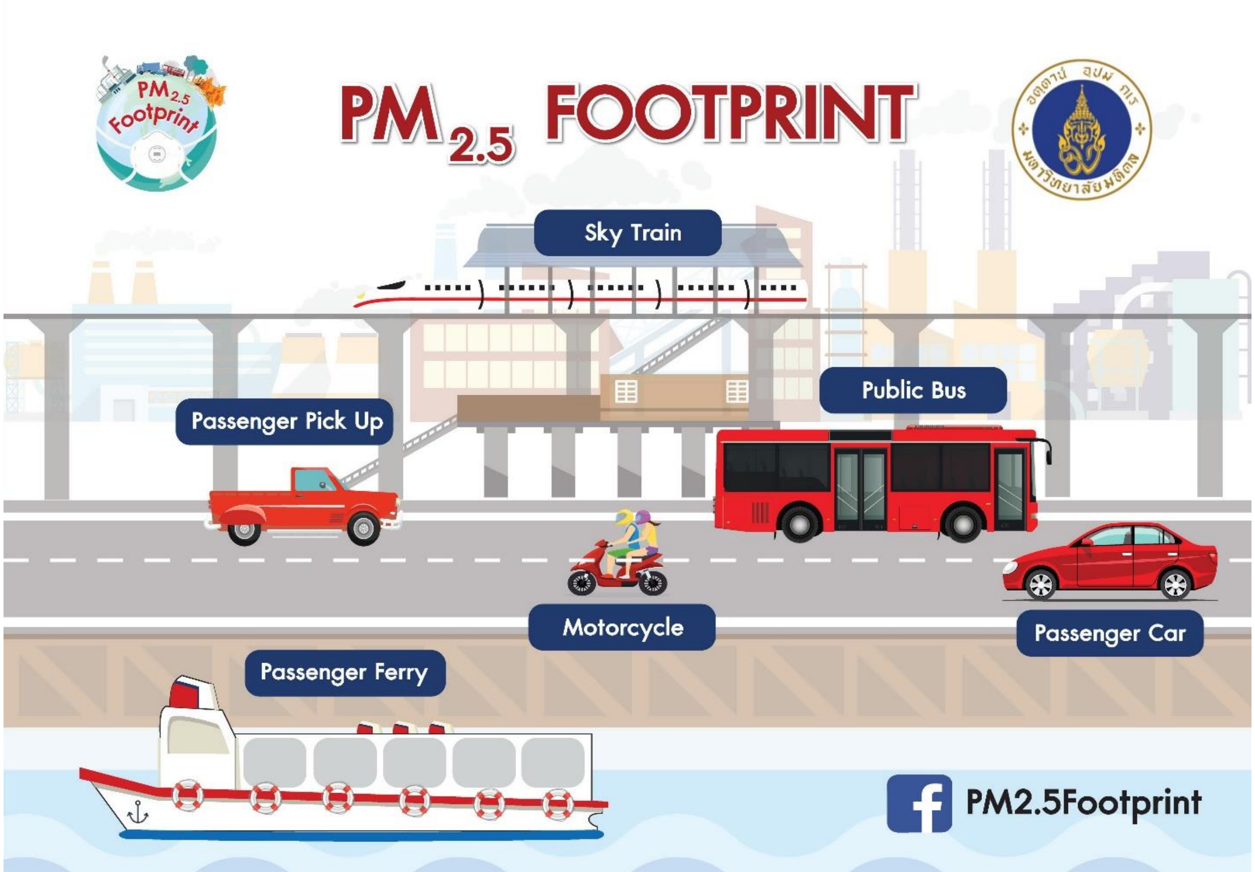

PM$_{2.5}$ Footprint Calculator v1.01

A tool for environmentally sustainable passenger transport in Thailand

Colophon

Title: $PM_{2.5}$ Footprint Calculator v1.01: A tool for environmentally sustainable passenger transport in Thailand - Background Report.

Report Version: 1.01

Date: 8 December 2021

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Funding Agency: Mahidol University (Policy Advocacy Grant 2020) under the project entitled "Awareness Raising and Policy Design for Reducing Health Impacts and Costs of Fine Particulate Matter Formation from Passenger Transport in Thailand".

