AIR QUALITY IMPROVEMENT PROGRAM IN THAILAND (AQIP)

Comprehensive Inventory Methodology Report for Chiang Mai Province, Thailand (2022)

Revision 00

Document Information

GENERAL INFORMATION

PROJECT MANAGER	Sophie MOUKHTAR – Head of Air Pollution Unit – Citepa David SHELLEY – AQIP Program Manager – Egis
AUTHOR(S)	Jean-Marc ANDRE – Head of the Air Pollution and Mobility Department – Citepa Quentin BEDRUNE – LULUCF project engineer - Citepa Tamara BRAISH – Solvent Project Engineer - Citepa Benjamin CUNIASSE – Energy Project Engineer - Citepa Jonathan HERCULE – Agriculture Project Engineer – Citepa Rania KAMAR – Industry Project Engineer – Citepa Vincent MAZIN – Waste Project Engineer – Citepa Adrien MERCIER – Transport Project Engineer – Citepa Colas ROBERT - Head of LULUCF (Land Use, Land Use Change and Forestry) Team – Citepa Nguyen Huy LAI– Research Specialist – AIT Ekbordin WINIJKUL – Associate Professor – AIT Nguyen Thi Kim OANH - Professor – AIT
Contributors	AQIP Consortium
Revision	00

REVISION HISTORY

Revision	Date	Checked by	Function	Organization
00	20-Sep-2024	David SHELLEY	Program Manager	AQIP (Egis)

RECIPIENTS

Name	Entity
Anne-laure ULLMANN	Agence Française de Développement (AFD)

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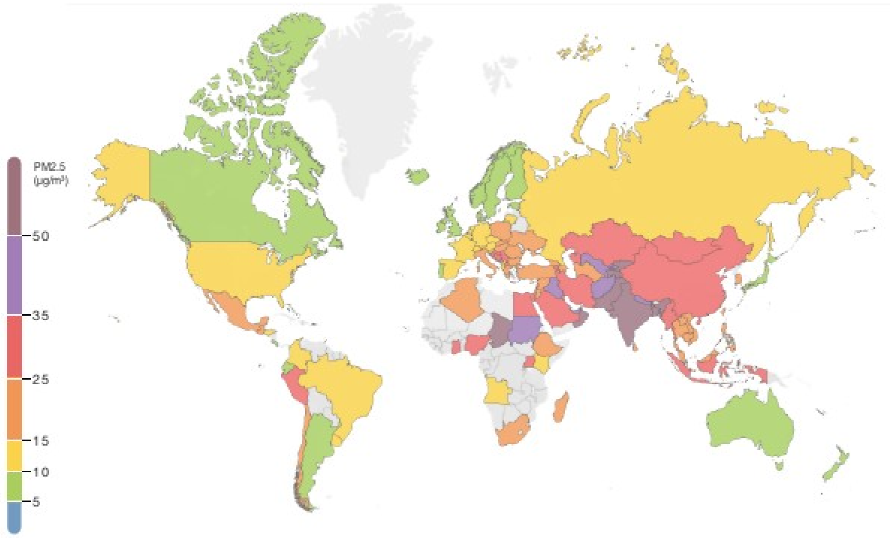
1 INTRODUCTION

1.1 CONTEXT

Air pollution is one of the greatest environmental risks for health while many of its drivers are also sources of greenhouse gas emissions. Ambient air pollution is estimated to have resulted in 4.2 million premature deaths globally in 2019. Approximately 89% of these deaths occurred in low- and middle-income countries, with the highest numbers reported in the South and Southeast Asia and Western Pacific Regions. Figure 1 illustrates the annual average $PM_{2.5}$ concentration in 2021, showing high levels observed in South, Southeast, and Eastern Asia.

FIGURE 1 – ANNUAL AVERAGE $PM_{2.5}$ CONCENTRATION IN 2021



Source: IQAir

To contribute to tackling this issue, AFD has prepared a program entitled Air Quality Improvement Program (AQIP) at a regional scale that aims to develop and implement solutions to cut down air pollution in the area. The AQIP focused on around two components, the first one at country level and the second one at regional level, covering the ten ASEAN Members States.

The AQIP program was first implemented in Thailand – which is already at an advanced stage of fighting air pollution compared to its neighbors.

The main goals of the AQIP Thailand are:

- To strengthen the current air quality management system,
- To build up capacities and sharp competencies of local Thai agencies,
- To provide technical support and recommendations,
- To assess the sources of air pollutants in the Province of Chiang Mai and their geographical location to settle targeted and effective mitigation measures and to implement "quick win" actions to reduce air pollution,
- To assess the feasibility of the introduction of zero-emission vehicles in a widespread urban area as Chiang Mai; and
- To give recommendations and to draft a roadmap for better air quality in Chiang Mai province.

1.2 PURPOSE OF THIS REPORT

A Spatialized emissions inventory was built for the Province of Chiang Mai. This report gives the detailed methodology used, the activity, the emission factors as well as the methodology for spatial attribution of the emissions for each sector. **This methodology report aims at being a reference for emissions inventory building and should be the base for a regular update and improvement of the Chiang Mai Emissions Inventory (EI).**

Other reports were produced in the framework of this project:

- An audit of emission inventories currently available in Thailand: the National Emissions Inventory (EI) and the EI for Bangkok Metropolitan Region (BMR) "Audit of the Emission Inventories in Thailand" (September 2023). This audit is the preliminary step for the construction of the Chiang Mai spatialized inventory and allows to identify available activity data and emission factors and the corresponding authorities and agencies. This report was produced by Citepa and Airparif.
- A traffic survey report that describes the methodology used to interview drivers and households, the analysis of data, and the assessment of the vehicles fleet ("Air Quality Improvement in Thailand – Output 4, Part1: Composition of the technological fleet in Chiang Mai", December 2023). This report was produced by Citepa and EGIS and the traffic survey was performed by EGIS and Chiang Mai University.
- A report was produced that gives the main sources of air pollutants and greenhouse gases (GHGs) in Chiang Mai province. In this report, a roadmap to reduce air emissions is proposed to the Local and National authorities "Sources of Air Pollution in Chiang Mai in 2022 – Main sources and measures to mitigate air pollution" (August 2024). This report was produced by Citepa with the collaboration of Asian Institute of Technology (AIT).

This methodological report starts with a general description of the methodology used and key characteristics and results, then give the detailed methodology and data used for the following sectors: Energy, Industrial Processes and Products Used (IPPU), Agriculture, Waste and Natural sources. Then, a Chapter is dedicated to the geographical spatialization of emissions.

1.3 INVENTORY PREPARATION PROCESSES

Citepa has established a fruitful cooperation with AIT which helps collecting information about some key categories of the inventory. Specifically, these activities aim at the improvement of provision and collection of basic data and emission factors, through exchange of information from scientific research projects and new sources.

The main data needed for the preparation of the Chiang Mai emissions inventory are energy statistics, such as the National Energy Balance published by the Department of Alternative Energy Development and Efficiency of the Ministry of Energy, statistics on industry, published by the Department of Industrial Works of the Ministry of Industry and agricultural production, published by the Office of Agricultural Economics of the Ministry of Agriculture and Cooperatives.

Numerous statistical data are also available from the NSO (National Statistical Office of Thailand) website (*http://www.nso.go.th/sites/2014en/statistics-from-majo-survey*), which includes both national and provincial data. This website also contains socio-economic data (population, GDP) that can be used as a proxy for calculating provincial emissions from national data when province-level data is not available.

In addition, an in-depth study was carried out on traffic in Chiang Mai, with EGIS carrying out a traffic survey in collaboration with Chiang Mai University (CMU). This study provided a better understanding of the province's technological vehicle fleet. The results of this traffic survey were published in December 2023 in the report "Air Quality Improvement in Thailand – Output 4, Part1: Composition of the technological fleet in Chiang Mai.

When possible, methodologies used in this EI are consistent with the 2019 and 2023 *EMEP/EEA Emissions Inventory Guidebook*, the *2006 IPCC Guidelines*, and Atmospheric Brown Cloud Emissions Inventory Manual (ABC EIM) (Shrestha et al., 2013). Country-specific emission factors are chosen in priority, when available, otherwise default emission factors from international guidebooks are used. Emission estimates are drawn up for each sector.

Activity data used in emission calculations and their sources are briefly described here below (Table 1).

This is the first time that the process of preparing the detailed inventory covering most of the source sectors, has focused solely on Chiang Mai province. Emissions were calculated for the year 2022, but where data was not available, activity data for 2021 was used. In addition, where data from previous years was available, calculation on a longer trend was carried out to assess the evolution of emissions.

All reference documents, estimates and spreadsheets, as well as documentation on scientific articles and background data required to compile the inventory, are stored and archived by Citepa and will be shared with PCD (Pollution Control Department).

2 GENERAL STATEMENT ON METHODOLOGY

2.1 LIST OF AIR POLLUTANTS

The following classes of pollutants should be included in the emission inventory:

Main Pollutants

- Sulphur oxides (SO_X), in mass of SO_2,
- Nitrous oxides (NO_X), in mass of NO_2,
- Non-methane volatile organic compounds (NMVOC),
- Ammonia (NH_3); and
- Carbon monoxide (CO).

Particulate matter

- TSP, total suspended particles,
- PM_{10}, particulate matter with aerodynamic diameter not above 10 microns,
- $PM_{2.5}$, particulate matter with aerodynamic diameter not above 2.5 microns; and
- Black Carbon and Organic Carbon.

Heavy Metals (when data is available)

- Priority Metals: Lead (Pb), Cadmium (Cd) and Mercury (Hg).

2.2 METHODS AND DATA SOURCES

An outline of methodologies and data sources used in the preparation of the emission inventory for each sector is provided in Table 1 which gives a summary of the data collected.

TABLE 1: MAIN ACTIVITY DATA AND SOURCES FOR THE CHIANG MAI EMISSIONS INVENTORY

SECTOR– NFR Code	ACTIVITY DATA		EF	REPARTITION KEYS	SOURCES
1 ENERGY					
	CHIANG MAI	NATIONAL			
1A1 Energy Industries	Power Plants in Chiang Mai Province (2019)	Fuel consumption Energy balance (2021)	EMEP/EEA 2019		• *Energy production in CM province:* Department of Alternative Energy Development and Efficiency, Ministry of Energy. *http://weben.dede.go.th/webmax/sites/default/files/BibA9434_2015.pdf.*
1A2 Manufacturing Industries and Construction	Manufacturing Industries: Provincial fuel consumption is **deduced from National consumption for Industrial Manufactures** **List of factories in Chiang Mai-that are permitted to operate as of the end of 2022.**	National energy balance for the industrial sector	EMEP/EEA 2019	GDP	• Energy Balance - Department of Alternative Energy Development and Efficiency, Ministry of Energy • Department of Industrial Works of the Ministry of Industry. *https://www.diw.go.th* • Energy Consumption for Manufacturing Sector by Type Year: 2011 – 2020 – NSO website
	Construction: Regional: Number and area of building construction by type of building and Area in the Northern Region		EMEP/EEA 2019	Regional population *vs* Chiang Mai population	• NSO Statistical services: Number of permits, number and area of building construction by type of building and area, Northern Region, 2014-2021. *http://www.nso.go.th/sites/2014en/statistics-from-majo-survey*
1A3 Transport	Road Transport: Fuel use (energy balance and traffic survey) Newly registered vehicles in Thailand from 1991 newly registered vehicles in Chang Mai from 1999 EGIS traffic survey in Chiang Mai Average vehicle kilometer of travel (kilometers/year)	Fuel consumption for transport - Energy balance Registered vehicles from 1991	EMEP/EEA 2023 IPCC Guidelines	Chiang Mai traffic density by road segment and vehicle type	• Energy Balance - Department of Alternative Energy Development and Efficiency, Ministry of Energy • DLT (Department of Land Transport) data available on the NSO (National Statistical Office) website *statbbi.nso.go.th/staticreport/page/sector/en/15.aspx* • Older data were supplied by the DLT on request: Chiang Mai (1999-2023) and National (1991-2023) • Air Quality Improvement in Thailand – Output 4, Part1: Composition of the technological fleet in Chiang Mai", December 2023 • ATRANS « An Analysis of Vehicle Kilometers of Travel of Major Cities in Thailand » (Final report 2009).

SECTOR– NFR Code	ACTIVITY DATA		EF	REPARTITION KEYS	SOURCES
1 ENERGY					
	CHIANG MAI	NATIONAL			
	Survival rate function for each type of vehicle Vehicle technological fleet: EGIS traffic survey				• Diesel Project 2004 (World Bank) • Department of Energy Business, Ministry of Energy
	Air transport: Number of aircraft landing and take-off cycles at Chiang Mai Airport	Number of aircraft landing and take-off cycles	ABC EIM EMEP/EEA 2023 2006 IPCC Guidelines		• Air traffic statistics from "New normal Digital transformation in the aviation industry, Annual report 2021", AOT - *https://www.airportthai.co.th/wp-content/uploads/2021/12/AnnualReport2021en.pdf*
	Railway transport: Railway length in Chiang Mai province	National energy balance for Railway National railway length	EMEP/EEA 2023	Length of railway	• Shapefile of railway length in Thailand for year 2021 *https://data.thailand.opendevelopmentmekong.net/en/dataset/thailand-railway-network?type=dataset*
	Maritime Transport: Not concerned				
	Inland Waterway: Not concerned				
	Other transportation (non-road mobile) Statistics of Land Utilization by Region and Province Year: 2011 - 2021 Fuel consumption per cultivated area and major crop cultivation.	National energy balance for agriculture National wood production.	EMEP/EEA 2023 2006 IPCC Guidelines		• Energy Balance - Department of Alternative Energy Development and Efficiency, Ministry of Energy. • Statistics of Land Utilization by Region and Province Year: 2011 - 2021 • Thailand_Energy_Commodity_Account_2021v2 • Forest cultivation and timber in Thailand: *FAOSTAT*

SECTOR– NFR Code	ACTIVITY DATA		EF	REPARTITION KEYS	SOURCES
1 ENERGY					
	CHIANG MAI	NATIONAL			
1A4 Residential-public-commercial sector	Fuel consumption in CM **deduced from National data**	National energy balance for residential and commercial sectors	Huy et al., 2021a and 2021b IPCC 2006 EMEP/EEA 2023	Population	• Energy Balance - Department of Alternative Energy Development and Efficiency, Ministry of Energy
1B Fugitive Emissions from Fuel	Number of gasoline and Natural gas stations in Chiang Mai		ABC EIM		• Department of Energy Business Ministry of Energy - Department of Energy Business, Ministry of Energy (doeb.go.th) *Department of Energy Business Ministry of Energy - Department of Energy Business, Ministry of Energy (doeb.go.th)*

SECTOR – NFR Code	ACTIVITY DATA		EF	REPARTITION KEYS	SOURCES
2 INDUSTRIAL PROCESSES	**List of factories in Chiang Mai-that are permitted to operate as of the end of 2022.**				• **Department of Industrial Works, Ministry of Industry. *https://www.diw.go.th***
	CHIANG MAI	NATIONAL			
2A5a Quarrying and mining	Production of minerals in Chiang Mai province.		EMEP/EEA guidebook 2023		• Department of Primary Industry and Mines, Ministry of Industry
2A5b Construction and demolition	Area of building construction by type of building in Northern region.		EMEP/EEA guidebook 2023	Population in Chiang Mai province vs population in Northern Region	• National Statistics from the Ministry of Industry.
2B Chemical Products	Lack of data.				Not estimated
2C Metal Products	Lack of data.				Not estimated
2D Solvent and Other Product Use	Population in Chiang Mai	2D3a: Detergent consumption in peri-urban Area of Bangkok (survey) - Jiawkok et al. 2012 2D3d: research study by Frost and Sullivan, 2017 in paint and coating consumption per capita. 2D3i: research study on adhesives in Thailand (Motor Intelligence, 2021)	EMEP/EEA 2019	Population	• Jiawkok et al. 2012 • Frost and Sullivan, 2017 • Motor Intelligence, 2021 • EMEP/EEA air pollutant emission inventory Guidebook 2019. 2.D.3.a Domestic solvent use including fungicides *2.D.3.a Domestic solvent use including fungicides 2019 — European Environment Agency (europa.eu)*

SECTOR – NFR Code	ACTIVITY DATA		EF	REPARTITION KEYS	SOURCES
3 AGRICULTURE					
	CHIANG MAI	NATIONAL			
3A Enteric fermentation	Livestock population statistics Milk yield from dairy cows		IPCC guidelines 2019		• Statistics from the Department of Livestock Development on animal numbers: NSO – per province data (2012-2022) from the Ministry of Agriculture and Livestock Development *Sector 11 Agriculture Statistics*. • Milk yield from dairy cows from FAOSTAT statistics • Fat content of milk from Wongpom et al., 2017
3B Manure management	Livestock population statistics		IPCC guidelines 2019 EMEP/EEA 2019		• Statistics from the Department of Livestock Development on animal numbers
3C Rice cultivation (CH_4)	Planted and harvested Area		IPCC guidelines 2019		• NSO – Data from the Ministry of Agriculture (*http://statbbi.nso.go.th/staticreport/page/sector/en/11.aspx*): Area, Production and Yield for rice (2012-2022)
3D Agricultural Soils	Livestock population statistics Planted and harvested Area	Nitrogen input in soils by type: animal manure, chemical fertilizer, crop residues, etc.)	IPCC guidelines 2019 EMEP/EEA 2019		• NSO – Data from the Ministry of Agriculture and Livestock Development (*http://statbbi.nso.go.th/staticreport/page/sector/en/11.aspx*): Area, Production and Yield for rice (2012-2022), maize (2012-2021), Cassava (2014-2023) and Pineapple (2013-2023). • NSO – per province data (2012-2022) from the Ministry of Agriculture and Livestock Development *Sector 11 Agriculture Statistics*. • 2013 Agricultural census Northern Region (Fertilizer and Pesticide use) *2013 Agricultural census Northern Region* • Agricultural production data: Office of Agricultural Economics *https://www-oae-go-th* (Agricultural economic data/ Agricultural production data)

SECTOR – NFR Code	ACTIVITY DATA		EF	REPARTITION KEYS	SOURCES
3 AGRICULTURE					
3F Field burning of Agricultural Residues	Agricultural surfaces, Production data: Based on 3D Agricultural soils. Estimation of residues available for burning based on IPCC 2019 methodology.		EMEP/EEA 2023 IPCC guidelines 2029 Phairuang et al., 2017		• NSO – Data from the Ministry of Agriculture and Livestock Development (*http://statbbi.nso.go.th/staticreport/page/sector/en/11.aspx*): Area, Production and Yield for rice (2012-2022), maize (2012-2021), Cassava (2014-2023) and Pineapple (2013-2023). • NSO – per province data (2012-2022) from the Ministry of Agriculture and Livestock Development *Sector 11 Agriculture Statistics*. • Agricultural production data: Office of Agricultural Economics *https://www-oae-go-th* (Agricultural economic data/ Agricultural production data)
3H CO_2 from Urea application	Based on 3D Agricultural soils.	Nitrogen input in soil.	IPCC 2006 guidelines		• NSO – Data from the Ministry of Agriculture and Livestock Development (*http://statbbi.nso.go.th/staticreport/page/sector/en/11.aspx*): Area, Production and Yield for rice (2012-2022), maize (2012-2021), Cassava (2014-2023) and Pineapple (2013-2023). • NSO – per province data (2012-2022) from the Ministry of Agriculture and Livestock Development *Sector 11 Agriculture Statistics*. • Agricultural production data: Office of Agricultural Economics *https://www-oae-go-th* (Agricultural economic data/ Agricultural production data) • 2013 Agricultural census Northern Region (Fertilizer and Pesticide use) *2013 Agricultural census Northern Region*

SECTOR – NFR Code	ACTIVITY DATA		EF	REPARTITION KEYS	SOURCES
5 WASTE					
	CHIANG MAI	NATIONAL			
5 Waste	• Amount of waste generated • Amount of waste collected • Amount of waste treated • Composition of waste • Provincial population • Number of corpses incinerated • Chiang Mai landfills	Protein supply quantity	ABC EIM EMEP/EEA 2023 IPCC GL - 5th volume - Waste Sector	Population	• NSO, Pollution Control Department, Ministry of Natural Resource and Environment, Quantity of solid waste by region and province, (2012-2021) *http://statbbi.nso.go.th/staticreport/page/sector/en/21.aspx* • Assessment of Air Pollution from Household Solid Waste Open Burning in Thailand, Pansuk et al. (2018) • Action Plan on Plastic Waste Management Phase II (2023-2027) - Ministry of Natural Resources and Environment • FAOSTAT Database *https://www.fao.org/faostat/en/#data* • Note on the statistics of cremations - The Cremation Society – Thailand *https://www.cremation.org.uk/thailand-2017* • Degree of use of the treatment system or discharge pathway for wastewater - United Nation Water *https://www.sdg6data.org/en*

SECTOR – NFR Code	ACTIVITY DATA		EF	REPARTITION KEYS	SOURCE
11 NATURAL SOURCES	**Forest and other vegetation fires (11B)**				
	CHIANG MAI	NATIONAL			
11 Natural sources and Forestry	Forest and soil surfaces Amount of biomass produced for residual biomass burnt assessment Area of agricultural and forest fire		AIT – Emissions inventory Bangkok, 2019		• NSO, The Royal Forestry Department, Ministry of Natural Resources and Environment – Forest Area by province (2014-2021) *http://statbbi.nso.go.th/staticreport/page/sector/en/21.aspx* • Kim Oanh et al. (2020). The study of source of $PM_{2.5}$ and precursors of secondary $PM_{2.5}$ in Bangkok Metropolitan Region (2019) – Appendix 5. • MODIS active fire and burned area products *https://modis-fire.umd.edu/index.html* • NOAA, Visible Infrared Imaging Radiometer Suite (VIIRS) *https://www.nesdis.noaa.gov/our-satellites/currently-flying/joint-polar-satellite-system/visible-infrared-imaging-radiometer-suite-viirs*

2.3 KEY CATEGORIES FOR THE CHIANG MAI EMISSIONS INVENTORY (2022)

A key category analysis of the Chiang Mai inventory is carried out according to the Approach 1 method described in the EMEP/EEA Guidebook (EMEP/EEA, 2019). According to this guidebook a key category is defined as an emission category that has a significant influence on a country's inventory in terms of the absolute level in emissions. Key categories are those which, when summed together in descending order of magnitude, add up to over 80% of the total emissions.

