidebook* (EEA, 2016) website Tier 3B: Use EUROCONTROL Advanced Emission Model (AEM) US/Federal Aviation Administration (FAA) Aviation Environmental Design Tool (AEDT) or similar tools with specific airport taxi times

Source: EMEP/EEA (2023)

Based on ICAO doc 9889 (simple method)

Aircraft LTO

$$E_x = \Sigma_{\text{type of aircraft}} (LTO_y \times FE_x)$$

Noten :

E_x = Emission of pollutant x (kg)

LTO_y = Number of landing & take-off

FE_x = Emission factor of pollutant x (kg/LTO)

Fleet Categories	In (kg/LTO)[a]						
	SO_2	CO_2	CO	NOx	CH_4	N_2O	$PM_{2.5}$[d]
Domestic							
LTO (kg/LTO)-Average fleet (B737-400)	0.8	2600	11.48	8.3	0.1	0.1	0.2
LTO (kg/LTO)-Old fleet (B737-100)	0.9	2900	4.8	8	0.1	0.1	0.2
Cruise (kg/tonne)- Average fleet (B737-400)	1.0	3150	2.0	10.3	0	0.1	0.2
Cruise (kg/tonne)- Old fleet (B737-100)	1.0	3150	2.0	9.4	0	0.1	0.2
International							
LTO (kg/LTO) Average fleet(B767)	1.6	5094	6.1	26	0	0.2	0.15
LTO (kg/LTO) Average fleet (short distance, B737-400)	0.8	2600	11.8	8.3	0.1	0.1	0.07
LTO (kg/LTO) Average fleet (long distance, B747-400)	3.4	10717	19.5	56.6	0.2	0.3	0.07
LTO (kg/LTO) Old fleet (DC-10)	2.4	7500	61.6	41.7	2.3	0.2	0.32
LTO (kg/LTO) Old fleet (short distance, B737-100)	0.9	2900	4.8	8	0.1	0.1	0.1
LTO (kg/LTO) Old fleet (long distance, B747-100)	3.4	10754	78.2	55.9	3.7	0.3	0.47

Ground support unit (GSE)

$$E = \Sigma_{\text{type of fuels}} (FT \times FE)$$

Note :

E = Total emission of GSE (g)

FE = Emission factor (g/kg of fuel)

FT = Fuel consumption (kg/day)

Pollutants	Emission factor (g/kg fuel)	
	Diesel oil	Gasoline
NO_x	48,2	9,6
CO	15,8	1193
PM	5,7	-
VOC	10,5	45,5
CO_2	3150	3140

Source: ICAO doc. 9889 (2011)

itenas
Institut Teknologi Nasional

EANET

Tool for inventory: AEDT 3c

External to AEDT

AEDT Standard Input File (ASIF)