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Citation:
Prapaspongsa, T., Chavanaves, S., Deuja, A., Sakpheng, P., Balasuriya, B.T.G. & Gheewala, S.H. (2021) $PM_{2.5}$ Footprint Calculator v1.01: A tool for environmentally sustainable passenger transport in Thailand - Background Report.

Website:
https://www.eg.mahidol.ac.th/dept/egce/pmfootprint/

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1. Calculator Framework

1.1 Overview

Fine particulate matter ($PM_{2.5}$ or fine particulate matter with a diameter up to 2.5 microns) is one of the most important causes of premature deaths. The World Health Organization (WHO) estimated that outdoor air pollution caused 4.2 million premature deaths globally in 2016 due to $PM_{2.5}$ exposure. The $PM_{2.5}$ exposure could lead to cardiovascular and respiratory disease, and cancers (WHO, 2021). In Thailand, overall $PM_{2.5}$ concentrations have been reduced continuously. Nonetheless, the annual average $PM_{2.5}$ concentrations in Thailand have still exceeded the World Health Organization standards throughout the past 10 years. Transport sector is one of the major sources of $PM_{2.5}$ emissions. Understanding the potential health impacts and costs of $PM_{2.5}$ formation from different modes of transport will help raising the awareness of the public due to the realisation on the $PM_{2.5}$ footprint of their actions. $PM_{2.5}$ footprint is considered as the health impacts from $PM_{2.5}$ formation throughout life cycle of products and organisations. $PM_{2.5}$ footprint is quantified by multiplying emissions with characterisation factors. Afterwards, the health costs could be obtained by economic evaluation of the health impacts. The $PM_{2.5}$ Footprint Calculator v1.01 was developed as a tool for enhancing environmentally sustainable passenger transport in Thailand. The $PM_{2.5}$ Footprint Calculator v1.01 can determine primary and secondary $PM_{2.5}$ emissions ($PM_{2.5}$, NO_x, NH_3, and SO_2) and assess health impacts and costs of passenger transport by road, water and rail in Thailand. The calculator consists of primary and secondary $PM_{2.5}$ emission inventory (for passenger transport), city-specific characterisation factors, and health cost conversion factor. The details of emission inventory, impact characterisation and economic valuation can be seen in Section 2 and 3. Features of the current version and future updates of the $PM_{2.5}$ footprint calculator are also documented in this report. .

The reference publications of the $PM_{2.5}$ Footprint Calculator v1.01 are listed below.

- Chavanaves, S., Fantke, P., Limpaseni, W., Attavanich, W., Panyametheekul, S., Gheewala, S.H. & Prapaspongsa, T. (2021). Health Impacts and Costs of Fine Particulate Matter Formation from Road Transport in Bangkok Metropolitan Region. Atmospheric Pollution Research, 12(10) 101191.
- Sakpheng, P., Chavanaves, S., Chutinthorn, M., Saengdao, S., Limpaseni, W., Panyametheekul, S., Winijkul, E., Fantke, P., Gheewala, S.H. & Prapaspongsa, T. (2021) $PM_{2.5}$ footprint: a tool for enhancing sustainable passenger transport. Proceedings of 8th International Conference on Green and Sustainable Innovation (ICGSI), 10-12 November 2021, Hybrid Conference, Krabi, Thailand.

1.2 Calculator Versions

The $PM_{2.5}$ Footprint Calculator v1.01 is provided in two versions:

- Web-Based $PM_{2.5}$ Footprint Calculator
- $PM_{2.5}$ Footprint Calculator (Microsoft Excel Program)

Users can directly apply the Web-Based $PM_{2.5}$ Footprint Calculator via the $PM_{2.5}$ footprint website (https://www.eg.mahidol.ac.th/dept/egce/pmfootprint/) or download the $PM_{2.5}$ Footprint Calculator (Microsoft Excel Program) from the $PM_{2.5}$ footprint website (Publications and Downloads) for own calculations. The Web-Based $PM_{2.5}$ Footprint Calculator computes the health impacts and costs from "well-to-wheel" including emissions from upstream fuel and electricity production; and exhaust emissions from fuel combustion. The $PM_{2.5}$ Footprint Calculator (Microsoft Excel Program) can assess health impacts and costs both from "well-to-wheel" and "tank-to-wheel”. In the tank-to-wheel scope, the exhaust emissions from fuel combustion (indicated as "vehicle use" in this excel) are considered.