EMISSIONS HAVE BEEN DISAGGREGATED INTO THE CATEGORIES REPORTED IN THE NATIONAL FORMAT REPORT (NFR); DETAILS VARY ACCORDING TO DIFFERENT POLLUTANTS TO REFLECT SPECIFIC LOCAL CIRCUMSTANCES. RESULTS ARE REPORTED IN

Table 2 for the year 2022 by pollutant.

Energy is the main source of SOx, NOx, CO and CO_2. Open burning of forest, agricultural residues and waste are the main sources of particles. Black carbon (BC) is emitted in a large part by the energy sector, especially road transport, and open-burning, especially waste.

Agriculture is a large source of air pollutants and GHGs, especially NH_3, N_2O and CH_4.

TABLE 2: KEY CATEGORIES FOR THE CHIANG MAI EMISSIONS INVENTORY 2022 (AIR POLLUTANTS AND GHG)

Key categories in 2022 for AIR POLLUTANTS							Total (%)
SOx	1A4b Residential (41.5%)	1A2 Manufacturing industries (28.7%)	1A3b Road Transport (10.4%)				80,6%
NOx	1A3b Road Transport (72.7 %)	1A4cii Off-road vehicles (7.7%)					80.5%
NH3	3B1 Manure management (45.5%)	3D Agricultural soils (45.4%)					90.9%
NMVOC	2D3d Paint and Coating Application (30.5%)	1A3b Transport (25.6%)	1A4b Residential (9.8%)	2D3i Other solvent use (8.4%)	5C2 Open-burning Waste (5.1%)	11B Forest fire (3.1%)	82.6%
CO	1A3b Road Transport (40.1%)	1A1b Residential (21.6%)	11B Biomass burning - forest fires (13.6%)	3F ARB (10.1%)			85.4%
PM10	3F ARB (23.3%)	1A1b Residential (18.2%)	11B Biomass burning - forest fires (17.1%)	1A3b Road Transport (14.4%)	3D Agricultural soils (7.1%)	5C2 Open-burning Waste (6.6%)	86.5%
PM2.5	3F ARB (29.6%)	1A1b Residential (24.6%)	1A3b Road Transport (15.4%)	11B Biomass burning - forest fires (15.0%)			84.6%
BC	1A3b Road Transport (42.0%)	5C2 Open-burning of wastes (18.4%)	1A1b Residential (11.1%)	3F ARB (10.5%)			81.9%

1 Energy	2 IPPU - Solvent and product use	5 Waste
2 IPPU - Industry	3 Agriculture	11 Forest fires

Key categories in 2022 for GHGs							Total (%)
CO2	1A3b Road Transport (67.1%)	1A1b Residential (11.9%)	3F ARB (5.1%)				84,0%
CH4	3C Rice (34.0%)	3A Enteric fermentation (23.2%)	5A Waste Landfill (20.3%)	5D1 Wastewater (10.9%)			80.5%
N2O	3D Agricultural soils (45.4%)	3B1 Manure management (45.5%)	1A3b Road transport (84.0%)				90.9%

1 Energy	2 IPPU - Solvent and product use	5 Waste
2 IPPU - Industry	3 Agriculture	11 Forest fires

2.4 QA/QC AND VERIFICATION METHODS

For quality assurance and quality control purposes, the datasheets were cross validated internally. In addition, the inventory results were compared with existing inventories, the Thailand inventory disaggregated in 77 provinces (Figure 2), to ensure that orders of magnitude were consistent. Finally, an external validation by AIT was also achieved at the end of the project.

The results from Chiang Mai inventory are consistent with the assessment of emissions from the National inventory. Differences are nonetheless apparent, which can easily be explained as the calculation of Chiang Mai's emissions from the national inventory consists of a combined top-down and bottom-up disaggregation of national emissions, whereas in this study, emissions were calculated specifically for the province, using a bottom-up approach wherever possible.

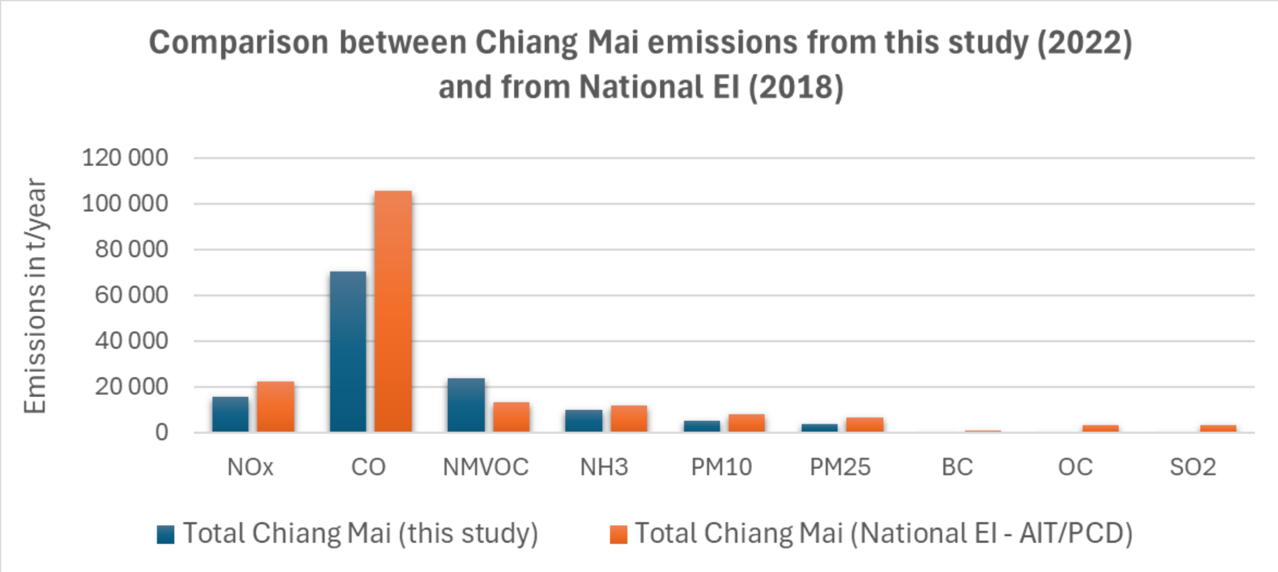


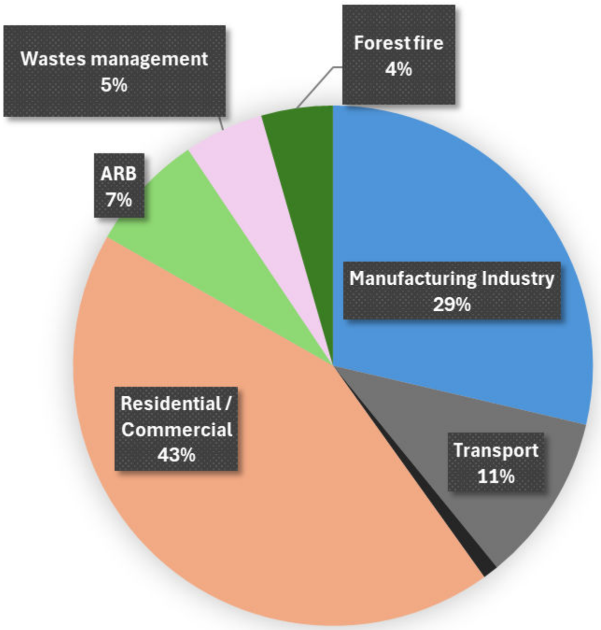
FIGURE 2: COMPARISON BETWEEN CHIANG MAI EMISSIONS (THIS STUDY) AND CHIANG MAI EMISSIONS FROM NATIONAL EI (PCD/AIT)

3 KEY CHARACTERISTICS

3.1 ACIDIFICATION, EUTROPHICATION AND PHOTOCHEMICAL POLLUTION

3.1.1 Sulphur dioxide (SO_2)

In Chiang Mai, SO_2 is mainly produced by the combustion of sulfur-containing fossil fuels: Manufacturing industry and residential/commercial and to a lesser extent transport, forest fires, agricultural residue burning and waste management, mainly waste open-burning (Figure 3).



Sector (t/year)	2022
Manufacturing Industry	242
Transport	89
Non-road mobile machinery	8
Residential and commercial	365
Agricultural residue burning (ARB)	62
Waste management	42
Forest fire	38
Total	845

FIGURE 3: MAIN SO_2 EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN TONNES/YEAR

Figure 4 illustrates the spatial distribution (grid size = 1km^2) of total sulfur oxide emissions from all source sectors in Chiang Mai province. As the main sources of SOx are anthropogenic, the highest emissions were recorded in urban areas and along the province's main roads.

It is essential to note that fuel combustion in small installations, such as in ceramic craft villages, might not be categorized under the industrial sector but instead under residential emissions or could even be omitted from the total emissions inventory (EI) altogether. This could result in an underestimation of SOx emissions from the industrial sector and an overestimation of emissions from the residential sector. Field surveys are necessary to more accurately account for emissions from craft villages and the industrial sector.

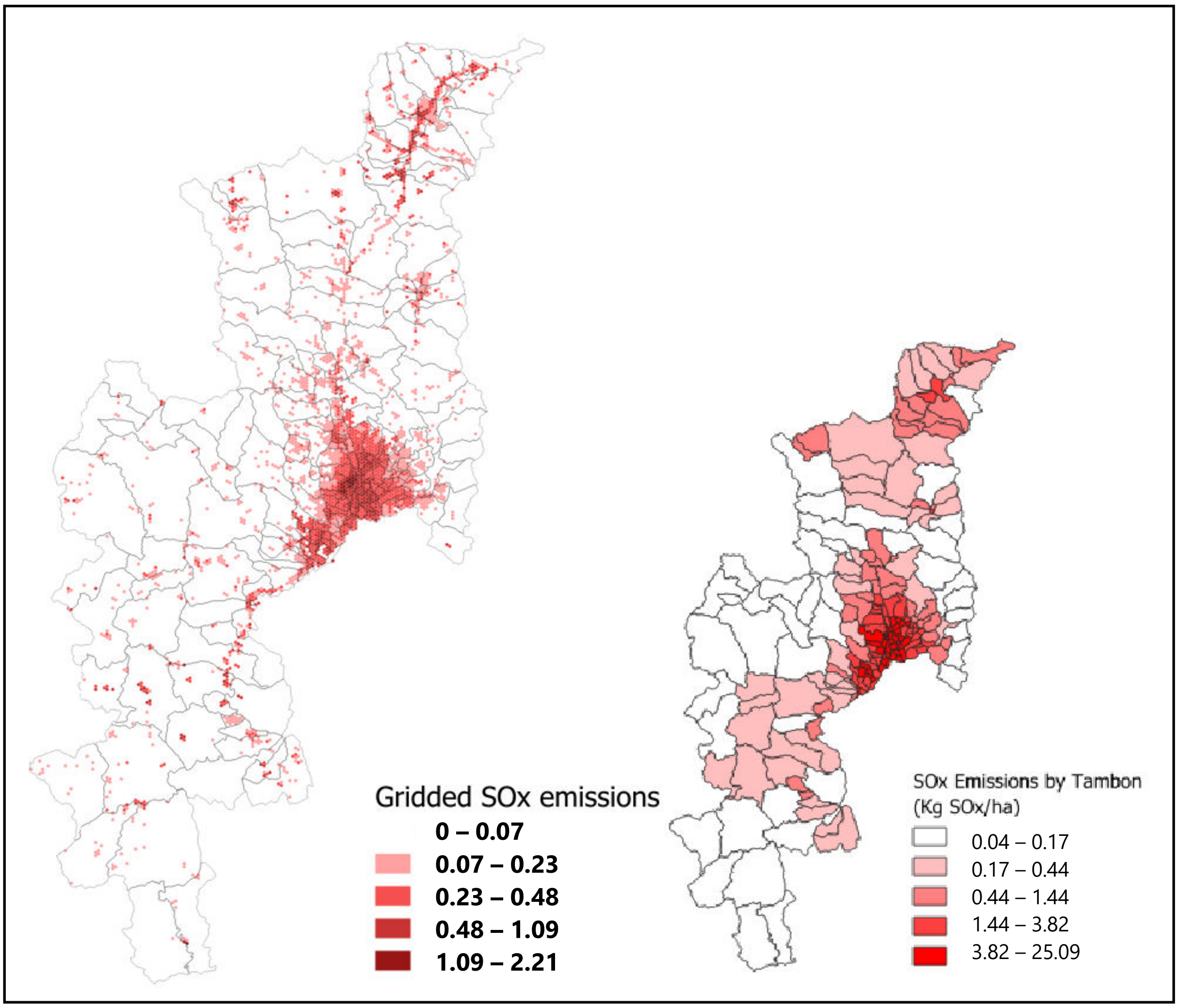


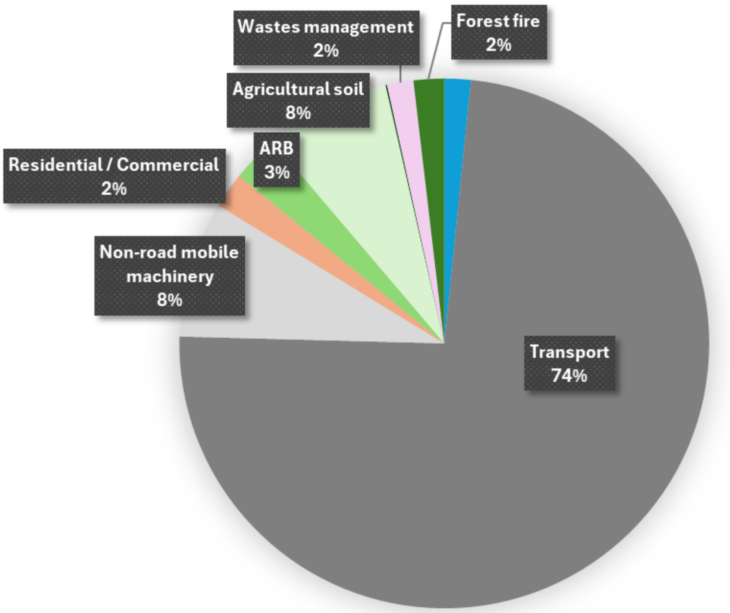
FIGURE 4: SPATIAL DISTRIBUTION OF TOTAL SULPHUR OXIDES (SOX) EMISSIONS IN CHIANG MAI

2.1.2 Nitrogen oxide (NOx)

NOx emissions are emitted during the combustion of fossil fuels or biomass in road transport, off-road vehicles and other machinery, the residential/commercial sector, and to a lesser extent, industry. The Energy sector is thus responsible for the majority (86%) of NOx emissions in 2022 (Figure 5). NOx is also emitted in agriculture through the biological processes of nitrification/denitrification in soils, following the application of mineral or organic nitrogen fertilizers; and, in small quantities, in livestock areas, at building/storage stations, from the nitrogen contained in animal manure.

Some industrial processes also emit NOx (nitric acid production, fertilizer manufacture, etc.) which could not be determined here due to the lack of data on industrial production. Nevertheless, we consider industry sector to be minor in Chiang Mai province in terms of NOx.

It is essential to note that fuel combustion in small installations, such as in ceramic craft villages, might not be categorized under the industrial sector but instead under residential emissions or could even be omitted from the total emissions inventory (EI) altogether. This could result in an underestimation of NOx emissions from the industrial sector and an overestimation of emissions from the residential sector. Field surveys are necessary to more accurately account for emissions from craft villages and the industrial sector.



Sector (t/year)	2022
Manufacturing Industry	253
Transport	11,602
Non-road mobile machinery	1,308
Residential/Commercial	340
ARB	454
Agricultural soil	1,203
Manure management	14
Cremation	11
Waste – Open burning	242
Forest fires	293
Total	15,718

FIGURE 5: MAIN NOx EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN TONNES/YEAR

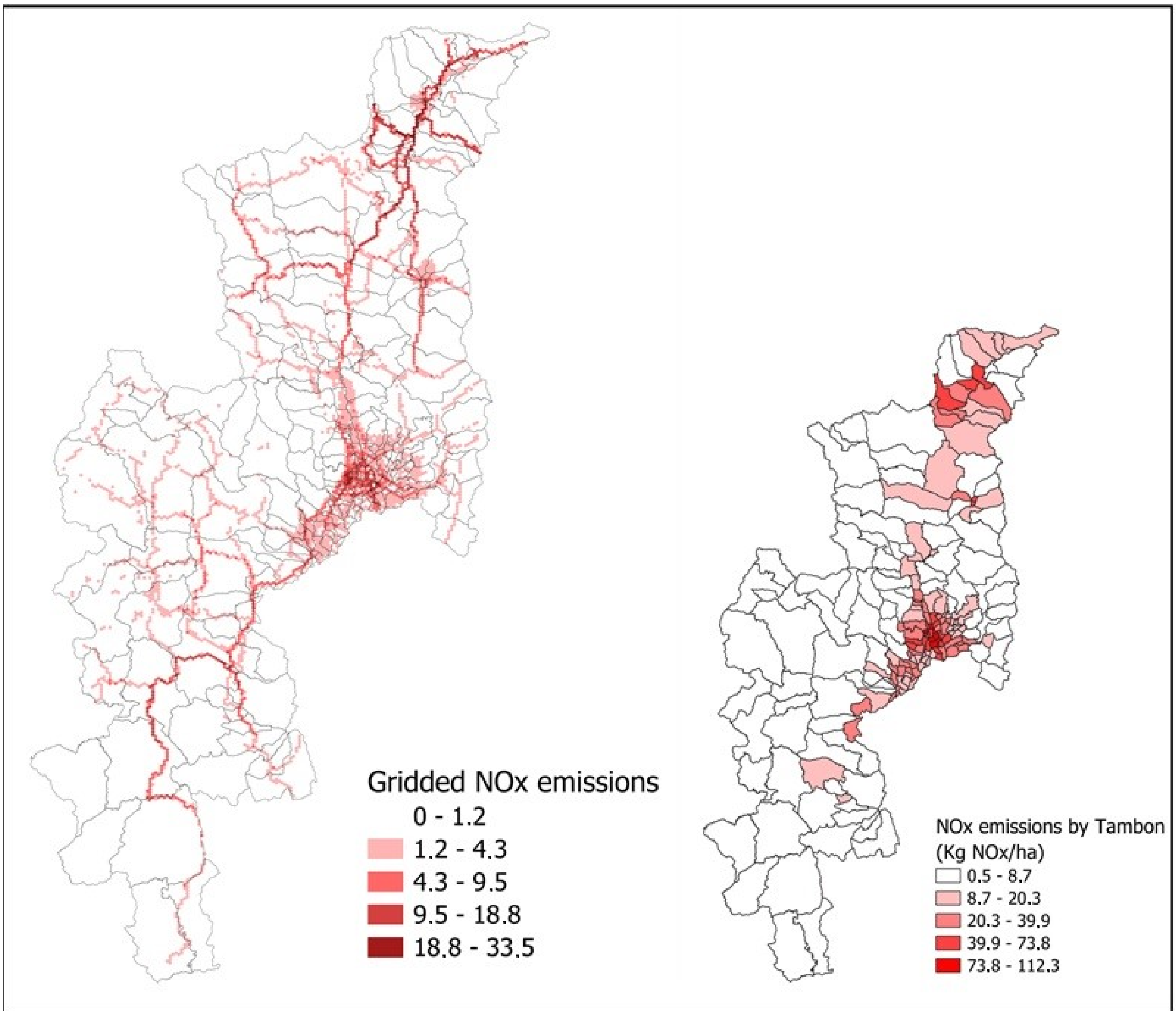


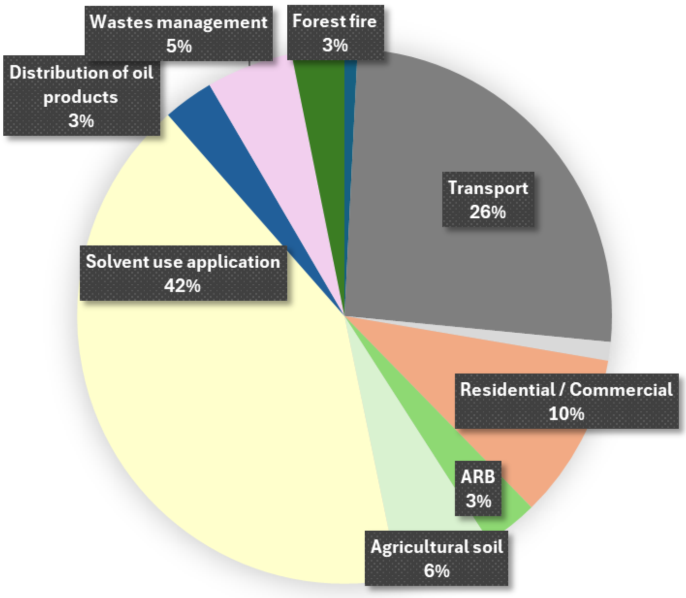
FIGURE 6: SPATIAL DISTRIBUTION OF TOTAL NITROGEN OXIDES (NOX) EMISSIONS IN CHIANG MAI

Figure 6 presents the spatial distribution (grid size = 1 km^2) of total NOx emissions in Chiang Mai Province. Emissions are maximal in the center city and along the roads as road transport is the main source of NOx in the Province.