Graphical User Interface

Study Database

Airports Database

Fleet Database

Aircraft Performance
Fuel Consumption

CDNL	EPNL	LCMAX	TAPNL
CEXP	LAEQ	NEF	TAUD
CNEL	LAEQD	PNLTM	TAUDSC
DNL	LAEQN	SEL	TAUDP
	LAMAX	TALA	TAUDPSC
		TALC	WECPNL

Fly Aircraft

Calculate Noise

Weather Calculations
Terrain Calculations

Calculate Emissions Dispersion

Calculate Emissions

CO	NOx	SO_2
CO_2	nvPM	SOx
H2O	PM 2.5	THC
NMHC	PM 10	TOG
NO_2	PMFO	VOC
	PMSO	

Total Results

Output

Emissions Dispersion

Fuel & Emissions Inventory

Noise Results

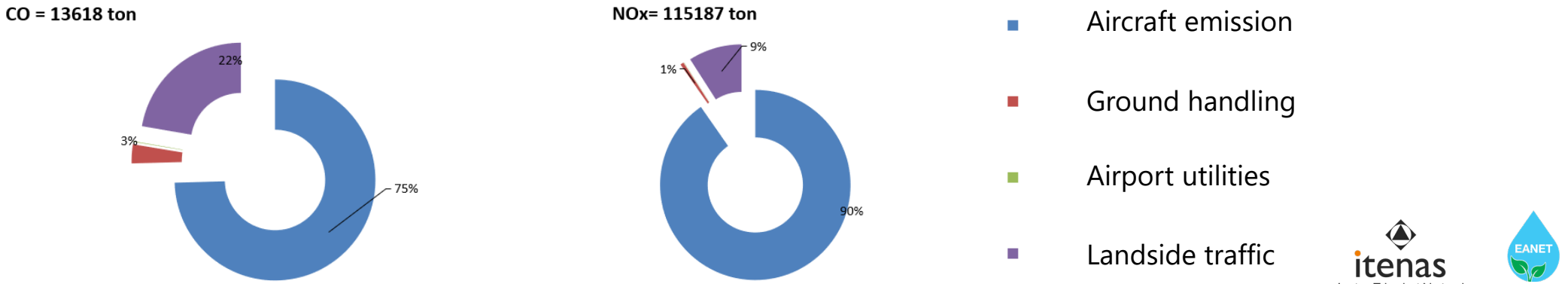
Contours

itenas
Institut Teknologi Nasional

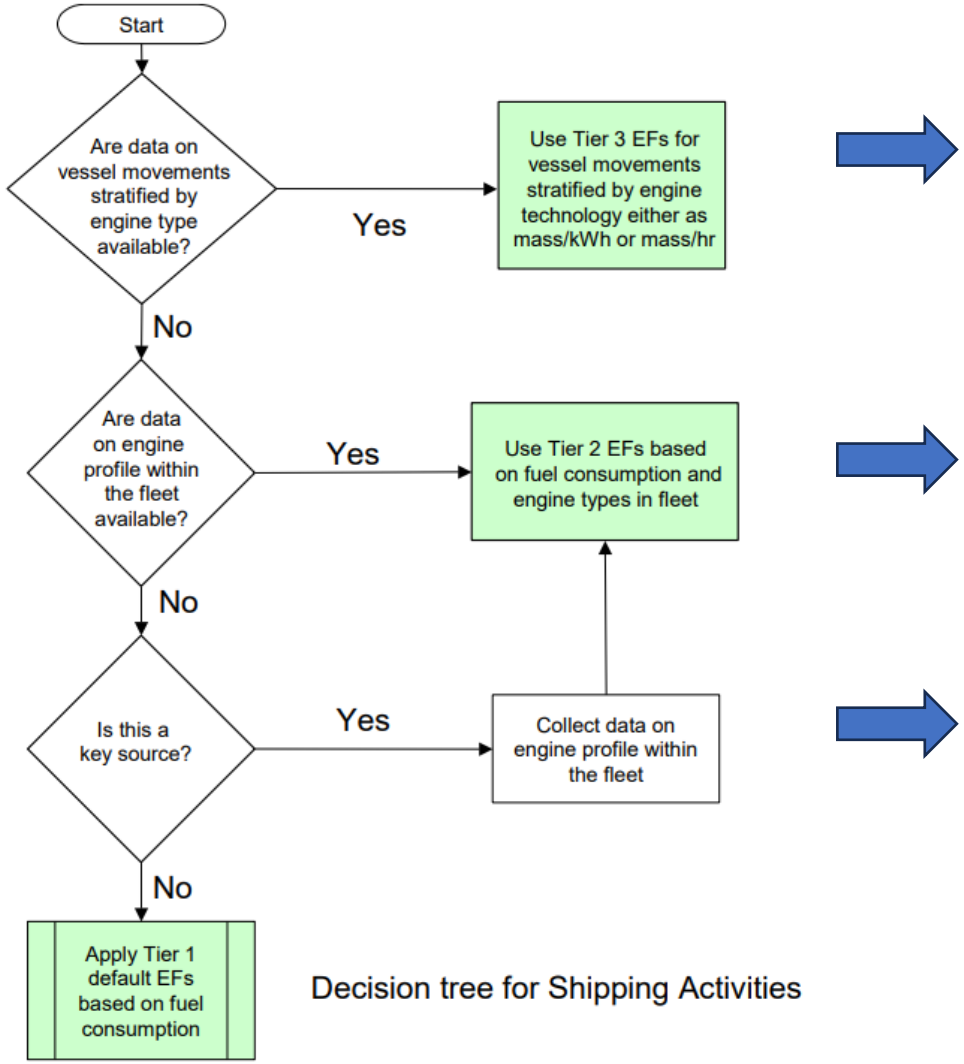
EANET

Case study: airports in Indonesia

Activity data	Remarks	Value
Average fuel consumption for GSE (kg/year/LTO)		0,77 -14,42 (3,87)
Fuel recharge (kg/year/LTO)	From hydrant to aircraft	936
	From fuel tank to aircraft	1403
Average fuel consumption for generator (l/year/LTO)		0,125 - 0,702
Average amount of waste incinerated at airports (kg/year/LTO)		26 - 81
Amount of fuel used for fire fighting simulation (l/year/LTO)		0,239 - 0,451
Fuel storage capacity at airports (l/year/LTO)	Working Loss	2785
	Standing Loss	39 -161 (81)
Electricity consumption (KwH /year/LTO)	From outside	535
	Sold to tenants	88