2. Emission Inventory

2.1 Methodology

The passenger transport emission inventory development involves integrating the transport specific emission factors and activity data. The principle equation for emission inventory development for road transport and sky train are adopted from EMEP/EEA (2019) (Kouridis et al., 2019) and is shown in below:

$$Emission = Emission\ Factor \times Activity\ Data$$

The above equation is applicable for emission calculation for two out of three secondary $PM_{2.5}$ precursors i.e., NO_x and NH_3. While for SO_2 emission, the following equation has been applied:

$$SO_2\ Emission = 2 \times Fuel\ Usage \times Fuel\ Sulphur\ Content$$

Emission inventory for water transport is developed by following the guidelines from the final report of Development of Emissions Inventory for Inland Water Transport in Bangkok, Thailand (Winijkul, 2021). The equation adopted for water transport has been depicted in the equation below:

$$Water\ transport\ Emission = Cruising\ Emission + Idling\ Emission$$

2.2 Features of the Current Version

The emission calculation in the current version is primarily divided into 2 sections: tank-to-wheel (emissions come from combustion of fuel) and well-to-tank (emissions come from upstream fuel and electricity production). The passenger transport considered are:

i. Road transport (private passenger cars, private passenger pickups, public buses, and private motorcycles).
   Furthermore, road transport emission calculation requires information on engine types, fuel types (Gasoline, B7, B20, LPG, and CNG), and technology ages
ii. Public water transport (Cross river ferries (100-300 hp), Chao Phraya boats (300-750 hp), Saen Saep boats (300-750 hp)).
iii. Sky train.

Specific data utilized in the current version for emission inventory development of different passenger transport based on Sakpheng et al. (2021) are provided in the tables below:

Table: Specific data utilized for road transport emissions (Kouridis et al., 2019)

Type of vehicle	Age (year)	Technology	Fuel	Primary $PM_{2.5}$ Emission Factor (g $PM_{2.5}$ /pkm)	NO_x Emission Factor (g NO_x /pkm)	NH_3 Emission Factor (g NH_3/pkm)	Typical Fuel Consumption (kg/km)	Sulfur Emissions standard (ppm)
Passenger Car	1< to 5	Euro 4	Gasoline	9.57E-07	5.30E-05	2.97E-05	0.07	50
			B7	2.47E-05	4.55E-04	7.85E-07	0.06	50
			B20	3.64E-06	6.72E-05	1.16E-07	0.06	50
			LPG	9.57E-07	4.87E-05	2.94E-05	0.06	140
			CNG	9.57E-07	4.87E-05	2.94E-05	0.06	50
Passenger Car	6 to 10	Euro 3 + 4	Gasoline	9.57E-07	7.18E-05	2.97E-05	0.07	50
			B7	2.83E-05	5.46E-04	7.85E-07	0.06	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.06	50
			LPG	9.57E-07	6.64E-05	2.94E-05	0.06	140
		Euro 4	CNG	9.57E-07	4.87E-05	2.94E-05	0.06	50
Passenger Car	11 to 15	Euro 2+3	Gasoline	1.15E-06	1.12E-04	4.19E-05	0.07	50
			B7	3.32E-05	5.98E-04	7.85E-07	0.06	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.06	50
			LPG	1.15E-06	9.39E-05	4.10E-05	0.06	140
		Euro 4	CNG	9.57E-07	4.87E-05	2.94E-05	0.06	50
Passenger Car	16 to 20	Euro 1 + 2	Gasoline	1.91E-06	3.02E-04	8.65E-05	0.07	50
			B7	5.23E-05	5.54E-04	7.85E-07	0.06	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.06	50
			LPG	1.91E-06	2.38E-04	8.31E-05	0.06	140
		Euro 4	CNG	9.57E-07	4.87E-05	2.94E-05	0.06	50
Passenger Car	>20	Euro 1	Gasoline	1.91E-06	4.22E-04	8.02E-05	0.07	50
			B7	6.61E-05	5.42E-04	7.85E-07	0.06	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.06	50
			LPG	1.91E-06	3.60E-04	7.65E-05	0.06	140
		Euro 4	CNG	9.57E-07	4.87E-05	2.94E-05	0.06	50
Passenger Pick ups	1< to 5	EURO 4	Gasoline	9.17E-07	5.33E-05	2.52E-05	0.10	50
			B7	3.08E-05	6.25E-04	9.03E-07	0.08	50
			B20	4.54E-06	9.23E-05	1.33E-07	0.08	50
			LPG	9.17E-07	4.67E-05	2.82E-05	0.06	140