2.1.3 Non-methane volatile organic compounds (NMVOCs)

NMVOCs are emitted during combustion, evaporation, and chemical or biological reactions. Figure 7 shows the main contributing sectors, which are listed below:

- Industrial processes (NFR 2): in connection with the use of solvents (base chemicals, fine chemicals, metal degreasing, application of paints, inks, glues, etc.) and the production of alcoholic beverages and bread,
- Energy (NFR 1): related to oil refining, industrial combustion plants and domestic wood-burning equipment, as well as transport and fuel distribution,
- Forest fire and waste management, especially open burning of waste, are also significant sources of NMVOCs; and
- Agriculture (NFR 3): linked to livestock manure management, silage warehouses (fermentation of fodder), but also the biological functioning of crops (emissions attracting pollinating insects, for example).



Sector (t/year)	2022
Manufacturing Industry	188
Transport	6,177
Non-road mobile machinery	270
Residential/Commercial	2,398
ARB	778
Agricultural soil	1,399
Solvent use application	10,014
Distribution of oil products	731
Waste management	1,257
Forest fires	762
Total	23,974

FIGURE 7: MAIN NMVOCS EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND T/YEAR

It is essential to note that fuel combustion in small installations, such as in ceramic craft villages, might not be categorized under the industrial sector but instead under residential emissions or could even be omitted from the total emissions inventory (EI) altogether. This could result in an underestimation of NMVOCs emissions from the industrial sector and an overestimation of emissions from the residential sector. Field surveys are necessary to more accurately account for emissions from craft villages and the industrial sector.

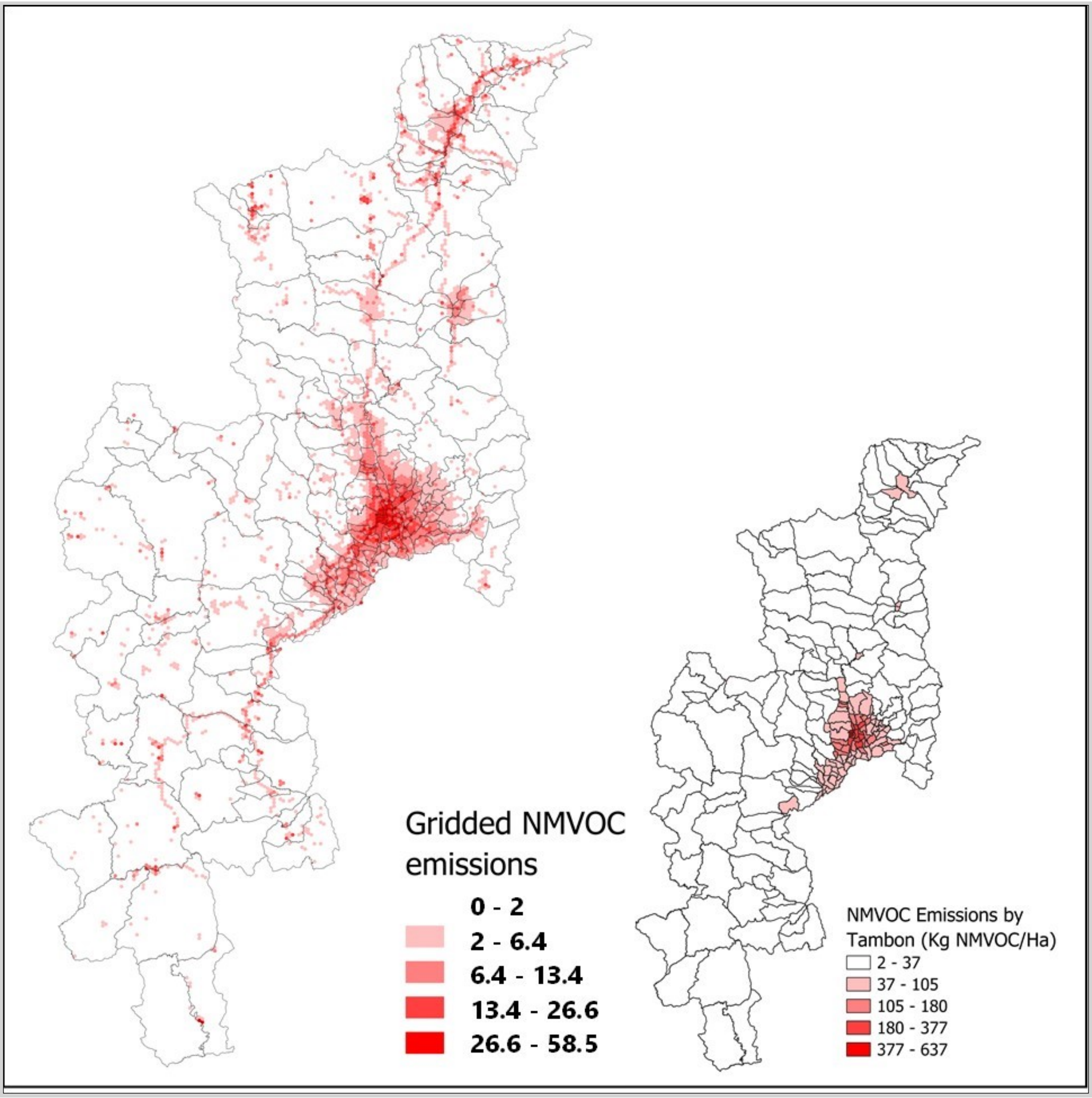


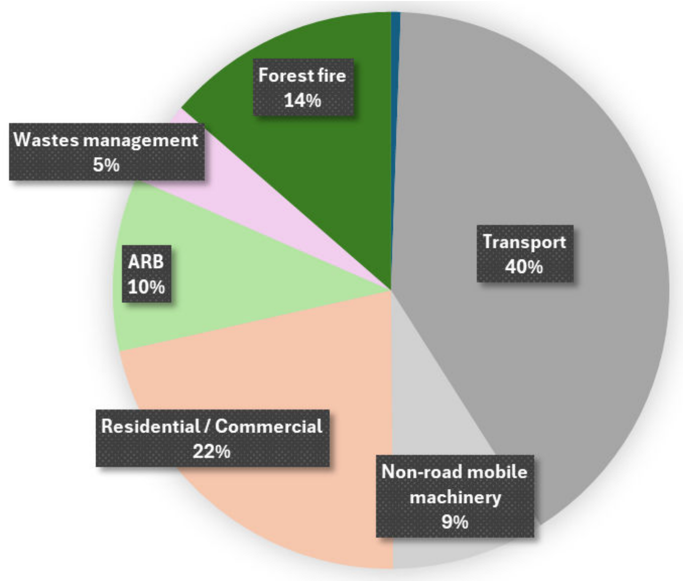
FIGURE 8: SPATIAL DISTRIBUTION OF TOTAL NON-METHANE VOLATILE ORGANIC COMPOUNDS (NMVOCS) EMISSIONS IN CHIANG MAI.

Figure 8 illustrates the spatial distribution (grid size = 1 km^2) of non-methane volatile organic compound (NMVOC) emissions in Chiang Mai province. NMVOC emissions are mainly due to anthropogenic sources, with the highest emissions in urban areas.

2.1.4 Carbon monoxide (CO)

As shown in Figure 9, the major contributing sectors in 2022 are:

- Energy (NFR 1): related to the incomplete combustion of any fossil fuel or biomass (gas, coal, fuel oil, wood), found in road traffic (exhaust gases) and in residential/commercial combustion (wood in particular); Energy sector is responsible for 71% of total CO emissions.
- Not controlled combustion from forest fires (14%), Agricultural residue burning (10%) and waste open-burning (5%).

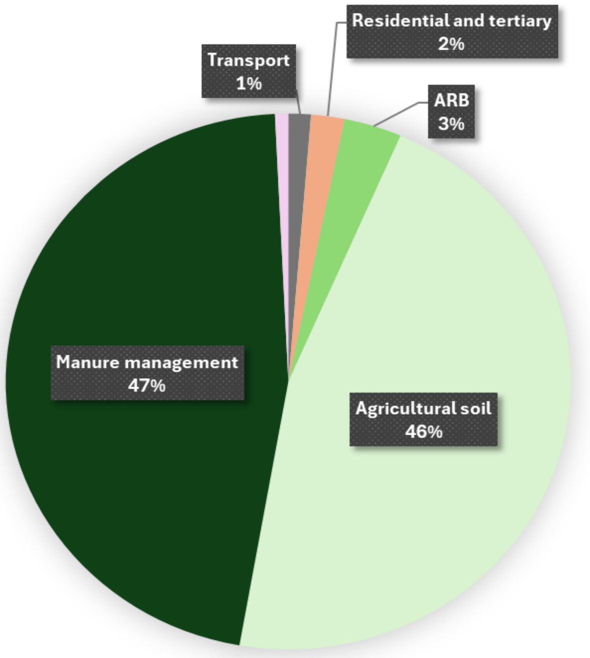


Sector (t/year)	2022
Manufacturing Industry	396
Transport	28,494
Non-road mobile machinery	6,272
Residential/Commercial	15,230
ARB	7,113
Waste management	3,393
Forest fires	9,594
Total	70,492

FIGURE 9: MAIN CO EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN T/YEAR

2.1.5 Ammonia (NH_3)

The main emitting sector is agriculture (NFR 3), due both to the management of animal manure (NFR 3B) and agricultural soils (NFR 3D), which respectively account for around 45% and 48% of the sector's emissions in 2022 (Figure 10). Energy (NFR 1) accounts for 3% of emissions in 2022, mainly due to NFR 1A4 (including residential/tertiary) in connection with biomass combustion. Agricultural Residue burning (3%) and waste management (1%) account for the remaining emissions.



Sector (t/year)	2022
Transport	128
Residential/Commercial	192
ARB	331
Agricultural soil	4,638
Manure management	4,658
Forest fire	204
Waste management	76
Total	10,023

FIGURE 10: MAIN NH_3 EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN T/YEAR

Figure 11 represents the spatial distribution (grid size = 1 km^2) of total NH_3 emissions in Chiang Mai province. As this pollutant is mainly emitted by agriculture, the highest emissions occur in rural areas with high agricultural activities.

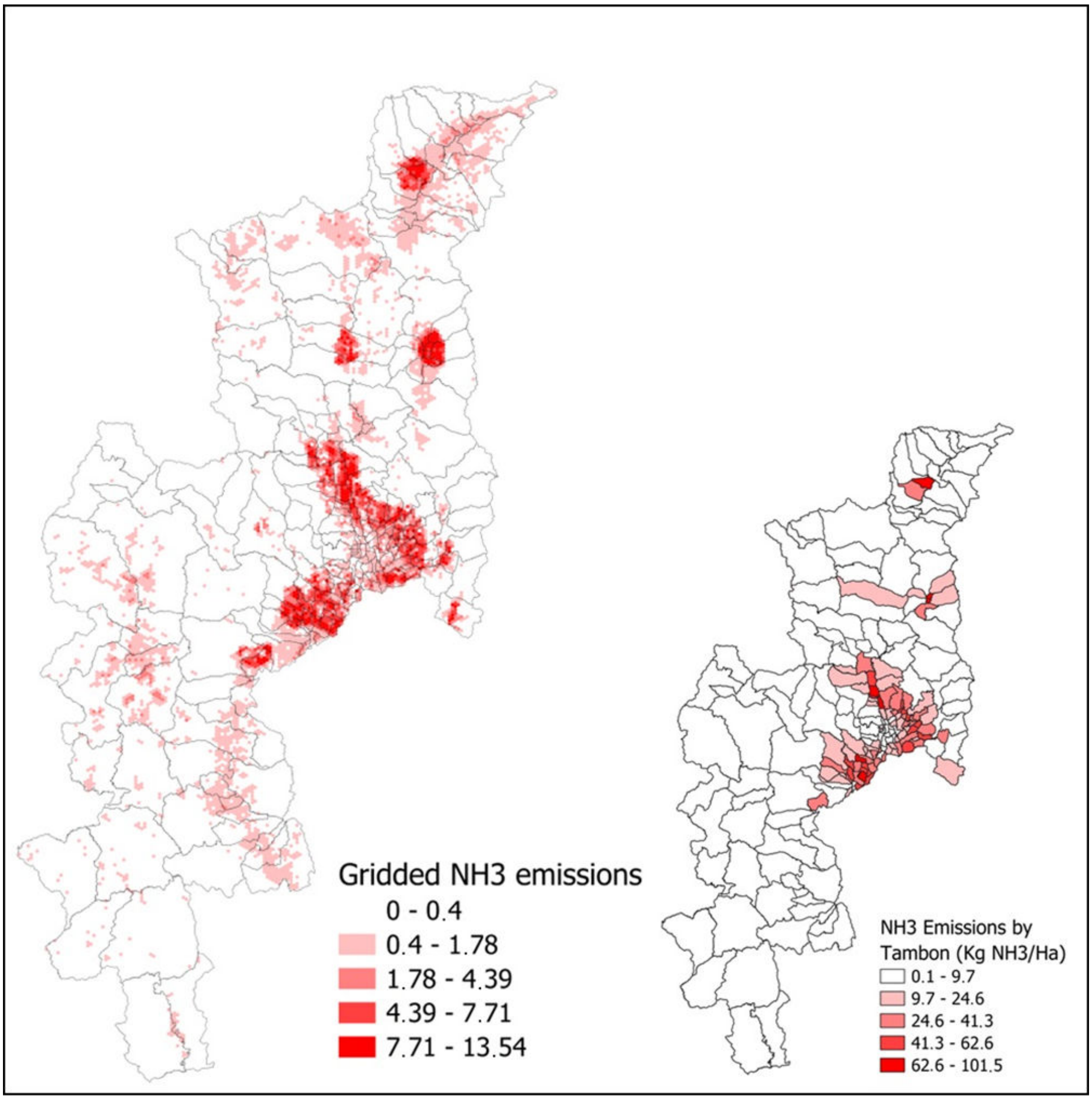


FIGURE 11: SPATIAL DISTRIBUTION OF TOTAL AMMONIA (NH_3) EMISSIONS IN CHIANG MAI

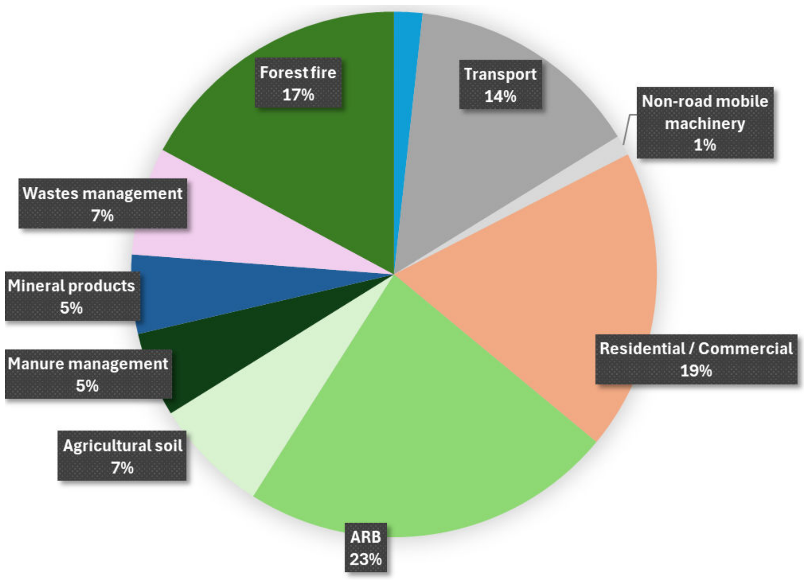
3.2 PARTICULATE MATTER

In 2022, the main emitting sectors are not-controlled fire, forest fires and agricultural residue burning, and energy sector, particularly road transport and residential sectors. Together, these four sectors account for almost 80% of PM_{10} emissions (Figure 12) and 85% of $PM_{2.5}$ (Figure 14). Agriculture, mainly due to crop ploughing, and manure management, industrial processes linked to building and construction activities, as well as rock extraction in quarries (Mineral products) and waste management, especially open-burning of waste, are also significant sources of particles.

Residential/commercial sector, due to wood combustion in domestic equipment, is a large source of PM emissions as it represents 19% of total PM_{10} and 25% of total $PM_{2.5}$ emissions (Figure 12 and Figure 14). However, it is essential to note that fuel combustion in small installations, such as in ceramic craft villages, might not be categorized under the industrial sector but instead under residential emissions or could even be omitted from the total emissions inventory (EI) altogether. This could result in an underestimation of particles emissions from the industrial sector and an overestimation of emissions from the residential sector. Field surveys are necessary to more accurately account for emissions from craft villages and the industrial sector.

The sources of particulate matter are diverse: there are natural sources such as forest fires, agricultural sources such as the burning of agricultural residues, and sources due to the combustion of fossil fuels such as transport and the residential sector. As a result, PM emissions are distributed throughout the province, in both the most densely urbanized and rural areas (Figure 13 and Figure 15).