(iii) Shipping emission



Decision tree for Shipping Activities

Source: EMEP/EEA (2023)

Ship movement methodology

$$E_{Trip} = E_{Hotelling} + E_{Manouverin\ g} + E_{Cruising}$$

Engine and fuel specific

$$Ei = \sum_{m}\left(\sum_{j} FC_{m,j} \times EF_{i,m,j}\right)$$

Default (fuel specific)

$$E_i = \sum_{m}\left(FC_m \times EF_{i,m}\right)$$

Default emission factors (1st tier)

Pollutants	EFs (kg/tonne fuel)[a]
CO_2[c]	3170
SO_2[c]	20xS
NO_x[d]	57
CO[d]	7.4
CH_4[d]	0.05
N_2O[d]	0.08
NMVOC[d]	2.4
$PM_{2.5}$	1.38[e,1], 1.58[e,2], 0.102[e,3], 1.1 (diesel), 6.7 (heavy fuel oil)
BC	1.02[b]
OC	0.49[b]

[a] EMEP/CORINAIR, 2006.
[b] Bond et al., 2004. Values are applicable for diesel and heavy oil.
[c] Fuel composition-dependent emission.
[d] Engine-dependent emission.
[e] APEG, 1999; Berdowski et al., 1997. [e,1] APEG: Fuel oil, $PM_{2.5}$ 23% of PM10; [e,2] Diesel, $PM_{2.5}$ 85%; [e,3] Gasoline, $PM_{2.5}$ 85%.

Case study: major harbours in Indonesia (i)

$$Em_{\square} = EF_{\square} \; x \; Power \; of \; vessels \; x \; N \; x \; Headway$$

Where,

Em = Emission load (g day^{-1})

EF = Emission factor (g/kWH) for propulsion and auxiliary engines

Power of vessels = Average power of vessels (Kilo Watt)

N = Number of ship call

Headway = Operational time in harbour (hour) in a day.

Fuel type	Emission factors (g/kWH)						
	SO_2	NO_x	CO	PM_{10}	$PM_{2.5}$	BC	OC
Shipping/harbour (g/kWH)							
Propulsion engine	10.29	18.1	1.4	1.42	1.31	0.37	0.52
Auxilliary engine	11.8	14.7	1.1	1.44	1.32	0.37	0.53

itenas Institut Teknologi Nasional

EANET

Case study: major harbours in Indonesia (ii)

Harbour	Type of vessels	Number of vessels per year	Headway time (minute / day)	Average power (kW)
Tanjung priok, Jakarta[a]	Tanker	1	66	2387
	Bulk carrier	10	90	4955
	Container ship	222	27	5038
	Passenger ferry	103	60	3573
Bakauheuni, Lampung[b]	Passenger Ferry and cargo	1,460	45-59.5	3573
Merak, Cilegon, Banten[c]	Passenger Ferry and cargo	1,460	54.2 – 67.1	3573

Note: [a] – Data from PUSTRAL – UGM (2015), [b] – Pramita et al. (2020), [c] – Pradana et al. (2019).

Harbour name	Emission (Tonnes/yr)					
	SO_2	NOx	CO	PM	BC	OC
Tanjung priok	1,268	1,866	142	312	42	59
Merak	1,446	2,129	162	356	48	68
Bakauheuni	2,527	3,684	280	620	84	119

itenas Institut Teknologi Nasional

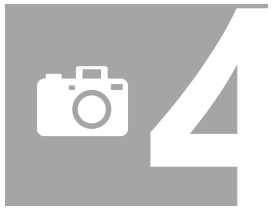
EANET

Summary

Transportation emission consists of on-road and non-road transports

Tier based emission calculations are available from the existing manual guidebooks

Availability of activity data and also resources will affect the selection of calculation methodology



Emission tools/models are good alternative to compile EI but should consider the Data availability → oftenly survey is needed

itenas
Institut Teknologi Nasional

EANET