Type of vehicle	Age (year)	Technology	Fuel	Primary $PM_{2.5}$ Emission Factor (g $PM_{2.5}$ /pkm)	NO_x Emission Factor (g NO_x /pkm)	NH_3 Emission Factor (g NH_3/pkm)	Typical Fuel Consumption (kg/km)	Sulfur Emissions standard (ppm)
			CNG	9.17E-07	4.67E-05	2.82E-05	0.06	50
Passenger Pick ups	6 to 10	Euro 3 + 4	Gasoline	9.17E-07	8.58E-05	2.52E-05	0.10	50
			B7	4.77E-05	7.15E-04	9.03E-07	0.08	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.08	50
			LPG	9.17E-07	6.37E-05	2.82E-05	0.06	140
		Euro 4	CNG	9.17E-07	4.67E-05	2.82E-05	0.06	50
Passenger Pick ups	11 to 15	Euro 2+3	Gasoline	1.12E-06	1.24E-04	3.53E-05	0.10	50
			B7	6.47E-05	8.04E-04	9.03E-07	0.08	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.08	50
			LPG	1.10E-06	9.00E-05	3.93E-05	0.06	140
		Euro 4	CNG	9.17E-07	4.67E-05	2.82E-05	0.06	50
Passenger Pick ups	16 to 20	Euro 1 + 2	Gasoline	1.92E-06	3.03E-04	7.08E-05	0.10	50
			B7	8.80E-05	9.18E-04	9.03E-07	0.08	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.08	50
			LPG	1.83E-06	2.28E-04	7.97E-05	0.06	140
		Euro 4	CNG	9.17E-07	4.67E-05	2.82E-05	0.06	50
Passenger Pick ups	>20	Euro 1	Gasoline	1.92E-06	4.69E-04	6.32E-05	0.10	50
			B7	8.80E-05	9.18E-04	9.03E-07	0.08	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.08	50
			LPG	1.83E-06	3.45E-04	7.33E-05	0.06	140
		Euro 4	CNG	9.17E-07	4.67E-05	2.82E-05	0.06	50
Public Buses	1< to 5	Euro 3	Gasoline	0.00E+00	2.63E-04	7.57E-08	0.24	50
			B7	7.45E-06	3.37E-04	1.04E-07	0.24	50
			B20	1.10E-06	4.98E-05	6.64E-05	0.24	50
			LPG	3.98E-07	3.98E-04	0.00E+00	0.50	140
			CNG	3.98E-07	3.98E-04	0.00E+00	0.50	50
Public Buses	6 to 10	Euro 3	Gasoline	0.00E+00	2.63E-04	7.57E-08	0.24	50
			B7	7.45E-06	3.37E-04	1.04E-07	0.24	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.24	50