3.2.1 Particles PM_{10}



Sector (t/year)	2022
Manufacturing Industry	96
Transport	794
Non-road mobile machinery	68
Residential/Commercial	1,018
ARB	1,236
Agricultural soil	391
Manure management	287
Mineral products	266
Waste management	365
Forest fire	941
Total	5,487

FIGURE 12: MAIN PM_{10} EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN T/YEAR

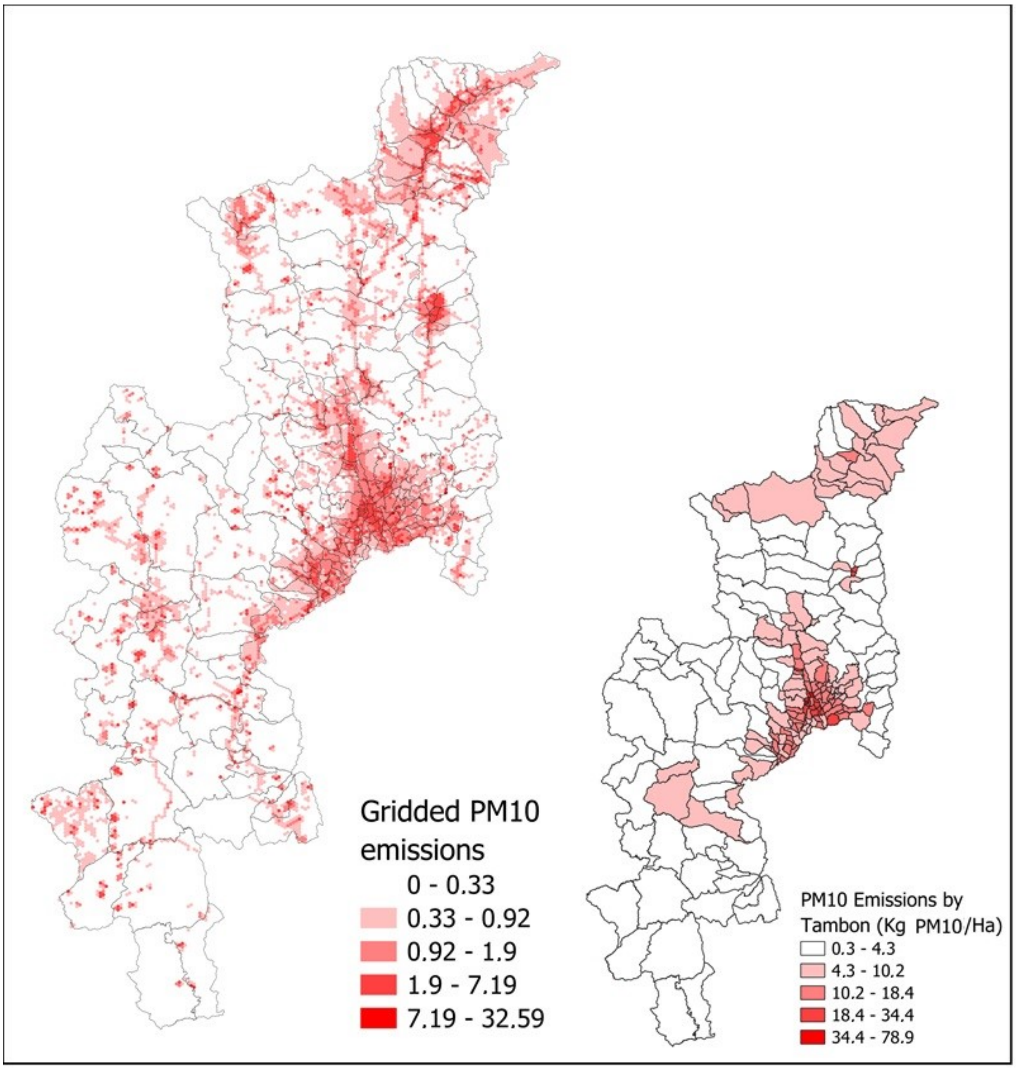
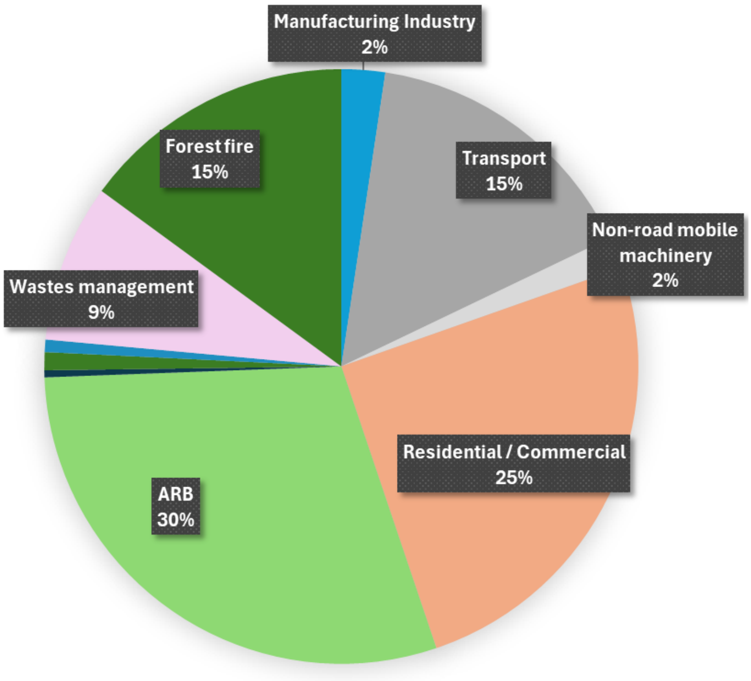


FIGURE 13: SPATIAL DISTRIBUTION OF TOTAL PARTICLES (PM_{10}) EMISSIONS IN CHIANG MAI

3.2.2 Particles $PM_{2.5}$



Sector (t/year)	2022
Manufacturing Industry	93
Transport	611
Non-road mobile machinery	68
Residential/Commercial	992
ARB	1,166
Agricultural soil	15
Manure management	38
Mineral products	27
Wastes management	339
Forest fire	589
Total	3,938

FIGURE 14: MAIN $PM_{2.5}$ EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN T/YEAR

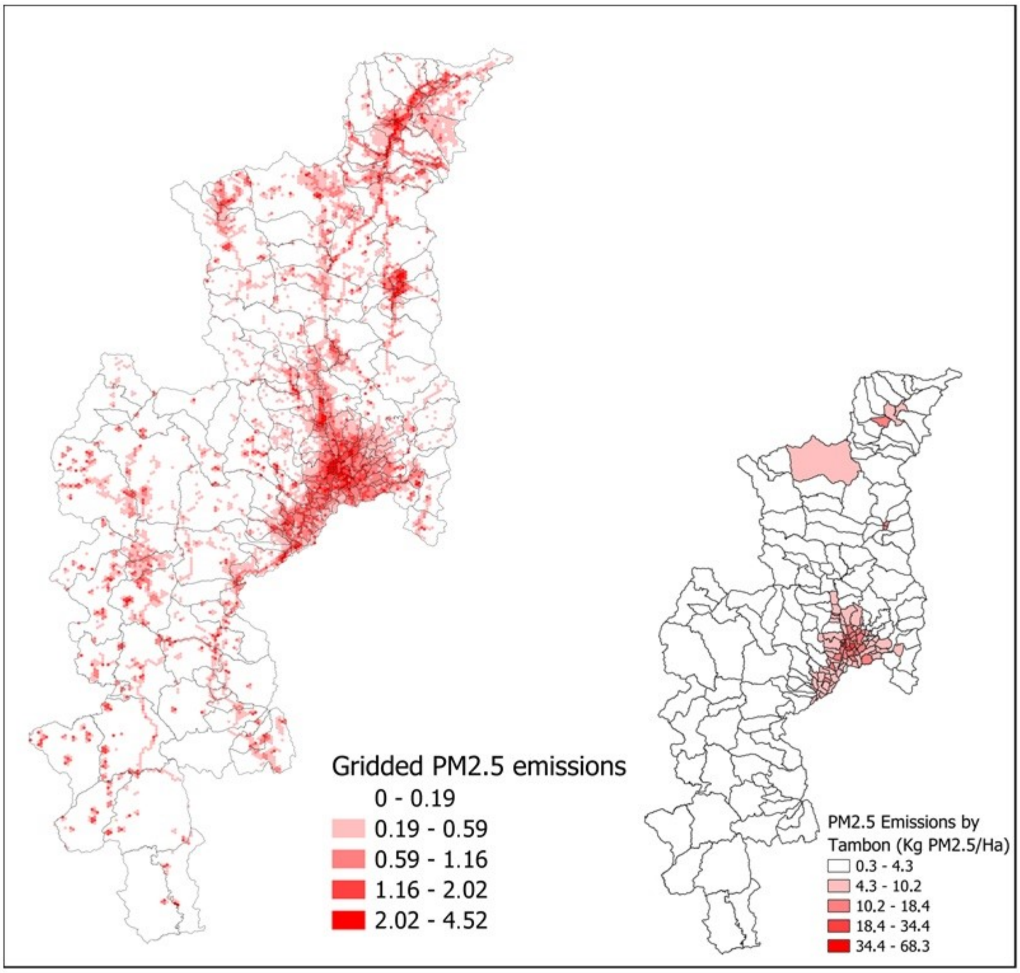
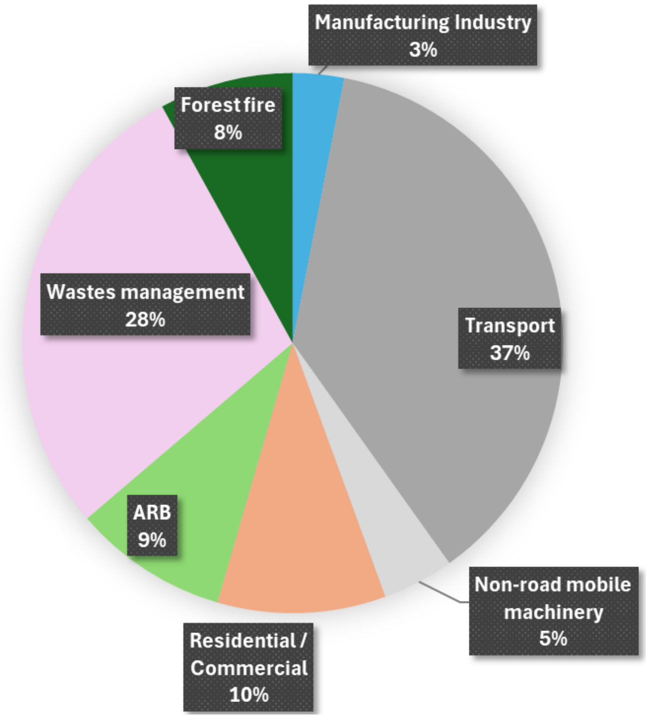


FIGURE 15: SPATIAL DISTRIBUTION OF TOTAL PARTICLES ($PM_{2.5}$) EMISSIONS IN CHIANG MAI

3.2.3 Black Carbon

The main source of BC in Chiang Mai is road transport (42%), followed by waste open burning (18%), residential / commercial sector (11%), agricultural residue burning (11%) and forest fire (9%). Non-road mobile machinery (5%) and Manufacturing industry (4%) are also minor sources of BC (Figure 16).



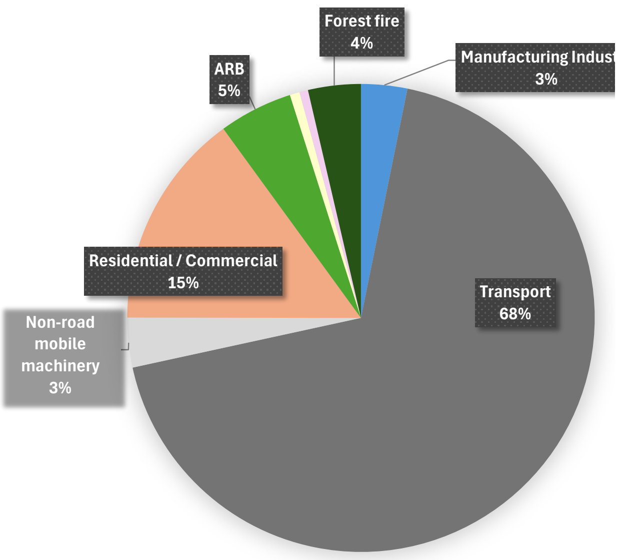
Sector (t/year)	2022
Manufacturing Industry	27
Transport	326
Non-road mobile machinery	38
Residential/Commercial	88
ARB	81
Waste management (open-burning)	142
Forest fire	71
Total	773

FIGURE 16: EMISSIONS OF BC BY MAIN SECTORS IN CHIANG MAI PROVINCE IN % AND TONNES/YEAR

3.3 GHGS

3.3.1 CO_2

The main source of CO_2 is transport (NFR 1A3), with 68% of CO_2 emissions. The other emitters of CO_2 are residential and commercial sector (NFR 1A4) (15%), Agricultural Residue Burning (NFR 3F) (5%), forest fire (NFR 11B) (4%), non-road mobile machinery (NFR 1A4cii) (3%) and manufacturing industry (1A2) (3%) (Figure 17).



Sector (t/year)	2022
Manufacturing Industry	130,578
Transport	2,798,643
Non-road mobile machinery	140,463
Residential/Commercial	611,750
ARB	208,905
Solvent use	27,764
Waste management	24,280
Forest fire	149,076
Total	4,091,458

FIGURE 17: EMISSIONS OF CO_2 BY MAIN SECTORS IN CHIANG MAI PROVINCE IN % AND TONNES/YEAR

Road transport is the main source of carbon dioxide emissions in Chiang Mai Province; thus, emissions are highest in urban areas on the main roads (Figure 18).

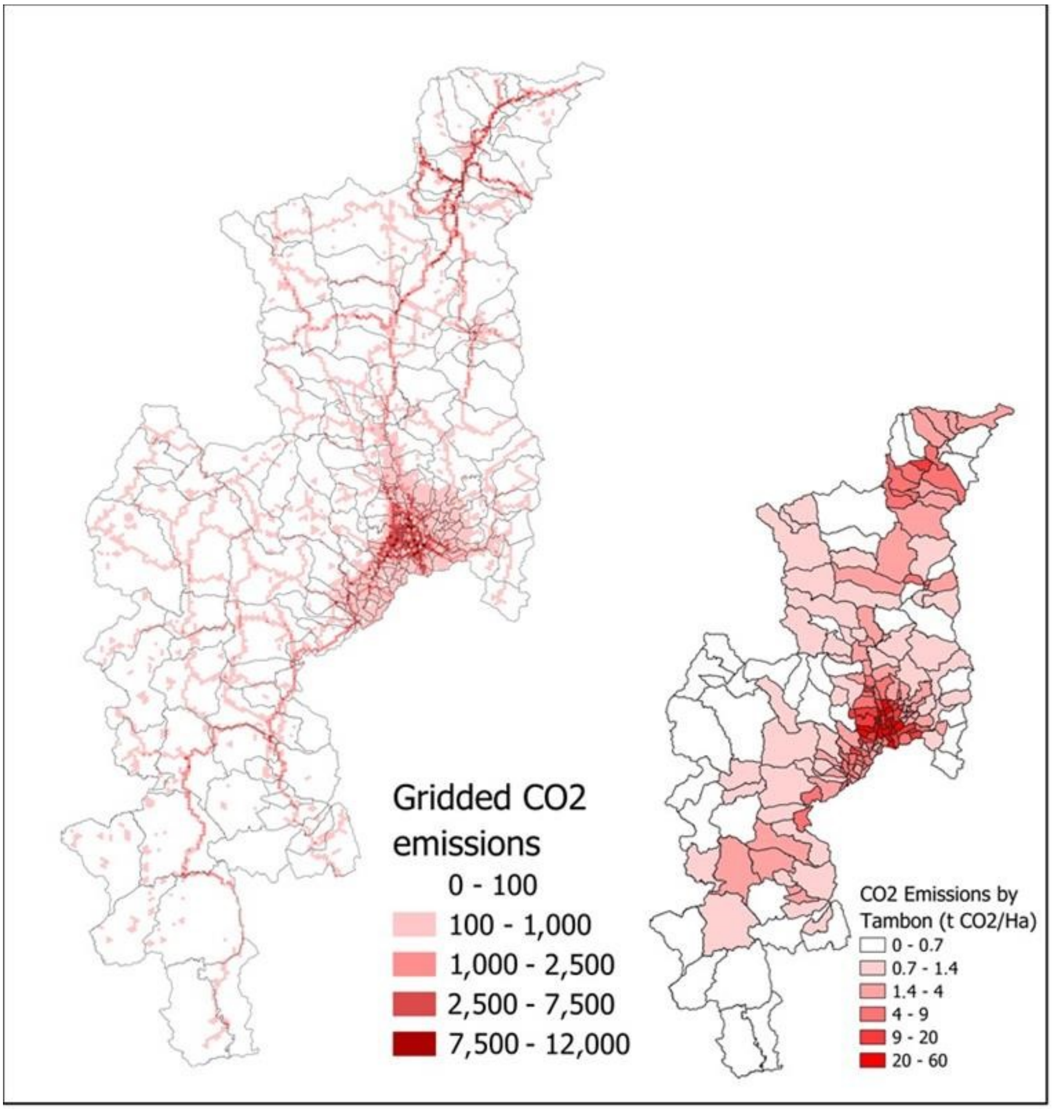
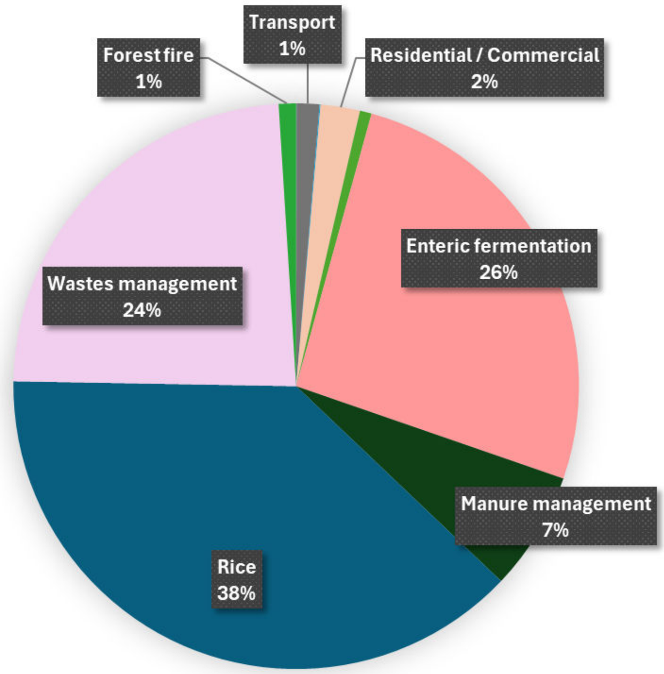


FIGURE 18: SPATIAL DISTRIBUTION OF TOTAL CARBON DIOXIDE (CO_2) EMISSIONS IN CHIANG MAI

3.3.2 Methane (CH_4)

The main source of methane is agriculture (71%): rice cultivation (NFR 3C) (38%), livestock enteric fermentation (NFR 3A) (26%), and livestock manure management (NFR 3B) (7%). Waste management (NFR 5) (23%), in particular landfilling (NFR 5A) (NFR 5D) and wastewater (NFR 5D), is also a major source of methane. Forest fires (NFR 11B) (2%), the residential and commercial sector (NFR 1A4) (2%), and transport (NFR 1A3) (1%) are minor sources of methane (Figure 19).