Type of vehicle	Age (year)	Technology	Fuel	Primary $PM_{2.5}$ Emission Factor (g $PM_{2.5}$ /pkm)	NO_x Emission Factor (g NO_x /pkm)	NH_3 Emission Factor (g NH_3/pkm)	Typical Fuel Consumption (kg/km)	Sulfur Emissions standard (ppm)
			LPG	3.98E-07	3.98E-04	0.00E+00	0.50	140
			CNG	3.98E-07	3.98E-04	0.00E+00	0.50	50
Public Buses	11 to 15	Euro 2+1	Gasoline	0.00E+00	2.63E-04	7.57E-08	0.24	50
			B7	9.78E-06	3.81E-04	1.04E-07	0.24	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.24	50
			LPG	4.78E-07	6.10E-04	0.00E+00	0.50	140
			CNG	4.78E-07	6.10E-04	0.00E+00	0.50	50
Public Buses	16 to 20	Euro 1	Gasoline	0.00E+00	2.63E-04	7.57E-08	0.24	50
			B7	1.72E-05	3.63E-04	1.04E-07	0.24	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.24	50
			LPG	7.97E-07	6.57E-04	0.00E+00	0.24	50
			CNG	7.97E-07	6.57E-04	0.00E+00	0.50	140
Public Buses	>20	Euro 1	Gasoline	0.00E+00	2.63E-04	7.57E-08	0.50	50
			B7	1.72E-05	3.63E-04	1.04E-07	0.24	50
			B20	0.00E+00	0.00E+00	0.00E+00	0.24	50
			LPG	7.97E-07	6.57E-04	0.00E+00	0.24	50
			CNG	7.97E-07	6.57E-04	0.00E+00	0.5	140
Motorcycle	1< to 5	Euro 3	Gasoline	3.18E-06	1.76E-04	1.73E-06	0.04	50
Motorcycle	6 to 10	Euro 3	Gasoline	3.18E-06	1.76E-04	1.73E-06	0.04	50
Motorcycle	11 to 15	Euro 2	Gasoline	1.10E-05	2.30E-04	1.73E-06	0.04	50
Motorcycle	16 to 20	Euro 1	Gasoline	3.55E-05	2.15E-04	1.73E-06	0.04	50
Motorcycle	>20	Euro 1	Gasoline	3.55E-05	2.15E-04	1.73E-06	0.04	50

Table: Emission Factor for fuel production

Fuel Types	Emission Factor (kg pollutant / kg fuel)			
	$PM_{2.5}$	NO_x	NH_3	SO_2
Gasoline	3.91E-04	2.34E-03	1.58E-05	5.38E-03
Diesel	2.57E-04	1.76E-03	1.00E-05	3.99E-03
LPG	2.97E-04	1.92E-03	1.13E-05	4.51E-03
CNG	4.58E-05	3.88E-04	1.20E-06	9.49E-04

Table: Specific data for quantification of sky train transport emissions (Moreno Ruiz et al., 2020)

Emission Factor (kg/kwh)				Electricity per 1 passenger-kilometre (kWh/pkm)
Primary $PM_{2.5}$	NO_x	NH_3	SO_2	
1.36E-04	8.67E-04	5.60E-06	1.22E-03	0.065

Table: Specific data for inland water transport emissions (Winijkul, 2021)

Type of boat	Load Factor, LF (Unitless)	Average Power (hp/passenger)	Cruising Emission Factor adj, g/pkm				Average Velocity (km/hr.)	Average Idling time (hr.)	Idling Factor			
			Primary $PM_{2.5}$	NO_x	NH_3	SO_2			Primary $PM_{2.5}$	NO_x	NH_3	SO_2
Cross river ferries (100-300 hp)	0.31	5	1.23E-02	2.15E-01	2.50E-05	4.00E-04	6.80	0.092	0.25	1.07	1	7
Chao Phraya boats (300-750 hp)	0.31	13.125	1.23E-02	2.15E-01	2.50E-05	4.00E-04	13.20	0.45	0.25	1.07	1	7
Saen Saep boats (300-750 hp)	0.14	7.5	7.00E-03	1.23E-01	1.43E-05	2.29E-04	20.80	0.14	0.25	1.07	1	7

2.3 Future Updates

The emission inventory developed in the current version is subjected to modifications in the future upgraded version. The elements that will be subjected to specific updates in emission inventory determination include:

i. Addition of new passenger transports (including different engine types, fuel types and techology ages) to the ones considered in the current version.
ii. Emission factors for primary and secondary $PM_{2.5}$ of all the considered passenger transport systems (including vehicle use and energy production).
iii. Modifications in the activity data (for both vehicle use and energy production phases) based on availability of updated data. The specific data that are subjected to update in the future include

Passenger Transport	Scope	Parameter
Road Transport	Vehicle Use	• Occupancy Rate
	Energy Production	• Ecoinvent Database selected • Occupancy rate • Fuel Consumption
Water Transport	Vehicle Use	• Occupancy Rate • Load Factor • Average Power • Average Velocity • Average Idling Time
	Energy Production	• Ecoinvent Database selected • Occupany Rate • Fuel Consumption
Sky Train	Vehicle Use	• Electricity per car train • Passenger per car train • Electricity per person
	Energy Production	• Electricity per car train • Passenger per car train • Electricity per person

3. Impact Characterization and Economic Valuation

3.1 Methodology

3.1.1 Impact Characterization

The health impact attributed to pollutant emission from different passenger transport is characterized by $PM_{2.5}$ Characterization Factors (CF). The calculation of CF for fine particulate matter impact category is composed of integrating two parameters i.e., Intake Fraction (iF) and Effect Factor (EF) as shown below (Fantke et al., 2014).

$$CF = iF \times EF$$

Intake fraction represents the ratio of amount of pollutant inhaled by exposed population to the total amount of pollutant emitted at source. Effect factor signifies the relationship between health effects and the dose of pollutant inhaled. The two parameters together represent the CF which help in estimating the health impacts of fine particulate matter. The CF is presented in the unit Disability Adjusted Life Years (DALY) per kilogram of pollutant emitted. DALY is the health metric which is used to represent the years of life lost, and years of life lived with a disability. City-specific CFs are calculated by determining the spatially differentiated iF and EF values. Finally, the spatially differentiated CFs are related with the estimated emission inventory (E) of various passenger transport to determine the health impact score (HI).

$$HI = CF \times E$$

3.1.2 Economic Evaluation

The determined health impact score is translated into monetary terms (in the unit THB per year) with the help of damage cost factors (THB/DALY) which have been calculated applying the budget constraint approach (Kaenchan and Gheewala, 2017). The budget constraint approach is used in monetizing the damage impact on human health by means of obtaining monetary value of 1 QALY (Quality Adjusted Life Years). QALY is the years lived at full well-being and is the reverse of DALY (1 QALY= -1 DALY). The monetary value of 1 QALY is considered equivalent to the annual income earned by an individual in the state of full-wellbeing, and this in turn is the maximum amount an individual is willing to pay for additional year of full well-being (Kaenchan and Gheewala, 2017).

$$Economic\ Cost = HI \times Damage\ Cost\ Factor$$

3.2 Features of the Current Version

3.2.1 Impact Characterization

The spatially differentiated characterization factors for fine particulate matter formation specific to the context of Thailand has been determined by adapting and updating the input parameters in existing models provided in the table below:

Table: Model applied for CF Calculation

Parameter	Pollutant	Spatial Resolution	Principle Model/Method Applied
Intake Fraction	Primary $PM_{2.5}$	City-specific	Microsoft Excel Workbook Model (Fantke et al., 2017)
	Secondary $PM_{2.5}$	Global Average	Default Factors (Humbert et al., 2011)
Effect factor	Primary & Secondary $PM_{2.5}$	City-specific	Microsoft Excel Workbook Model (Fantke et al., 2019)

Since, the damaging effects of inhaling pollutants emitted at a specific city can be transmitted beyond that city, the overall determination of CF in the current version has considered the effects of $PM_{2.5}$ emission in the city of interest (i.e., 77 Provinces of Thailand) and its effect within the city of interest along with its effects throughout Thailand and within the sub-continental region of Indochina. Further, the intake fraction model has considered the effect of city-specific outdoor emission on both indoor and outdoor compartments. The parameters considered in the intake fraction model to determine spatially differentiated values are city-specific population, area, linear population density, $PM_{2.5}$ concentration, mixing height, wind velocity and dilution rate. Similarly, the parameters considered to obtain city-specific effect factors are mortality data, severity factors, population and $PM_{2.5}$ concentration.