Sector (t/year)	2022
Manufacturing Industry	19
Transport	711
Non-road mobile machinery	33
Residential/Commercial	1,245
ARB	372
Enteric fermentation	14,389
Manure management	3,764
Rice	21,317
Waste management	13,137
Forest fire	547
Total	55,356

FIGURE 19: EMISSIONS OF CH_4 BY MAIN SECTORS IN CHIANG MAI PROVINCE IN % AND TONNES/YEAR

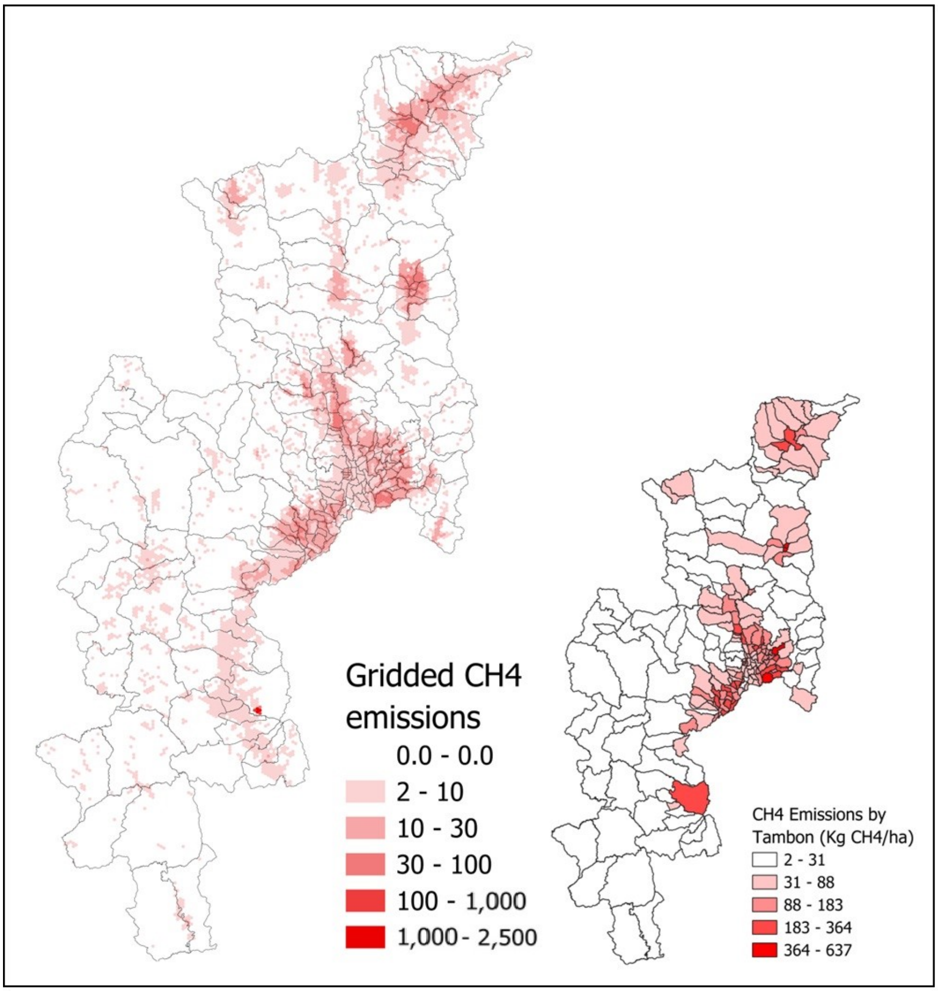


FIGURE 20: SPATIAL DISTRIBUTION OF TOTAL METHANE (CH4) EMISSIONS IN CHIANG MAI

Methane emissions are mainly due to agriculture and waste management and are therefore distributed throughout rural and urban areas (Figure 20).

4 ENERGY (NFR SECTOR 1)

4.1 OVERVIEW OF THE SECTOR

The energy sector includes emissions linked to energy consumption by the energy industries (energy producers: power stations, oil refineries, and the production of solid and gaseous fuels in particular), the manufacturing industries, transport, as well as energy consumption by the residential/tertiary sector and agriculture. There are also the fugitive emissions from the production of petroleum products and from the extraction and distribution of fuels (mines, natural gas transport networks, service stations, etc.).

- Electricity production (power plants and Industrial producers),
- Refineries (Combustion),
- Iron and steel industries (Combustion),
- Chemical and petrochemical industries (Combustion),
- Construction industries (roof tiles, bricks),
- Other industries (metal works factories, food, textiles, others),
- Road Transport,
- Railways,
- Aircraft,
- Other transport,
- Domestic cooking, heating, and lighting,
- Commercial cooking, heating, and lighting,
- Public Service,
- Forestry and Construction machinery; and
- Fugitive emissions are also reported under the energy sector as well as emissions from geothermal production.

The main information source for calculating emissions from the "Energy" sector is the **energy consumption information available from the National Energy Balance** (Department of Alternative Energy Development and Efficiency, Ministry of Energy of Thailand). At the provincial scale, less data is available regarding fuel/energy consumption. Thus, the National Energy Balance is used and extrapolated at the provincial scale using specific proxies (population in most of the cases).

4.2 ENERGY INDUSTRY (NFR 1A1)

This chapter deals with emissions from categories 1A1a Public electricity and heat production, 1A1b Petroleum refining, and 1A1c Manufacture of solid fuels and other energy industries.

4.2.1 Public Electricity and Heat Production (NFR 1A1a)

The consumption considered in sector 1A1a concerns the centralized production of electricity, the centralized production of heat, in particular district heating, and the incineration of household waste with energy recovery.

IN CHIANG MAI, CATEGORY 1A1A IS NOT REPRESENTED. THERE IS NO PUBLIC PRODUCTION OF ELECTRICITY AND HEAT FROM FOSSIL FUELS. THERE ARE 11 SMALL POWER PLANTS USING RENEWABLE ENERGIES (

Table 3) with no impact on air pollutants and GHGs emissions. This category is therefore not included in this inventory.

4.2.2 Refineries (1A1b)

In Chiang Mai, category 1A1b is not represented. There are no petroleum refining facilities in the province.

4.2.3 Manufacture of Solid Fuels and Other Energy Industries (1A1c)

Given the lack of data available for the industrial sector, all industrial emissions are covered in section 1A2 (Manufacturing Industries and Construction).

4.2.4 Recommendations for improvements

Category 1A1 is not a key sector in Chiang Mai province.

4.3 MANUFACTURING INDUSTRIES AND CONSTRUCTION (1A2)

4.3.1 Overview of the sector

THIS CHAPTER COVERS THE METHODS AND DATA USED TO ESTIMATE EMISSIONS ASSOCIATED WITH FUEL COMBUSTION IN MANUFACTURING INDUSTRIES AND CONSTRUCTION. THE COMBUSTION ACTIVITIES UNDERTAKEN IN MANUFACTURING INDUSTRIES GENERALLY PROVIDE PROCESS HEAT (DIRECTLY OR INDIRECTLY USUALLY VIA STREAM, WATER OR OIL), ELECTRICITY, OR THE FUEL MAY BE TRANSFORMED IN THE PRODUCTION ACTIVITY. THERE WERE 1,055 MANUFACTURING INDUSTRIES OF VARIOUS SIZES IN CHIANG MAI PROVINCE IN 2022. A LIST OF THESE INDUSTRIES IS AVAILABLE FROM DIW (DEPARTMENT OF INDUSTRIAL WORKS, MINISTRY OF INDUSTRY) AND IS SUMMARIZED IN

Table 3.

TABLE 3: INFORMATION ON MANUFACTURING INDUSTRIES IN CHIANG MAI PROVINCE – SOURCE: DIW.

Industry type	Activity	Number of factories	Number of workers	Horsepower (Hp)
1	The factory engages in the business of curing tea leaves or tobacco leaves	4	475	14,631.5
2	The factory engages in business related to one or more of the agricultural products	119	2,310	91,897.6
3	The factory engages in business related to gravel, sand or soil for use in the construction	101	673	49,949.3
4	The factory engages in animal related business which is not aquatic animals	31	558	17,687.7
5	Food beverages and tobacco	4	119	6,640.2
7	The factory engages in business related to oil from plants or animals or fats from animals	2	33	331.3
8	The factory engages in business related to vegetables, plants or fruits	41	4,029	111,857.9
9	The factory engages in business related to seeds or plant heads	63	472	18,632.7
10	The factory engages in business relating to food starches	13	546	7,774.5
12	The factory engages in the business of tea, coffee, cocoa, or chocolate	11	173	1,793.1
13	The factory engages in business related to ingredients or cooking ingredients	3	142	838.1
14	The factory engages in business about making ice or cutting, crushing or shredding ice	53	541	37,752.0
15	The factory engages in animal foods	8	69	3,951.9
16	Distillation or liquor mixing plant	1	126	12,826.1
19	The factory engages in business related to malt or beers	1	1	221.8
20	The factory engages in the business of drinking water. Non-alcoholic beverages, soft drinks or mineral water	10	657	19,430.8
22	The factory engages in business related to textiles, fibers, or fibers, not asbestos	6	143	13,391.2
23	The factory engages in business about textile products	3	531	298.8
25	A factory that produces mats or rugs by means of weaving, weaving, or tying which are not mats or rugs made of rubber or plastic or linoleum	2	65	138.3
28	The factory engages in apparel which is not shoes	18	2,315	2,006.2
32	Factory producing products or parts of products which is not clothing or shoes	1	70	10.8
34	The wood factory	32	904	11,664.5
35	Container manufacturing or utensils from bamboo, rattan, reed straw or water hyacinth	5	200	713.5
36	The factory engages in one of the products of wood or cork	19	684	3,002.4
37	The factory makes furniture or interior decorations from wood, glass, rubber, or other nonmetals, which is not furniture or interior decoration of extruded plastic and including parts of the said product	42	1,791	7,740.5
38	Pulp and paper factory	2	303	3,961.6

Industry type	Activity	Number of factories	Number of workers	Horsepower (Hp)
39	The factory produces containers from all types of paper or fiber sheets (fiberboard)	4	216	5,089.0
40	The factory engages in business related to pulp or paperboard	4	116	469.7
41	The factory engages in printing, file making, document storage, staple, cover or decorate print	3	55	216.5
43	The factory runs fertilizer business or pesticides	4	63	634.4
46	The factory runs one of the drug-related businesses	4	97	638.5
47	The factory engages in soap, cosmetics, or body preparation	3	107	382.2
48	The factory engages in chemical products	5	272	798.7
50	The factory engages in businesses relating to petroleum, coal or lignite products	25	186	14,563.8
52	The factory engages in businesses relating to rubber	2	44	451.7
53	The factory runs one of the plastic products	24	667	11,057.4
54	Glassworks, glass fibers, or glass products	1	189	65.8
55	Product factory glazed tile machine earthenware including the preparation of materials for the aforementioned	14	795	3,611.0
56	Brick factory tiles or tubes for use in the construction of crucibles decorative tiles (architectural terracotta) secondary in a fireplace, pipe or chimney top or refractory materials from clay	15	296	2,242.0
57	The factory runs a business about cement, lime, or plaster	1	166	376.4
58	The factory runs of the non-ferrous products	84	1,213	20,788.1
60	The factory engages in smelting, mixing, purifying, melting, casting, rolling, pulling, or initially producing metal which is not steel or steel (non-ferrous metal basic industries)	1	20	92.3
61	Manufacturing, decorating, modification or repairing of tools or appliances made of iron or steel and including the components or equipment of such tools or appliances	1	10	128.0
62	Factory for making, decorating, modifying or repairing of furniture or interior decoration of metal or metal mostly and including components or equipment of furniture or such decoration	2	47	591.9
63	The factory engages in metal products for use in construction or installation	12	468	5,553.1
64	The factory engages in metal products	21	617	4,678.4
65	Manufacturing, assembly or modification or repair of engines turbine and including engine components or equipment or the aforementioned turbine	5	88	563.2
66	Manufacturing, assembly, modification or repairing of machinery for use in agriculture or animal husbandry and including the components or equipment of the machine	1	18	70.0

Industry type	Activity	Number of factories	Number of workers	Horsepower (Hp)
68	Manufacturing, assembly, modification or repairing of machinery for the paper, chemical, food industry, spinning, printing, cement production or clay products, construction, mining drilling for petroleum or refined oil and including the components or equipment of the machine	1	53	181.0
70	Manufacturing, assembly, modification or repair of pumps air or gas compressor blowers adjustable or ventilator sprinkler refrigerator or refrigerator assembly vending machines, washing machines, dry cleaning or ironing machines, sewing machines, mechanical transmitters, lifting machines, elevators, escalators, trucks, tractors, trailers for industrial use, stacker, stoves or ovens for industrial use or for home use but that product must not use electrical power and including the components or devices of that product	5	86	887.6
72	Manufacturing, assembly, modification or repair of radio receivers television receiver broadcasting or audio recorder CD player dictation recorder, tape recorder dictation recorder, tape recorder players or recorders (video), recordable magnetic tape recorders telephone or telegraphic equipment, with or without wires radio television transmitter or receiver radar device products that are semiconductors or related semiconductors (semi-conductor or related sensitive semi-conductor devices) capacitors or fixed or variable electronic condensers, fixed or variable electronic capacitors or condensers fluoroscope or machines or x-ray tubes and including the production of equipment	4	1,482	4,952.2
73	Manufacturing plants, assembling or modifying tools or appliances that are not listed in any order and including the components or devices of that product	1	15	103.4
74	The factory engages in electrical equipment	2	65	149.9
77	The factory engages in business related to cars or trailers	3	21	462.9
80	The factory is manufacturing, assembling, modifying, or repairing wheels that are powered by humans or animals which are not bicycles and include the components or equipment of the product	1	17	592.9
81	The factory engages in business about tools, appliances or scientific equipment or either medicine	3	138	365.1
84	The factory engages in business related to jewels, gold, silver, swordfish or gems	10	1278	2,335.9
86	Manufacturing or assembly of tools or sports appliances, exercise playing billiards, bowling or fishing, and including the parts or equipment thereof	4	393	268.0
87	The factory engages in business about toys tools or appliances	6	857	1,022.3
88	Electricity power plants (thermal and renewable)	11	86	38,517.4
89	Gas plant which is not natural gas wholesale or distribution of gas	2	13	1,572.1
90	Water supply factory, water purification or distribute water to buildings or industrial plants	4	27	31,882.3
91	The factory packed the products in the container	2	171	961.6
92	Cool room factory	48	1439	39,443.5

Industry type	Activity	Number of factories	Number of workers	Horsepower (Hp)
95	The factory engages in motor-driven vehicles, trailers, bicycles and tricycles, bicycle or components of the vehicles	93	2837	12,572.2
98	Laundry, dry cleaning, laundering, pressing, or dyeing of clothing, carpet or wool	10	230	13,715.8
100	The factory runs a business about decorating or changing product characteristics or components of the products	6	236	2,087.8
104	Manufacturing plants, assembling, modifying, or repairing boilers or boilers that use liquid or gas as heat conductors' pressure resistant container and including the components or devices of that product	1	16	197.9
105	The factory engages in separation or landfill operations or unused materials that have the characteristics and qualifications as specified in the Ministerial Regulation NO. 2 (B.E. 2535) issued under the Factory Act 1992	6	72	1,191.0
106	The factory engages in the business of using unused industrial products or waste from the factory to produce new raw materials or products through industrial production processes	1	20	497.0
	Total	**1,055**	**33,822**	**666,166.2**

4.3.2 Methodology

The methodology adopted to calculate emissions from stationary combustion in manufacturing industries is based on numerous assumptions and hypotheses. This is because fuel consumption data by industry are not available, and data on fuel consumption by industry sector in Chiang Mai province are also not available. To estimate emissions, fuels used in the province and energy consumption must be defined.

The industrial energy consumption for Chiang Mai is estimated based on Thailand national consumption, which is a reliable source of information to start with. Therefore, the data used as activity is the Energy Balance for Thailand as a whole and data per industry from the DIW (Department of Industrial Works from the Ministry of Industry). The fuel consumption for combustion in manufacturing industries in Chiang Mai is calculated by deduction from the national fuel consumption, by applying the ratio of activity levels between total national GPP (Gross Provincial Product) and the GPP for the province of Chiang Mai. The GPP data are provided by the office of the National Economic and Social Development Council. Due to lack of data of GPP for the year 2022, the GPP data for the year 2021 is used.

The equation used for fuel consumption calculation is as follows:

$$\mathbf{FC_i\ (Chiang\ Mai) = FC_i\ Thailand * (GPP\ for\ Chiang\ Mai/\ GPP\ for\ Thailand)}$$

Where:

- FC: Fuel Consumption
- i: Different fuel type

<u>Hypotheses:</u>

Numerous assumptions have been made due to the lack of information on manufacturing industries in Chiang Mai. As the industrial sector is a relatively small source of emissions in Chiang Mai province compared with, for example, the road traffic, the calculation assumptions should not significantly affect the quality of the final results.

It is assumed that there is no natural gas consumption from fixed installations. In fact, there is no gas pipeline between the south of the country and Chiang Mai. If natural gas was to be consumed in the province, it could only be transported by lorries or trains, which is not yet a very common practice.

Based on the national energy balance, it is assumed that there is no coal or heavy fuel-oil consumption in manufacturing industries in the province. We can therefore assume that the province's manufacturing industries only use small boilers or furnaces that run on diesel (which is light fuel oil), LPG or simply electrical energy. It is essential to note that, with this assumption, fuel combustion in small installations, such as in ceramic craft villages, might not be categorized under the industrial sector but instead under residential emissions or could even be omitted from the total emissions inventory (EI) altogether. This could result in an underestimation of emissions from the industrial sector and an overestimation of emissions from the residential sector.

The combustion of biofuels and biogas is assumed to be mainly used for electricity generation. The consumption of liquid biofuels, biogas and the incineration of wastes are considered in the treatment of LIS (Large Individual Sources), that are intended to produce electrical energy.

The main fuel used is liquefied petroleum gas (LPG) for manufacturing industries in the province. The industrial installations in Chiang Mai are considered as small plants, consuming less than 10 MW as small boilers or furnaces, based on the examination of industry Horsepower for Chiang Mai province. Therefore, a Tier 1 methodology is applied, based on EMEP/EEA guidebook 2023 for category 1.A.4 small plants.

Parameters and emission's methodology:

The methodology used to calculate emission is Tier 1 from EMEP/EEA guidebook 2023. The same methodology is provided by the ABC EIM (Shrestha et al., 2013). The fuel consumption for the Chiang Mai province (**FC_i Chiang Mai)** obtained through the GPP is multiplied by emissions factors.

The equation used for emissions calculation is as follows:

$$\mathbf{Em_{i,j} = FCi^* \; EF_{i,j}}$$

Where:

- i= Fuel Type i
- $Em_{i,j}$ = Emission of pollutant j, from fuel type i
- FC_i = Consumption of fuel type i
- $EF_{i,j}$ = Emission factor specific to pollutant j and fuel type i

The emission factors (EF) used for gasoline and diesel are derived from the ABC EIM. Emission factors for LPG and fuel oil are taken from the EMEP/EEA 2023 guidelines (for 1.A.4 combustion in small plants).

For SO_2, an assumption of 2.72 % sulfur content in fuel oil was assumed. This value corresponds to the average sulfur content of heavy fuel oil prior to the introduction of IMO low-sulfur regulations. In addition, this value is considered in the French national emissions inventory as a reference for high-sulfur heavy fuel oil. A sulfur content of 0.005% was applied to diesel and gasoline, in line with fuel specifications in Thailand in 2022. For kerosene, an international sulfur content of 0.05% was used, which is very close to ICAO standards.

TABLE 4: EMISSION FACTORS FOR COMBUSTION IN MANUFACTURING INDUSTRIES IN KG/TJ.

Pollutants	PETROLEUM PRODUCTS							
	Liquefied petroleum gas	Petrol				Kerosene	High speed diesel	Fuel oil
		Octane 95	91	95	E 20 Octane 95			
NOx	74	373	373	373	373	485	632	306
CO	29	15	15	15	15	15	15	93
NMVOC	23	5	5	5	5	5	5	20
PM10	0.78	-	-	-	-	-	7.7	21
PM2.5	0.78	-	-	-	-	-	5.6	18
NH3	1.31	-	-	-	-	-	-	0.101
BC	0.0312	-	-	-	-	-	0.61	10.08
OC	0	-	-	-	-	-	0.18	0.37
CO2	63,100	69,300	69,300	69,300	69,300	71,900	74,100	77,400
CH4	1	3	3	3	3	3	3	3
N2O	0.1	0.6	0.6	0.6	0.6	0.6	0.6	0.6
SO2	0.67	2.29	2.29	2.29	2.29	23.4	2.29	1,360

4.3.3 Methodological issues

This method relies on several assumptions. The fuel consumption data is unavailable for the Chiang Mai province and its industries. The types and quantities of fuel consumption used in the emissions calculation are dependent on many factors and assumptions, which can cause biases in the calculation. The horsepower data didn't seem very reliable to be used as a ratio between National and provincial energy consumption. The GPP ratio used instead was only available for the year 2021 and not 2022. There was also a lack of details on energy consumption per type of industry and for the factories, the distribution of results per industry or factory wasn't possible.

4.3.4 Ways of Improvements

To improve calculations, more detailed activity data is needed, which are only acquired by survey. Data on fuel consumption at the provincial level would greatly improve provincial emissions inventories. To go a step further, emissions and fuel consumption data for large facilities would be very useful. Thailand is working on a pollutant release and transfer register that would provide the necessary information for the most significant emitters. In addition, local measurement of emission factors for different industry facilities and types of industry are needed to improve EI results.

Such precise data would allow an assessment of the impact of the industrial sector on overall emissions, as well as an estimate of the major emitting facilities and thus the identification of targeted mitigation measures where necessary.