Further details on the model input parameters, data sources and additional information on the methodology used to determine the spatially differentiated intake fraction and effect factors has been provided in the section below. The work has been developed based upon Chavanaves et al. (2021).

A. Intake Fraction:

Input Parameter (Unit)	Spatial Resolution	Data Source (Year)	Methodology/ Remarks
Population of urban environment (capita)	City-specific	National Statistical Office of Thailand (2019)	Data recorded by Department of Provincial Administration (DOPA) of Thailand.
Population of rural environment (capita)	Sub-continental region specific	Default model data (Based on Impact World+)	City-specific population is subtracted from total population of Indochina.
Area of city (km^2)	City-specific	DOPA (2017)	Area of all provinces of Thailand.
Percent of Urban Area (%)	City-specific	Land Development Department (LDD), Thailand (2019)	Based on Thailand's land use map/data.
Area of outdoor urban environment (km^2)	City-specific		$Area\ of\ outdoor\ urban\ environment = Area\ of\ city\ \times\ Urban\ Area\ (\%)$
Area of outdoor rural environment (km^2)	Sub-continental region specific	Default model data (Based on Impact World+)	Area of outdoor urban environment (city-specific urban area) is subtracted from total area of subcontinental region (Indochina)
Linear Population Density (LPD) (capita/m)	City-specific		$LPD = \frac{Population\ of\ urban\ environment}{\sqrt{Area\ of\ outdoor\ urban\ environment}}$
$PM_{2.5}$ Concentration ($\mu g/m^3$)	City-specific	Pollution Control Department (PCD), Thailand (2019)	• Province-wise annual average $PM_{2.5}$ concentration obtained from permanent PCD stations. • Regional average annual $PM_{2.5}$ concentration was used for provinces without permanent PCD stations.
Breathing rate (m^3/person/day)	Global average	Default value (Based on Hodas et al., 2016)	Average individual breathing rate (without differentiation between outdoor and indoor average breathing rate).
Deposition velocity of urban environment (m/d)	Global average	Model default value	Underlying assumption made that there are no differences in surface roughness between different cities in urban area.
Deposition velocity of rural environment (m/d)	Sub-continent specific	Model default value	
Mixing Height of outdoor urban environment (m)	City-specific	1) AIT (2020) 2) Model default values	1) City-specific mixing height obtained for Bangkok Metropolitan Region (BMR) from Weather Research Forecasting (WRF) model simulation by AIT Air Quality Lab in 2016. (Adapted from Chavanaves et al., 2021) 2) For remaining provinces, regional average mixing height were calculated for provinces available in the default model.

Input Parameter (Unit)	Spatial Resolution	Data Source (Year)	Methodology/ Remarks
Wind velocity (m/s)	City-specific	Thai Meteorological Department (TMD) (2015-2019)	Wind velocity of each province measured at a reference height (averaged over 5-years).
Reference Height (m)	1) City-specific 2) Global average	1) TMD (2019) 2) Apte et al. (2012)	1) For BMR, reference height where windspeed is measured was available 2) For the remaining provinces, standard reference height of 10m has been taken.
Wind Velocity averaged over mixing height (m/s)	City-specific	Adapted from Apte et al., 2021	Wind velocity averaged over mixing height is calculation using equation SI.3a of Apte et al., (2012) as follows: $u(t) = \frac{u_{ref}(t)}{p+1}\left(\frac{H(t)}{H_{ref}}\right)^p$ for z ≤ $H_{\max}$ $u(t) = \frac{H_{max}\left[\frac{u_{ref}(t)}{p+1} \times \left(\frac{H_{max}}{H_{ref}}\right)^p\right] + (H(t) - H_{max})\left[u_{ref}(t) \times \left(\frac{H_{max}}{H_{ref}}\right)^p\right]}{H(t)}$ for z > $H_{\max}$ where, u(t) = average wind speed over mixing height uref = windspeed measured at reference height p = empirical constant (dimensionless) which has a default value = 0.32 H(t) = Mixing Height
Dilution Rate (m^2/s)	City-specific	Adapted from Chavanaves et al., (2021)	$Dilution\ Rate = \underbrace{Wind\ Velocity}_{Averaged\ over\ Mixing\ Height} \times Mixing\ Height$