4.4 AVIATION (NFR SUBSECTOR 1.A.3.A)

4.4.1 Overview of the sector

The current sector covers emissions of the aviation sector since Chiang Mai province has an international airport. As a result, this sector represents only a tiny fraction of total provincial emissions in 2022 since it contributes as follows: NOx emissions for 0.49% of the total, emissions of CO for 0.14 %, NMVOCs for 0.06%, PM_{10} and $PM_{2.5}$, for 0.03% and 0.05%, respectively, of the total. However, as we shall see later, the results must be qualified by the fact that air traffic in 2022 will still be a long way from its pre-covid level.

4.4.2 Methodology

The methodology used to estimate aviation emissions is described by the following equation and follows the Tier 1 approach from the ABC EIM (Shrestha et al., 2013).

$$E_i = LTO_i \times EF_i$$

Where:

- LTO_i The number of landings and take-offs by type of flight i (domestic or international).
- $EF_{i,j}$ emission factor depending on the type of flight i expressed in kg/LTO.

4.4.2.1 Activity data

The number of landings and take-offs in Chiang Mai was provided by the Air Transport Information Division (AOT)[1]. It should be noted that since no information was available concerning kerosene consumption in Chiang Mai or the origins and destinations of aircraft, only LTO phase emissions were considered. Finally, the identification of fuel consumption by LTO was based on the CO_2 emission factor and net calorific value of the jet fuel. Note that only jet fuel is considered for aviation.

[1] Airports of Thailand Public Company Limited (airportthai.co.th)

Consequently, the jet-fuel consumption by LTO is the following:

- For domestic flights: 850 kg/LTO.
- For international flights: 1,666 kg/LTO.

4.4.2.2 GHG emissions

Carbon dioxide (CO_2)

CO_2 emission factor is taken from the Tier 1 approach from the Atmospheric Brown Cloud, Emissions Inventory Manual (Shrestha et al., 2013).

- For domestic flights: 2,600 kg/LTO.
- For international flights: 5,094 kg/LTO.

Nitrous oxide (N_2O)

N_2O emission factor is provided by the IPCC 2006 guidelines and is associated with fuel consumption. The emission factor is equal to 0.002 kg/GJ, which applied for both domestic and international flights.

Methane (CH_4)

CH_4 emission factor is provided by the IPCC 2006 guidelines and is associated with fuel consumption. The emission factor is equal to 0.005 kg/GJ, which applied for both domestic and international flights.

4.4.2.3 Atmospheric pollutants emissions

Pollutant emission factors are mostly taken from the ABC EIM (Shrestha et al., 2013) and expressed in kg of pollutant by LTO except for:

- NMVOC for which the emission factor is taken from IPPC guidelines and expressed in kg/TJ.
- SO_2 where the fuel sulfur content in the fuel considered is equal to 500 ppm, in accordance with the sulfur content given by the guidebook EMEP/EEA (1A3a Aviation).

Table 5 below compiled the pollutant emission factors considered as a function of the flight type.

TABLE 5: AIR POLLUTANT EMISSION FACOTRS FOR BOTH DOMESTIC AND INTERNATIONAL FLIGHTS.

Flight type	Pollutant	Unit	Emission factor
International	SO2	%m S in fuel	0.05%
	CO	kg/LTO	6.1
	NOX	kg/LTO	26
	TSP	kg/LTO	0.15
	PM10	kg/LTO	0.15
	PM2.5	kg/LTO	0.15
	BC	g/kg fuel	0.10
	OC	g/kg fuel	0.03
	NMVOC	kg/[TJ]	45
Domestic	SO2	%m S in fuel	0.05%
	CO	kg/LTO	11.5
	NOX	kg/LTO	8.3
	TSP	kg/LTO	0.20
	PM10	kg/LTO	0.20
	PM2.5	kg/LTO	0.20
	BC	g/kg fuel	0.10
	OC	g/kg fuel	0.03
	NMVOC	kg/[TJ]	45.0

4.4.3 Results: Emissions from aviation

Aviation emissions for the years 2003 to 2022 are presented in Table 6 and Table 7 for international and domestic types of flights, respectively.

TABLE 6: EMISSIONS RESULTS FOR INTERNATIONAL FLIGHTS EXPRESSED IN TONNES

	SO2	CO2	CO	NOX	CH4	N2O	TSP	PM10	PM2.5	BC	OC	NMVOC
2003	3.3	10,175	12	52	0.71	0.28	0.30	0.30	0.30	0.33	0.10	6.4
2004	4.6	13,975	17	71	1.0	0.39	0.41	0.41	0.41	0.46	0.14	8.8
2005	4.1	12,440	15	63	0.87	0.35	0.37	0.37	0.37	0.41	0.12	7.8
2006	4.7	14,492	17	74	1.0	0.41	0.43	0.43	0.43	0.47	0.14	9.1
2007	4.2	12,883	15	66	0.90	0.36	0.38	0.38	0.38	0.42	0.13	8.1
2008	3.0	9,223	11	47	0.64	0.26	0.27	0.27	0.27	0.30	0.09	5.8
2009	2.2	6,752	8.1	34	0.47	0.19	0.20	0.20	0.20	0.22	0.07	4.2
2010	2.3	6,989	8.4	36	0.49	0.20	0.21	0.21	0.21	0.23	0.07	4.4
2011	3.1	9,541	11	49	0.67	0.27	0.28	0.28	0.28	0.31	0.09	6.0
2012	4.0	12,088	14	62	0.85	0.34	0.36	0.36	0.36	0.40	0.12	7.6
2013	6.1	18,766	22	96	1.3	0.52	0.55	0.55	0.55	0.61	0.18	12
2014	9.4	28,855	35	147	2.0	0.81	0.85	0.85	0.85	0.94	0.28	18
2015	13	39,015	47	199	2.7	1.1	1.1	1.1	1.1	1.3	0.38	25
2016	14	43,368	52	221	3.0	1.2	1.3	1.3	1.3	1.4	0.43	27
2017	15	46,103	55	235	3.2	1.3	1.4	1.4	1.4	1.5	0.45	29
2018	17	52,295	63	267	3.7	1.5	1.5	1.5	1.5	1.7	0.51	33
2019	21	63,986	77	327	4.5	1.8	1.9	1.9	1.9	2.1	0.63	40
2020	9.0	27,548	33	141	1.9	0.77	0.81	0.81	0.81	0.90	0.27	17
2021	0.0075	23	0.027	0.12	1.60E-03	6.41E-04	6.75E-04	6.75E-04	6.75E-04	7.50E-04	2.25E-04	0.014
2022	0.69	2,106	2.5	11	0.15	0.059	0.062	0.062	0.062	0.069	0.021	1.3

TABLE 7: EMISSIONS RESULTS FOR DOMESTIC FLIGHTS EXPRESSED IN TONNES

	SO2	CO2	CO	NOX	CH4	N2O	TSP	PM10	PM2.5	BC	OC	NMVOC
2003	5.0	15,313	68	49	1.1	0.43	1.2	1.2	1.2	0.50	0.15	9.6
2004	6.3	19,145	85	61	1.3	0.54	1.5	1.5	1.5	0.63	0.19	12
2005	7.4	22,721	100	73	1.6	0.64	1.7	1.7	1.7	0.74	0.22	14
2006	8.0	24,413	108	78	1.7	0.68	1.9	1.9	1.9	0.80	0.24	15
2007	9.2	28,145	124	90	2.0	0.79	2.2	2.2	2.2	0.92	0.28	18
2008	9.3	28,313	125	90	2.0	0.79	2.2	2.2	2.2	0.93	0.28	18
2009	8.6	26,300	116	84	1.8	0.74	2.0	2.0	2.0	0.86	0.26	17
2010	10.5	32,081	142	102	2.2	0.90	2.5	2.5	2.5	1.05	0.31	20
2011	11.5	35,170	155	112	2.5	0.98	2.7	2.7	2.7	1.15	0.35	22
2012	13.1	40,073	177	128	2.8	1.12	3.1	3.1	3.1	1.31	0.39	25
2013	14.4	44,105	195	141	3.1	1.23	3.4	3.4	3.4	1.44	0.43	28
2014	16.3	49,855	220	159	3.5	1.39	3.8	3.8	3.8	1.63	0.49	31
2015	20.1	61,500	272	196	4.3	1.72	4.7	4.7	4.7	2.01	0.60	39
2016	21.3	65,139	288	208	4.6	1.82	5.0	5.0	5.0	2.13	0.64	41
2017	22.9	70,122	310	224	4.9	1.96	5.4	5.4	5.4	2.29	0.69	44
2018	23.4	71,579	316	229	5.0	2.00	5.5	5.5	5.5	2.34	0.70	45
2019	23.6	72,036	318	230	5.0	2.01	5.5	5.5	5.5	2.36	0.71	45
2020	15.5	47,427	209	151	3.3	1.33	3.6	3.6	3.6	1.55	0.47	30
2021	9.3	28,458	126	91	2.0	0.80	2.2	2.2	2.2	0.93	0.28	18
2022	13.8	42,065	186	134	2.9	1.18	3.2	3.2	3.2	1.38	0.41	26

4.4.4 Methodological issues and ways of improvements

Aviation emissions inventory could be improved by considering GHG emissions during cruise phase for domestic flights to be in line with UNFCCC guidelines. This implies either having bunkering data for domestic and international flights (top-down approach) or having database of aircraft movement.

4.5 ROAD TRANSPORT (NFR SUBSECTOR 1.A.3.B)

4.5.1 Overview of the sector

The calculation includes the following vehicle categories:

- 1.A.3.b.i Passenger cars
- 1.A.3.b.ii Light-duty trucks
- 1.A.3.b.iii Heavy-duty vehicles including buses
- 1.A.3.b.iv Mopeds and motorcycles
- 1.A.3.b.v Gasoline evaporation
- 1.A.3.b.vi Road transport: Automobile tire and brake wear
- 1.A.3.b.vii Road transport: Automobile Road abrasion

4.5.2 Methodology

Exhaust emissions from road transport have been calculated according to the Tier II approach of the EMEP/EEA guidebook 2023. This method considers an intermediate level of detail, namely:

- Vehicle type,
- Segment of roads,
- Engine (gasoline, diesel, electric, etc.); and
- Emission standard.

Consequently, vehicle speed, road type, and cold emissions are not directly considered as parameters but are included in the emission factor based on an average distribution. Thus, tailpipe road transport emissions can be estimated using the following equation:

$$E_{i,j,k}[g] = \sum_{k} N_{j,k} \times M_j \times EF_{i,j,k}$$

Where:

- $EF_{i,j,k}$ technology-specific emission factor of pollutant i for vehicle category j and technology k [g/veh-km].
- M_j average annual distance driven per vehicle of category j [km/veh].
- $N_{j,k}$ number of in-use vehicles in the province's fleet of category j and technology k.

4.5.2.1 Activity data

The activity data associated with both abrasion and combustion emissions is related to the distance travelled by vehicles. On the other hand, for gasoline evaporation-related emissions, the activity data considered is the number of days in a year.

The following sections present how the total distance travelled, expressed in veh.km, is estimated.

In-use vehicle fleet estimation

In-use vehicle fleet is estimated using the following equation (Kolli et al, 2012)

$$N_{veh}(t,n) = SR(t,n) \times I_{veh}(n-t)$$

Where:

- N_{veh}: In-use vehicle number.
- SR : Survival rate.
- I_{veh}: The number of newly registered vehicles.
- *t*: vehicle age.
- *n*: year.

The survival rates for passenger cars, light-duty trucks, and motorcycles were estimated from two data sets, namely:

- The number of vehicles surveyed by EGIS, extrapolated to the whole province using a population repartition key.
- The annual trend of the number of newly registered vehicles in Chiang Mai province.

More details about survival rate estimation are presented in a dedicated report (Air Quality Improvement in Thailand – Output 4, Part1: Composition of the technological fleet in Chiang Mai", December 2023 - EGIS, 2023).

For buses and trucks, the survival function has been established based on data from the ATRANS study for Nakhorn Ratchasima province, assuming a similarity with Chiang Mai province. The methodology is like the one presented in the previous report but with a larger sample size.

Note that SR is first calculated experimentally and then approximated with a Weibull function which is a function depending on the vehicle age and two coefficients, namely *T*, a curve positioning parameter expressed in years and related to vehicle longevity and k, a shape parameter that allows the curve to be straightened to a greater or lesser extent at the inflection point. Finally, the value *a corresponds to the vehicle age (a).*

$$SR = e^{-\frac{a}{T^k}}$$

The corresponding *T* and *k* coefficients were iteratively adjusted so that the Weibull function was fitted as closely as possible to the experimental curve. *T* and *k* are and are shown in the table below:

Vehicle type	T coefficient	K coefficient
Passenger cars	17	1.6
Light duty trucks	21	2.2
Mopeds and motorcycles	12	2.3
Heavy-duty vehicles	16	2.1
Buses and coaches	17	1.6

Figure 21 shows the different survival rates used in this study for different vehicle categories.

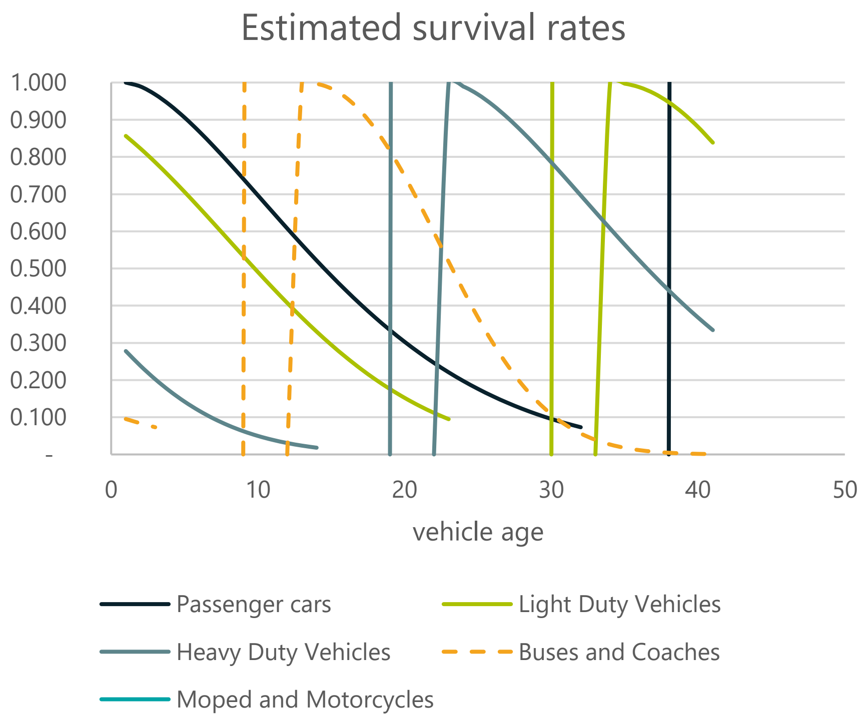


FIGURE 21 : SURVIVAL RATE ESTIMATION FOR THE DIFFERENT VEHICLE CATEGORIES

Vehicle kilometers travelled estimation.

The estimated average annual distances travelled by vehicles were based on the results of the traffic model produced by EGIS (Air Quality Improvement in Thailand – Output 4, Part1: Composition of the technological fleet in Chiang Mai", December 2023). The model is based on road counts carried out in the Chiang Mai metropolitan area, which were then extrapolated to the entire province.

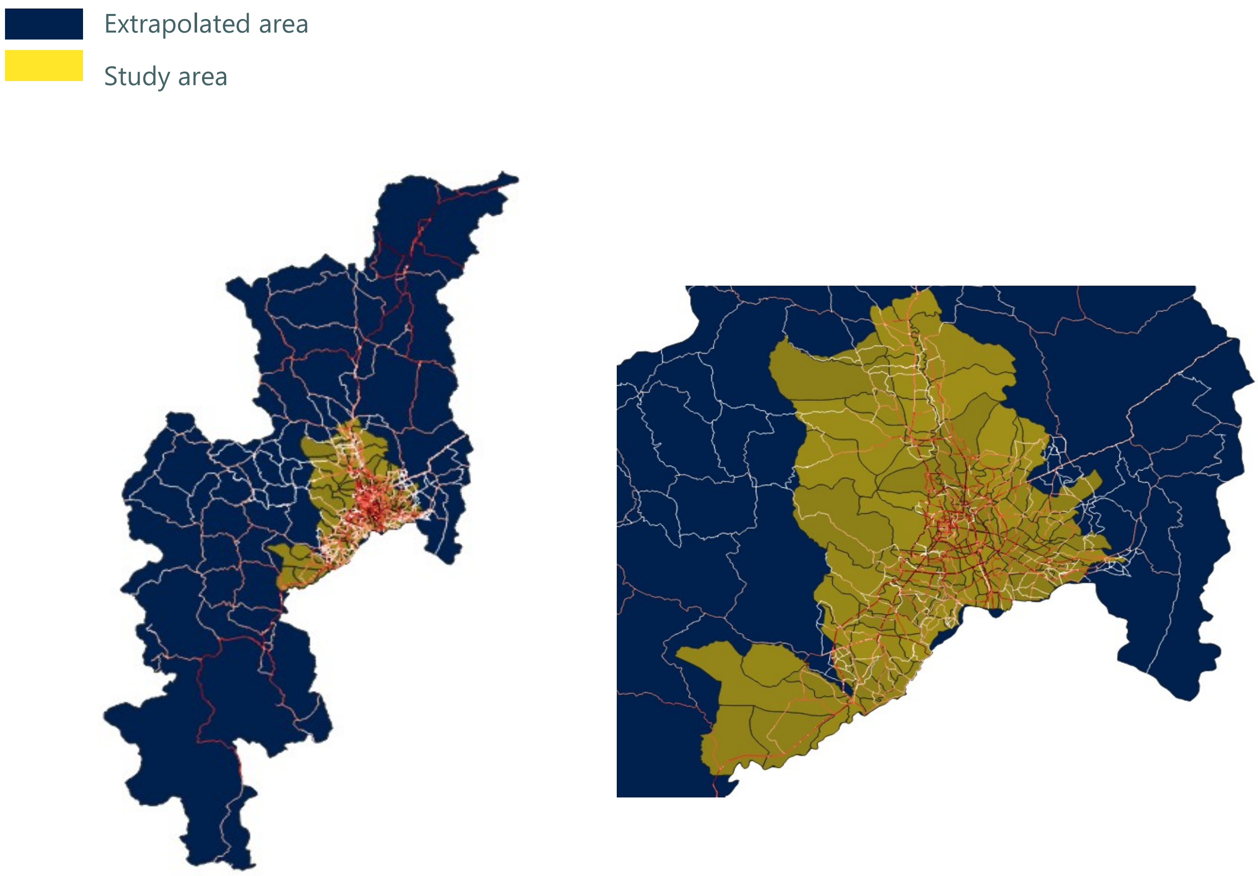


FIGURE 22: ILLUSTRATION OF TRAFFIC DENSITY ON CHIANG MAI PROVINCE'S ROAD NETWORK

Figure 22 shows, in dark yellow, the area over which the vehicle count survey was performed, and in dark blue the extrapolated area. Road segments are represented on a color scale from white to red, depending on the level of traffic on the road. It can be logically noticed that most of the traffic in the province is in Chiang Mai city and on the main routes to and from the city. Also, Table 8 shows that the total VKT is equally spread between motorcycles and cars which represents approximately 35 % of the total traffic whereas LDV category represent 25 % of the total traffic. It should be noted that although truck traffic has been estimated, it has not been considered in the following sections due to the high level of uncertainty associated with too small a sample.

TABLE 8: TOTAL TRAFFIC EXPRESSED IN VEH.KM IN CHIANG MAI PROVINCE

	Motorcycle	Car	LDV	Truck
Peak hour	1,107,302	1,026,985	719,994	52,504
Daily	13,277,002	12,313,966	8,633,019	629,545
Yearly	4,846,105,820	4,494,597,453	3,151,052,067	229,784,012

Finally, the average annual mileage associated with each vehicle category was obtained by dividing total VKT by the number of vehicles in each category. The results are presented in the Table 9 and show good consistency with the average annual mileage usually found in the literature (National EI, ATRANS, 2009).

TABLE 9: SUMMARY TABLE OF THE NUMBER OF VEHICLES, THE TOTAL MILEAGE COVERED IN A YEAR AND THE AVERAGE ANNUAL MILEAGE COVERED BY A VEHICLE.