B. Effect Factor

Input Parameter (Unit)	Spatial Resolution	Data Source (Year)	Methodology/ Remarks
Population (capita)	• City-specific • Countrywide	National Statistical Office of Thailand (2019)	Population of each province of Thailand and total population of Thailand
$PM_{2.5}$ Concentration ($\mu g/m^3$)	• City-specific • Countrywide	Pollution Control Department (PCD), Thailand (2019)	• Province-wise and countrywide annual average $PM_{2.5}$ concentration obtained from permanent PCD stations. • Regional average annual $PM_{2.5}$ concentration was used for provinces without permanent PCD stations.
Breathing rate (m^3/person/day)	Global average	Default value (Based on Hodas et al., 2016 and Nazaroff et al., 2015)	• Average individual breathing rate (accounting for time fraction spent outdoor and indoor).
Mortality (deaths)	City-specific	GBD Collaborative Network (2019)	Country-specific mortality Data is retrieved for 5 diseases (with specific age groups): • Ischemic Heart Disease (IHD): 12 age groups (25-29 years, 30-40 years, …., 75-80 years and >80 years. • Stroke: 12 age groups (25-29 years, 30-39 years, …., 75-79 years and >80 years. • Chronic Obstructive Pulmonary Disease (COPD): >25 years • Lung Cancer: > 25 years • Lower Respiratory Infection (LRI): <5 years Countrywide mortality is scaled to city-specific mortality by multiplying total mortality of Thailand with ratio of city to county population.
Severity Factor (SF) (DALY/death)	Countrywide	GBD Collaborative Network (2019)	The data of DALY for Thailand (for the 5 diseases of same age groups as mortality) is divided by mortality data of Thailand. Here the countrywide SF data is used consistently for all cities.

3.2.2 Economic Evaluation

The value of 1 DALY is based on the year 2011 (Kaenchan and Gheewala, 2017). Considering the effect of time value of money, the predicted value of 1 DALY for future years have been derived in the current version. Future value of 1 DALY has been calculated by applying average inflation rate of Thailand from base year (2011) till reference year (2021). The future value of the economic cost per DALY has been determined by referring to equation by Haputta et al. (2020).

$$Future\ value\ of\ DALY = Value\ of\ DALY_{2011} \times (1+r)^{t-2011}$$

where,

t = Year of interest for currency used in valuation

r = Average inflation rate (Average consumer price) of Thailand (IMF, 2020).

3.3 Future Updates

3.3.1 Impact Characterization

Further enhancements in the spatially differentiated $PM_{2.5}$ Characterization Factors (CFs) of the current version i.e., v1.01 can be expected in the future upgraded versions. The elements that will be subjected to specific updates in characterization factor determination include:

i. The city-specific data of Thailand applied in various input parameters of Intake Fraction and Effect Factor models can be modified annually by updating with the most recent year's data. Based on availability of data, the following parameters may be updated:

Intake Fraction	Effect Factor
• City-specific population • Percent of urban area • $PM_{2.5}$ concentration • Wind speed • Mixing Height	• City-specific population • $PM_{2.5}$ concentration • Mortality data of Thailand • DALY data of Thailand

ii. The methods applied in determining values for certain input parameters of the Intake Fraction model in the current version are either not city-specific or are not available for all cities of Thailand. Hence, revision in the methods applied for the following model parameters can be expected in the future versions:

a. Mixing Height

b. Deposition velocity of urban environment

3.3.2 Economic Evaluation

The future value of 1 DALY determined in the current version can be subjected to modification in the next updates. The adjustment in the future value of 1 DALY is based on average inflation of Thailand between the base year of 2011 and the selected reference year.

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