Category	In-use-fleet (veh)	Yearly mileage (veh.km)	Annual traveled distance (km/veh)
Motorcycles	624,219	4,846,105,820	7,763
Passenger cars	225,045	4,494,597,453	19,972
Light Duty Vehicles	156,290	3,151,052,067	20,162
Buses and coaches	4,988		44,616
Heavy Duty Vehicles	15,776		49,323

In the case of trucks and buses, the annual distances travelled have been estimated based on a compilation of data from the literature (Limanond et al 2009, Vilaiphorn et al 2010, ATRANS 2009, PCD 2004).

Breakdown of vehicles by segment and engine type

Before associating a fuel consumption to each vehicle, it is important to divide the vehicles first by engine type, then by segment (according to power, weight, or cubic capacity criteria), to limit the error in estimating the unit fuel consumption of the vehicles. The split by segment and motorization of the categories entitled passenger cars, LDV and motorcycle are taken from the results of the EGIS traffic survey and are presented in the dedicated report (EGIS, 2023).

For heavy vehicles, buses and coaches, the breakdown by engine type is taken from the survey categories entitled “Truck” and “Bus, Minibus and Van” respectively, despite the small sample size. Correspondence tables between categories are given in *EGIS, 2023.* Table 10 presents the number of vehicles, split by engine type for the different categories.

TABLE 10: NUMBER OF VEHICLES, SPLIT BY ENGINE TYPE, FOR THE DIFFERENT CATEGORIES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	586,032	116,907	27,224	-	2,470
LPG	-	5,618	5,145	-	-
Diesel	35,307	101,484	122,474	4,988	13,305
BEV	2,880	390	370	-	-
CNG	-	646	1,077	-	-
Total	**624,219**	**225,045**	**156,290**	**4,988**	**15,776**

The considered breakdowns by segment for the different vehicle categories are presented in the following table (Table 11). It should be noted that the breakdown of buses, coaches and heavy-duty vehicles by segment was established based on experience feedback, as the traffic survey was based mainly on motorcycles, passenger cars and light duty vehicles. It should also be pointed out that the diesel motorcycle pairing refers to micro-car vehicles.

TABLE 11: BREAKDOWN BY SEGMENT FOR THE DIFFERENT VEHICLE CATEGORIES

Category	Motorization	Segment	Fleet fraction
Buses and coaches	Diesel	Urban bus standard 15 - 18 t	30%
Buses and coaches	Diesel	Coach standard <= 18 t	70%
Heavy Duty Vehicles	Diesel	inf 7,5 t	5%
Heavy Duty Vehicles	Diesel	7,5 - 12 t	12%
Heavy Duty Vehicles	Diesel	12 - 14 t	8%
Heavy Duty Vehicles	Diesel	14 - 20 t	32%
Heavy Duty Vehicles	Diesel	20 - 26 t	25%
Heavy Duty Vehicles	Diesel	26 - 28 t	5%
Heavy Duty Vehicles	Diesel	28 - 32 t	5%
Heavy Duty Vehicles	Diesel	28 - 34 t	8%
Heavy Duty Vehicles	Petrol	inf 7,5 t	100%
Light Duty Vehicles	Petrol	N1-II	100%
Light Duty Vehicles	Diesel	N1-II	100%
Light Duty Vehicles	BEV	N1-II	100%
Light Duty Vehicles	CNG	N1-II	100%
Motorcycles	Petrol and BEV	Mopeds 4-stroke <50 cm^3	0.914%
Motorcycles	Petrol and BEV	Mopeds 2-stroke <50 cm^3	0.914%
Motorcycles	Petrol and BEV	Motorcycles 4-stroke <250 cm^3	93%
Motorcycles	Petrol and BEV	Motorcycles 4-stroke 250 - 750 cm^3	3.1%
Motorcycles	Petrol and BEV	Motorcycles 4-stroke >750 cm^3	1.626%
Motorcycles	Diesel	Motorcycles 4-stroke >750 cm^3	100%
Passenger cars	undifferentiated	Small	2.72%
Passenger cars	undifferentiated	Medium	62.12%
Passenger cars	undifferentiated	Large	33.15%

Considering the previous steps, the vehicle fleet broken down by standard or age and segment is associated with a unit fuel consumption for each combination, taken from the Tier II methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023). Engine oil consumption has also been modelled based on the same source, with the added correction of consumption levels according to vehicle age, in line with the methodology developed in the French inventory.

The following tables summarize the breakdown of the fleet by euro standard made possible by the age-dependent distribution of vehicles (Table 12 and 13).

TABLE 12: COMPOSITION OF THE TECHNOLOGICAL FLEET FOR MOTORCYCLES, PASSENGER CARS AND LDV

Euro Norm	Motorcycles	Passenger cars	Light Duty Vehicles
ECE 15/04	-	390	-
Conventional	-	792	4,001
Euro 1	-	1,773	3,079
Euro 2	-	4,678	7,650
Euro 3	624,219*	27,957	29,953
Euro 4	-	189,065	111,236
Euro 6 d	-	390**	370

**As motorcycles are not subject to regulation, they have been assigned to the Euro 3 standard by default. This is an optimistic assumption.*
*** by default, electric vehicles are associated with the latest standard in Europe*

TABLE 13: COMPOSITION OF THE TECHNOLOGICAL FLEET FOR BUSES, COACHES AND HDV

Euro Norm	Buses and coaches	Heavy Duty Vehicles
Conventional	26	2,607
Euro I	5	44
Euro II	338	833
Euro III	4,618	12,291

4.5.2.2 GHG emissions

Carbon dioxide (CO_2)

Carbon dioxide emissions are calculated using emission factors from the same references for all fuel types, namely IPCC Guidelines (Volume 2, Chapter 3: Mobile Combustion). The associated activity data is the fuel consumption. This fuel consumption is estimated by category, type of engine, segment and euro standard in accordance with the Tier 2 method in the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023).

- For petrol fuel: 69.3 kg/GJ.
- For diesel fuel: 74.1 kg/GJ.
- For LPG fuel: 63.1 kg/GJ.
- For CNG fuel: 56.1 kg/GJ.

Nitrous oxide (N_2O)

Nitrous oxide emissions are calculated using emission factors from the same references for all fuel types which is the Tier II methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023). The associated activity data is the total travelled distance.

Methane (CH_4)

Methane emissions are computed using two data sources:

- Tail pipe NMVOC emission factors from the same references for all fuel types which is the Tier II methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023).
- Ratio CH_4/THC in the exhaust gases from IPCC Guidelines (Volume 2, Chapter 3: Mobile Combustion).

- For 2-stroke petrol engines: 0.9%.
- For 4-stroke petrol engines: 17.5%.
- For diesel engines: 1.6%.
- For LPG engines: 29.6%.
- For CNG engines: 91.6%.

4.5.2.3 Atmospheric pollutants emissions

Sulphur dioxide (SO_2)

Sulphur dioxide emissions depend directly on the amount of sulfur in the fuel, and therefore on fuel regulations. Sulfur concentrations in gasoline and diesel, in accordance with the information provided by the Department of Energy Business, have been estimated at 50 ppm by mass. For LPG and CNG fuels, the emission factors used are the same as those in the French inventory.

- For petrol fuel: 2.37 g/GJ
- For diesel fuel: 2.24 g/GJ
- For LPG fuel: 2.20 g/GJ
- For CNG fuel: 0.50 g/GJ

Nitrogen oxide (NOx)

Nitrogen oxide emissions are calculated using emission factors from the same references for all fuel types which is the Tier II methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023). The associated activity data is the total travelled distance.

Non-methane volatile organic compounds (NMVOC)

Tail pipe NMVOC emissions are calculated using emission factors from the same references for all fuel types which is the Tier II methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023). The associated activity data is the total travelled distance.

Gasoline fuel evaporation is also responsible for NMVOC emissions. The associated emission factors are expressed in g/veh/day and come from the EMEP/EEA 2023 guidebook (Tier 1 - 1.A.3.b.v Gasoline evaporation). Please note that these only apply to petrol engines, thus mainly to motorcycles and passenger cars.

- For motorcycles: 7.5 g/veh/day.
- For passenger cars: 14.6 g/veh/day.
- For LDV: 22.2 g/veh/day.
- For buses and coaches: 22.2 g/veh/day.
- For HDV: 22.2 g/veh/day.

Carbon monoxide (CO)

CO emissions are calculated using emission factors from the same references for all fuel types which is the Tier 2 methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023). The associated activity data is the total travelled distance.

Particulate Matter (PM)

Tail pipe PM emissions are calculated using emission factors from the same references for all fuel types which is the Tier II methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023). The associated activity data is the total travelled distance. For road transport, it is assumed that 100% of TSP are $PM_{2.5}$.

Abrasion PM emissions are calculated using emission factors from the same references for all fuel types which is the Tier 2 methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.vii Road transport: Automobile Road abrasion and 1.A.3.b.vi Road transport: Automobile tire and brake wear). The associated activity data is the total travelled distance. This includes emissions from tire abrasion, brakes and the road.

Black Carbon (BC)

BC emissions are calculated using emission factors from the same references for all fuel types which is the Tier 2 methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023). They are expressed as a fraction of $PM_{2.5}$.

Abrasion BC emissions are calculated using emission factors from the same references for all fuel types which is the Tier 2 methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.vii Road transport: Automobile Road abrasion and 1.A.3.b.vi Road transport: Automobile tire and brake wear). The associated activity data is the total travelled distance. This includes emissions from tire abrasion, brakes and the road.

Ammonia (NH_3)

NH_3 emissions are calculated using emission factors from the same references for all fuel types which is the Tier 2 methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023). The associated activity data is the total travelled distance.

Heavy Metals

Heavy metal emissions are calculated using emission factors from the same references for all fuel types which is the Tier 2 methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.i-iv Road transport 2023). They are expressed as a function of either the fuel (gasoline or diesel) or the lube consumption.

TABLE 14: HEAVY METAL EMISSION FACTORS EXPRESSED IN PPM/WT

CATEGORY	PB	CD	CU	CE	NI	SE	ZN	HG	AS
Petrol	0.0016	0.0002	0.0045	0.0063	0.0023	0.002	0.033	0.0087	0.0003
Diesel	0.0005	5 E-05	0.0057	0.0085	0.0002	0.0001	0.018	0.0053	0.0001
Lubricant	0.0332	4.56	778	19.2	31.89	4.54	450.2	-	-

Heavy metal emissions are also emitted by brake and tire abrasion. The corresponding emission factors come from the same references for all fuel types which is the Tier 2 methodology of the EMEP/EEA 2023 guidebook (1.A.3.b.vii Road transport: Automobile Road abrasion and 1.A.3.b.vi Road transport: Automobile tire and brake wear).

4.5.3 Results: Emissions from road transport in 2022

4.5.3.1 GHG emissions

Carbon dioxide (CO_2)

TABLE 15: TAIL PIPE CO_2 EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN KT

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	497	517	118	-	66
LPG	-	19	18	-	-
Diesel	26	341	553	186	411
BEV	-	-	-	-	-
CNG	-	2.2	3.9	-	-
Total	**523**	**879**	**693**	**186**	**476**

Nitrous oxide (N_2O)

TABLE 16: TAIL PIPE N_2O EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	9.0	5.1	29	-	0.7
LPG	-	0.5	11	-	-
Diesel	1.4	19	21	1.3	3.1
BEV	-	-	-	-	-
CNG	-	0.01	0.69	-	-
Total	**10**	**25**	**62**	**1.3**	**3.8**

Methane (CH_4)

TABLE 17: TAIL PIPE CH_4 EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	450	39	28	-	136
LPG	-	5.5	15	-	-
Diesel	0.70	0.58	2.3	1.5	2.8
BEV	-	-	-	-	-
CNG	-	4.9	22	-	-
Total	**451**	**50**	**68**	**1.5**	**138**

4.5.3.2 Atmospheric pollutants emissions

Sulphur dioxide (SO_2)

TABLE 18: TAIL PIPE SO_2 EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	17	18	4.0	-	2.2
LPG	-	0.65	0.64	-	-
Diesel	0.8	10.3	16.7	5.6	12
BEV	-	-	-	-	-
CNG	-	0.0	0.0	-	-
Total	**18**	**29**	**21**	**5.6**	**15**

Nitrogen oxide (NOx)

TABLE 19: TAIL PIPE NOX EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	881	190	95	-	804
LPG	-	8.3	16	-	-
Diesel	223	1,232	2,266	1,822	3,893
BEV	-	-	-	-	-
CNG	-	0.72	1.3	-	-
Total	**1,104**	**1,431**	**2,378**	**1,822**	**4,697**

Non-methane volatile organic compounds (NMVOC)

TABLE 20: TAIL PIPE NMVOC EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	2,192	182	134	-	640
LPG	-	13	35	-	-
Diesel	43	36	140	91	170
BEV	-	-	-	-	-
CNG	-	0.45	2.0	-	-
Total	**2,236**	**231**	**311**	**91**	**810**

TABLE 21: EVAPORATION RELATED NMVOC EMISSIONS BY VEHICLE CATEGORY FOR PETROL ENGINE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	1,604	623	221	-	20

Carbon monoxide (CO)

TABLE 22: TAIL PIPE CO EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	13,721	1,944	1,939	-	7,250
LPG	-	96	393	-	-
Diesel	255	207	1,069	473	896
BEV	-	-	-	-	-
CNG	-	7.9	51	-	-
Total	**13,975**	**2,255**	**3,452**	**473**	**8,146**

Particulate Matter (PM_{10})

TABLE 23: TAIL PIPE PM_{10} EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	17	2.7	0.67	-	-
LPG	-	0.13	0.13	-	-
Diesel	41	70	152	42	82
BEV	-	-	-	-	-
CNG	-	0.014	0.024	-	-
Total	**58**	**73**	**153**	**42**	**82**

TABLE 24: ABRASION PM_{10} EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	43	63	21	-	12
LPG	-	2.9	3.9	-	-
Diesel	2.6	55	93	22	64 by applying a CO_2 emission factor to the determined
BEV	0.21	0.15	0.20	-	-
CNG	-	0.35	0.82	-	-
Total	**45**	**122**	**118**	**22**	**75**

Particulate Matter ($PM_{2.5}$)

TABLE 25: TAIL PIPE $PM_{2.5}$ EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	17	2.7	0.67	-	-
LPG	-	0.13	0.13	-	-
Diesel	41	70	152	42	82
BEV	-	-	-	-	-
CNG	-	0.014	0.024	-	-
Total	**58**	**73**	**153**	**42**	**82**

TABLE 26: ABRASION $PM_{2.5}$ EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	23	33	11	-	6.4
LPG	-	1.5	2.0	-	-
Diesel	1.4	28	48	12	34
BEV	0.11	0.09	0.12	-	-
CNG	-	0.18	0.42	-	-
Total	**24**	**63**	**61**	**12**	**41**

Black Carbon (BC)

TABLE 27: TAIL PIPE BC EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	4.1	0.42	0.11	-	-
LPG	-	-	0.02	-	-
Diesel	10	59	122	31	60
BEV	-	-	-	-	-
CNG	-	-	-	-	-
Total	**14**	**60**	**122**	**31**	**60**

TABLE 28: ABRASION BC EMISSIONS BY VEHICLE CATEGORY AND ENGINE TYPE EXPRESSED IN TONNES

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	3.6	4.7	1.7	-	1.7
LPG	-	0.22	0.32	-	-
Diesel	0.2	4.1	7.5	3.1	9.1
BEV	0.02	0.01	0.02	-	-
CNG	-	0.03	0.07	-	-
Total	**3.9**	**9.1**	**10**	**3.1**	**11**

Ammonia (NH_3)

TABLE 29: TAIL PIPE NH_3 EMISSIONS BY VEHICLE CATEGORY IN KG

	Motorcycles	Passenger cars	Light Duty Vehicles	Buses and coaches	Heavy Duty Vehicles
Petrol	8.6	84	18	-	0.23
LPG	-	4.0	3.4	-	-
Diesel	0.27	2.0	3.0	0.65	1.9
BEV	-	-	-	-	-
CNG	-	0.44	0.65	-	-
Total	**8.8**	**91**	**25**	**0.65**	**2.1**

Heavy Metals

TABLE 30: TAIL PIPE HEVAY METALS EMISSIONS BY VEHICLE CATEGORY IN KG

	Pb	Cd	Cu	Cr	Ni	Se	Zn	Hg	As
Motorcycles	1,092	0.70	115	3.9	5.1	0.70	72	1.5	0.050
Passenger cars	1,137	2.6	441	13	18	2.6	262	2.0	0.062
Light Duty Vehicles	268	2.1	357	11	15	2.1	210	1.3	0.029
Buses and coaches	0.03	0.32	55	1.8	2.2	0.32	33	0.31	0.01
Heavy Duty Vehicles	0.083	1.10	188	5.9	7.7	1.11	111	0.87	0.019
Total	**2,497**	**6.9**	**1 157**	**35**	**48**	**6.8**	**688**	**6.0**	**0.17**

TABLE 31: ABRASION HEVAY METALS EMISSIONS BY VEHICLE CATEGORY IN KG

	Pb	Cd	Cu	Cr	Ni	Se	Zn	As
Motorcycles	113	0.51	920	42	6.5	0.80	321	1.3
Passenger cars	359	1.5	2,961	135	20	2.1	870	4.1
Light Duty Vehicles	340	1.5	2,791	127	19	2.2	868	3.9
Buses and coaches	108	0.47	887	40	6.2	0.69	279	1.2
Heavy Duty Vehicles	378	2	3,101	141	22	2	974	4
Total	**1,298**	**6**	**10,659**	**485**	**74**	**8**	**3,312**	**15**

4.5.4 Methodological issues and ways of improvements

4.5.4.1 Activity data

More detailed information on the vehicle fleet in Chiang Mai represents the main source of improvement in activity data. Another important source of improvement would be to produce average annual vehicle mileage broken down per engine type and age. It is generally observed that gasoline-powered vehicles travel fewer kilometers than diesel-powered vehicles. This is also true for older vehicles compared to newer ones.

A high degree of uncertainty is associated with heavy-duty vehicle and bus fleets. For example, it might be relevant to identify the bus routes to know more precisely the mileage covered by the fleet. Also, a survey of merchandise transport in Chiang Mai could help to better understand truck activity in the region.

Finally, given the large number of vehicle categories in Chiang Mai, it would seem appropriate to disaggregate the categories at a finer level, to include tuk-tuks and songthaews, in particular.

4.5.4.2 Exhaust emissions.

The calculation of emissions associated with fuel combustion could be refined by distinguishing emission factors by type of road network. This would mean using the Tier 3 method of the EMEP/EEA guidebook. In fact, the Tier 2 method uses average hot/cold emission distributions and network types, mostly derived from tests carried out in Europe.

Isolating tuktuk and songthaew activity would also enable local emission factors to be associated with them.

4.5.4.3 Evaporation

Emissions from gasoline evaporation can be improved by taking local temperature conditions into account, i.e. by moving from Tier 1 to Tier 2.

4.5.4.4 Emissions from automobile tire and brake wear and road abrasion

Increased knowledge of the distances covered by vehicles will have a direct positive impact on the accuracy of abrasion emissions calculations.

4.6 RAILWAYS (NFR SUBSECTOR 1.A.3.C)

4.6.1 Overview of the sector

The current sector covers emissions of the railway sector. Chiang Mai province has just one railway station, located in the city. As a result, only one train line exists, coming from the Bangkok region, and for which the length of the network within Chiang Mai province is small, i.e. 24 km. As a result, this sector represents only a tiny fraction of total provincial emissions since it contributes in 2022 as follows: NOx emissions for 0.081% of the total, emissions of CO for 0.004%, NMVOC for 0.005%, PM_{10} and $PM_{2.5}$, for 0.006% and 0.009%, respectively, of the total.

4.6.2 Methodology

The methodology used to estimate rail emissions is described by the following equation:

$$E_{i,j} = EC_{nat} \times \frac{L_{CM}}{L_{Nat}} \times EF_{i,j}$$

Where:

- EC_{nat} the national energy consumption of the railway sector.
- L_{CM} network length in Chiang Mai.
- L_{Nat} national network length.
- $EF_{i,j}$ emission factor depending on pollutant and energy source.

4.6.2.1 Activity data

The national rail energy consumption is given by the Thai energy balance for the year 2014 to 2022. This was then declined on a provincial level according to the length of the rail network[2]. Note that only diesel and electricity are considered energy sources.

4.6.2.2 GHG emissions

GHG emissions calculation methodology follows IPCC guidelines for mobile sources. The following emissions factor are therefore considered:

Carbon dioxide (CO_2)

- For diesel fuel: 74.1 kg/GJ.

Nitrous oxide (N_2O)

- For diesel fuel: 0.029 kg/GJ.

Methane (CH_4)

- For diesel fuel: 0.004 kg/GJ.

4.6.2.3 Atmospheric pollutants emissions

Atmospheric pollutant emissions calculation methodology follows the Tier 1 approach of the guidebook EMEP/EEA (1.A.3.C Railways). The following emissions factors are therefore considered (Table 32):

TABLE 32: POLLUTANT EMISSION FACTORS CONSIDERED FOR RAIL SECTOR

Pollutant	Unit	Emission factor
SO_2	kg/TJ	2.25
NOx	kg/tonne fuel	52
CO	kg/tonne fuel	11
NMVOC	kg/tonne fuel	4.7
NH_3	kg/tonne fuel	0.007
TSP	kg/tonne fuel	1.52
PM_{10}	kg/tonne fuel	1.4
$PM_{2.5}$	kg/tonne fuel	1.4
BC	kg/tonne fuel	0.65
Cd	kg/tonne fuel	0.010
Cu	kg/tonne fuel	1.7

Note that SO_2 emissions were calculated considering a sulfur content of 50 ppm in diesel fuel, data taken from fuel specifications provided by the Department of Energy Business.

4.6.3 Results: Emissions from rail transport in 2022

The table below summarizes the energy consumption and emissions associated with the rail sector.

TABLE 33: ENERGY CONSUMPTION AND ASSOCIATED EMISSIONS – RAIL SECTOR

Pollutant	Unit	2014	2015	2016	2017	2018	2019	2020	2021	2022
Fuel cons.	TJ	16.88	18.07	18.31	16.17	18.55	17.12	16.88	16.17	20.21
SO2	kg	38	41	41	36	42	39	38	36	46
NOx	kg	19,921	21,324	21,604	19,079	21,885	20,201	19,921	19,079	23,849
CO	kg	4,068	4,354	4,412	3,896	4,469	4,125	4,068	3,896	4870
NMVOC	kg	1,768	1,892	1917	1,693	1,942	1,793	1,768	1,693	2,116
NH_3	kg	2.7	2.8	2.9	2.5	2.9	2.7	2.7	2.5	3.2
TSP	kg	578	619	627	553	635	586	578	553	692

[2] Railway Network of Thailand - Dataset OD Mekong Datahub (opendevelopmentmekong.net)

Pollutant	Unit	2014	2015	2016	2017	2018	2019	2020	2021	2022
PM_{10}	kg	547	586	594	524	601	555	547	524	655
$PM_{2.5}$	kg	521	558	565	499	572	528	521	499	624
BC	kg	247	265	268	237	271	251	247	237	296
Cd	kg	3.8	4.1	4.1	3.6	4.2	3.9	3.8	3.6	4.6
Cu	kg	646	692	701	619	710	655	646	619	774
CO_2	tonnes	1,251	1,339	1,356	1,198	1,374	1,269	1,251	1,198	1,498
CH_4	kg	70	75	76	67	77	71	70	67	84
N_2O	kg	483	517	524	463	531	490	483	463	578

4.6.4 Methodological issues and ways of improvements

As the rail sector is far from being a key source of emissions, the challenges of methodological improvement are not great. Nevertheless, rather than using a ratio of network length, it might be interesting to know the number of locomotives in Chiang Mai, as well as their annual running times.

4.7 PIPELINE COMPRESSORS (NFR SUBSECTOR 1.A.3.E)

Pipeline compressors category (1.A.3e) includes all emissions from fuels delivered to the transportation by pipelines and storage of natural gas. Relevant pollutant emissions typical of a combustion process, such as SO_X, NO_X, CO, and PM emissions, derive from this category.

As we have assumed that no natural gas is used in Chiang Mai province, this emission sector is not included.

4.8 CIVIL SECTOR: SMALL COMBUSTION AND OFF-ROAD VEHICLES (NFR SUBSECTOR 1.A.4 - 1.A.5)

Emissions from energy use in the civil sector cover combustion in small-scale combustion units, with thermal capacity < 50 MWth and off-road vehicles in the commercial, residential, and agriculture sectors.

The emissions refer to the following categories:

- 1 A 4 a i Commercial / Institutional: Stationary,
- 1 A 4 a ii Commercial / Institutional: Mobile - IE (Included Elsewhere),
- 1 A 4 b i Residential: Stationary plants,
- 1 A 4 b ii Residential: Household and gardening (mobile) - IE,
- 1 A 4 c i Agriculture/Forestry/Fishing: Stationary,
- 1 A 4 c ii Agriculture/Forestry/Fishing: Off-road Vehicles and Other Machinery,
- 1A 4 c iii Agriculture/Forestry/Fishing: National Fishing,
- 1 A 5 a Other, Stationary (including military) - IE; and
- 1 A 5 b Other, Mobile (Including military, land based and recreational boats) - IE.

4.8.1 Commercial/Institutional (1A4a)

4.8.1.1 Overview

The Commercial / Institutional emissions arise from the energy used in the institutional, service, and commercial buildings.

4.8.1.2 Methodology

Activity data

The fuel consumption of the Chiang Mai province for the commercial/institutional sector is not directly known. They are deduced from the national energy balance and the number of buildings distribution between the

Chiang Mai province and the national level (ฐานข้อมูล Building Energy Code (BEC) - https://bec.dede.go.th/bec/ - accessed in 2024 January). The year for which the building numbers are provided is unclear. It is assumed that the data is from 2021, and due to the absence of additional building information, this assumption is applied to the entire time period (

Table 34).

TABLE 34. NUMBER OF BUILDINGS IN THE CHIANG MAI PROVINCE AND AT NATIONAL LEVEL

Building Type	Thailand	Chiang Mai
Hospital	194	7
School	432	32
Office	1,181	60
Conventional building	198	26
Theaters	20	1
Hotel	810	147
Entertainment building	162	6
Department Store	881	13
Mixed use	401	43
Not specified	-	-
Condominium (excluded)	3,416	386
Total	4,279	335

Only two different types of fuel are attributed to this sector in the Thai national energy balance:

- Liquefied Petroleum Gases.
- Natural Gas.

Net Calorific Values (NCV) for all fuels were derived from Thailand Energy Balance and presented below (Table 35). If necessary, they are used to convert fuel consumption data into energetic unit.

TABLE 35. NET CALORIFIC VALUES USED IN THE COMMERCIAL/INSTITUTIONAL SECTOR

Fuel Type	LPG	Natural Gas
Net Calorific Value	26.62 MJ/liter	1.02 MJ/scf

LPG fuel consumptions for the years 2014-2017 were recalculated from residential and commercial total petroleum product consumption data available in the 2018 and 2019 energy balances for these years by assuming the proportion between the two sectors was the same for 2018-2019 and 2014-2017.

It is assumed that there is no natural gas consumption for fixated installations. In fact, there is no gas pipeline between the south of the country and Chiang Mai. If natural gas was to be consumed in the province, it could only be transported by lorry or train, which is not yet a very common technique. Thus, we consider that there is no natural gas consumption in the Chang Mai province.

For the GHGs and pollutant emissions, emission factors from the ABC EIM (Shrestha et al., 2013) were used in priority if available considering they refer to more specific studies applicable in the Southeast Asian area. If no emission factor is available though:

- GHG emissions factors of LPG and natural gas are provided by the IPCC 2006 guidelines. Default emission factors from IPCC are used.
- Pollutant emission factors are provided by the EMEP/EEA 2023 guidebook - Tier 1.

For natural gas, emission factors are available for two specific uses: "Stationary Combustion Device" or "Space Heating" but there may be difference in the units that are presented in table 3.19 of ABC EIM which the authors converted the unit g/kg for consistency with other fuel types. Hence, default EFs from IPCC are used instead.

GHG emissions

A Tier 1 methodology IPCC 2006 is applied, following this equation:

EQUATION 2.1
GREENHOUSE GAS EMISSIONS FROM STATIONARY COMBUSTION

$$Emissions_{GHG,\,fuel} = Fuel\ Consumption_{fuel} \bullet Emission\ Factor_{GHG,\,fuel}$$

Where:

$Emissions_{GHG,fuel}$ = emissions of a given GHG by type of fuel (kg GHG)

$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)

$Emission\ Factor_{GHG,fuel}$ = default emission factor of a given GHG by type of fuel (kg gas/TJ). For CO_2, it includes the carbon oxidation factor, assumed to be 1.

Total emissions for each GHG are computed using the following equation:

EQUATION 2.2
TOTAL EMISSIONS BY GREENHOUSE GAS

$$Emissions_{GHG} = \sum_{fuels} Emissions_{GHG,fuel}$$

Carbon dioxide emissions

CO_2 emissions were calculated using emission factors:

- from the ABC EIM (2013) for the LPG fuel (in gCO_2/kg fuel) type: 2,958.62 g/kg.
- and from the IPCC 2006 - Volume 2 Chapter 2 Stationary combustion for the natural gas fuel type (in gCO_2/GJ fuel): 56,100 g/GJ.

Methane emissions

Methane emissions were calculated using emission factors:

- from the ABC EIM (2013) for the LPG fuel type (in gCH_4/kg fuel): 0.04 g/kg.
- and from the IPCC 2006 - Volume 2 Chapter 2 Stationary combustion for the natural gas fuel type (in gCH_4/GJ fuel): 5.0 g/GJ.

Nitrous oxide emissions

Nitrous oxide emissions were calculated using emission factors:

- from the ABC EIM (2013) for the LPG fuel type (in gN_2O/kg fuel): 0.19 g/kg.
- and from the IPCC 2006 - Volume 2 Chapter 2 Stationary combustion for the natural gas fuel type (in gN_2O/GJ fuel): 0.10 g/GJ.

Atmospheric pollutants emissions

A Tier 1 methodology EMEP/EEA 2023 is applied, following this equation:

$$E_{pollutant} = AR_{fuelconsumption} \times EF_{pollutant}$$

where:

$E_{pollutant}$	= the emission of the specified pollutant,
$AR_{fuelconsumption}$	= the activity rate for fuel consumption,
$EF_{pollutant}$	= the emission factor for this pollutant.

SO_2 emissions

SO_2 emission factors for LPG that are provided in the 3.19 table of the ABC EIM (2013) are expressed in sulfur content and thus cannot be used as such. The EF provided in table 3.17 for the residential sector of the same reference was used instead.

Sulfur oxide emissions were calculated using emission factors:

- from the ABC EIM (2013) for the LPG fuel type: 0.33 g/kg.

  and from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-8 Tier 1 emission factor for NFR source category 1.A.4.a/c, 1.A.5.a, using gaseous fuels) for the natural gas fuel type: 0.67 g/GJ.

NOx emissions

Nitrogen oxide emissions were calculated using emission factors:

- from the ABC EIM (2013) for the LPG fuel type: 3.1 g/kg.
- and from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-8 Tier 1 emission factor for NFR source category 1.A.4.a/c, 1.A.5.a, using gaseous fuels) for the natural gas fuel type: 74 g/GJ.

NMVOCs emissions

NMVOCs emissions were calculated using emission factors from the same reference for both fuel types (and from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion - Table 3-8 Tier 1 emission factor for NFR source category 1.A.4.a/c, 1.A.5.a, using gaseous fuels): 23 g/GJ.

CO emissions

Carbon monoxide emissions were calculated using emission factors:

- from the ABC EIM (2013) for the LPG fuel type: 0.43 g/kg.
- and from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-8 Tier 1 emission factor for NFR source category 1.A.4.a/c, 1.A.5.a, using gaseous fuels) for the natural gas fuel type: 29 g/GJ.

Particulate emissions

TSP, PM_{10} and $PM_{2.5}$ emissions were calculated using emission factors:

- from the ABC EIM (2013) for the LPG fuel type: 0.52 g/kg for the $PM_{2.5}$.

  LPG emission factors for TSP and PM_{10} are based on $PM_{2.5}$ EF but are deduced from the EMEP/EEA 2023 guidebook - Tier 1 using $PM_{2.5}/PM_{10}$ and $PM_{2.5}$/TSP ratios (*i.e.*. 100%).
- and from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-8 Tier 1 emission factor for NFR source category 1.A.4.a/c, 1.A.5.a, using gaseous fuels for the natural gas fuel type: 0.78 g/GJ for TSP, PM_{10} and $PM_{2.5}$.

<u>Heavy metals emissions</u>

Heavy metal emissions were calculated using emission factors from the same reference for both fuel types (and from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-8 Tier 1 emission factor for NFR source category 1.A.4.a/c, 1.A.5.a, using gaseous fuels):

- For lead (Pb): 11 µg/GJ.
- For cadmium (Cd): 0.9 µg/GJ.
- For mercury (Hg): 100 µg/GJ.

4.8.1.3 Methodological issues

Activity data

Fuel consumption levels are calculated using building number repartition data between national level and the Chang Mai province. This assumption should be reviewed and verified.

The fuel consumption data doesn't distinguish between different uses that may have different emission factors.

Emission factors

Emission factors that were used originated from Southeastern Asian references if available.

4.8.1.4 Ways of improvements

Activity data

It may be a more appropriate approach to calculate emissions from the commercial/residential sector from a more accurate reference, for example energy supply tables for the Northern Region or even better for the Chang Mai province itself.

Emission factors

It may be a more appropriate approach to use country-specific emission factors and associated with a more detailed disaggregation of commercial/institutional fuel use.

4.8.2 Residential (1A4b)

4.8.2.1 Overview of the sector

In the residential sector the emissions arise from the energy used in residential buildings and the sector includes emissions from household and gardening machinery.

4.8.2.2 Methodology

Activity data

The fuel consumption of the Chiang Mai province for the residential sector is not directly known. They are deduced from the national energy balance and population distribution between the Chiang Mai province and the national level (Statistics of the population from Registration - NSO - Dashboard - accessed 15 December 2023) as presented in Table 36.

TABLE 36. POPULATION DATA

Scale	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Thailand	64,073,033	64,456,695	64,785,909	65,124,716	65,729,098	65,931,550	66,188,503	66,413,979	66,558,935	66,186,727	66,171,439
Northern region	11,783,311	11,802,566	11,825,955	11,846,651	12,072,421	12,079,106	12,098,164	12,115,915	12,119,572	12,027,271	12,010,024
Chang Mai	1,646,144	1,655,642	1,666,888	1,678,284	1,728,242	1,735,762	1,746,840	1,763,742	1,779,254	1,784,370	1,789,385

Five different types of fuel are attributed to this sector in the Thai national energy balance:

- Firewood,
- Charcoal,
- Paddy husk,
- Agricultural waste; and
- Liquefied Petroleum Gases.

Net Calorific Value (NCV) for all fuels was derived from Thailand Energy Balance (Table 37). They are only used when emission calculation relies on emission factors that are available in GJ.

TABLE 37. NET CALORIFIC VALUES USED IN THE RESIDENTIAL SECTOR

Fuel Type	Firewood	Charcoal	Paddy husk	Agricultural waste	LPG
Net Calorific Value	15.99 MJ/kg	28.88 MJ/kg	14.40 MJ/kg	12.68 MJ/kg	26.62 MJ/liter

LPG fuel consumptions for years 2014-2017 are recalculated from residential and commercial total petroleum product consumption available in the 2018 and 2019 energy balances for these years by assuming the proportion between the two sectors is the same for 2018-2019 and 2014-2017.

For the greenhouse gases and pollutant emissions, emission factors from SEA references (Huy et al., 2021a and 2021b) were used in priority ("typical residential cookstoves") if available considering they refer to more specific studies applicable in the Southeast Asian area. If no emission factor is available though:

- GHG emissions factors of LPG and natural gas are provided by the IPCC 2006 guidelines. Default emission factors from IPCC are used.
- Pollutant emission factors are provided by the EMEP/EEA 2023 guidebook - Tier 1.

GHG emissions

A Tier 1 methodology IPCC 2006 is applied, following this equation:

EQUATION 2.1

GREENHOUSE GAS EMISSIONS FROM STATIONARY COMBUSTION

$$Emissions_{GHG,\,fuel} = Fuel\ \ Consumption_{fuel} \bullet Emission\ \ Factor_{GHG,\,fuel}$$

Where:

$Emissions_{GHG,fuel}$ = emissions of a given GHG by type of fuel (kg GHG)

$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)

$Emission\ Factor_{GHG,fuel}$ = default emission factor of a given GHG by type of fuel (kg gas/TJ). For CO_2, it includes the carbon oxidation factor, assumed to be 1.

Total emissions for each GHG are computed using the following equation:

EQUATION 2.2

TOTAL EMISSIONS BY GREENHOUSE GAS

$$Emissions_{GHG} = \sum_{fuels} Emissions_{GHG,\,fuel}$$

<u>Carbon dioxide emissions</u>

Carbon dioxide emissions are calculated using emission factors from the same references for all fuel types (Huy et al., 2021a and 2021b):

- For firewood: 1,564 g/kg fuel.

- For charcoal: 2,436 g/kg fuel.
- For paddy husk: 1,101 g/kg fuel.
- For agricultural waste: 1,101 g/kg fuel.
- For LPG: 3,085 g/kg fuel.

Methane emissions

Methane emissions are calculated using emission factors from the same references for all fuel types (Huy et al., 2021a and 2021b):

- For firewood: 5.03 g/kg fuel.
- For charcoal: 8.1 g/kg fuel.
- For paddy husk: 4.32 g/kg fuel.
- For agricultural waste: 4.32 g/kg fuel.
- For LPG: 0.28 g/ kg fuel.

Nitrous oxide emissions

Nitrous oxide emissions are calculated using emission factors from the same references for all fuel types (Huy et al., 2021a and 2021b):

- For firewood: 0.18 g/kg fuel.
- For charcoal: 0.21 g/kg fuel.
- For paddy husk: 0.18 g/kg fuel.
- For agricultural waste: 0.18 g/kg fuel.
- For LPG: 0.12 g/kg fuel.

Atmospheric pollutants emissions

A Tier 1 methodology EMEP/EEA 2023 is applied, following this equation:

$$E_{pollutant} = AR_{fuelconsumption} \times EF_{pollutant}$$

where:

$E_{pollutant}$	= the emission of the specified pollutant,
$AR_{fuelconsumption}$	= the activity rate for fuel consumption,
$EF_{pollutant}$	= the emission factor for this pollutant.

SO_2 emissions

Sulphur oxide emissions are calculated using emission factors from the same references for all fuel types (Huy et al., 2021a and 2021b):

- For firewood: 1.31 g/kg fuel.
- For paddy husk: 1.70 g/kg fuel.
- For agricultural waste: 1.70 g/kg fuel
- For LPG: 0.38 g/kg fuel

SO_2 emissions from charcoal are estimated with emission factor originated from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-6, Tier 1 emission factor for NFR source category 1.A.4.b, using biomass): 11 g/GJ.

NOx emissions

Nitrogen oxide emissions were calculated using emission factors from the same references for all fuel types (Huy et al., 2021a and 2021b):

- For firewood: 0.12 g/kg fuel.
- For paddy husk: 0.17 g/kg fuel.
- For agricultural waste: 0.17 g/kg fuel.
- For LPG: 3.26 g/kg fuel.

NO_X emissions from charcoal are estimated with emission factor originated from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-6, Tier 1 emission factor for NFR source category 1.A.4.b, using biomass): 50 g/GJ.

NMVOCs emissions

Non Methanic Volatile Organic Compounds emissions were calculated using emission factors from the same references for all fuel types (Huy et al., 2021a and 2021b):

- For firewood: 7.9 g/kg fuel.
- For paddy husk: 8.49 g/kg fuel.
- For agricultural waste: 8.49 g/kg fuel.
- For LPG: 2.7 g/ kg fuel.

NMVOC emissions from charcoal are estimated with emission factor originated from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-6, Tier 1 emission factor for NFR source category 1.A.4.b, using biomass): 600 g/GJ.

CO emissions

Carbon monoxide emissions are calculated using emission factors from the same reference for all fuel types (Huy et al., 2021a and 2021b):

- For firewood: 48 g/kg fuel.
- For paddy husk: 57 g/kg fuel.
- For agricultural waste: 57 g/kg fuel.
- For LPG: 17.9 g/ kg fuel.

CO emissions from charcoal are estimated with emission factor originated from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-6, Tier 1 emission factor for NFR source category 1.A.4.b, using biomass): 4,000 g/GJ.

Particulate emissions

$PM_{2.5}$ emissions were calculated using emission factors from the same reference for all fuel types (Huy et al., 2021a and 2021b):

- For firewood: 3.4 g/kg fuel.
- For charcoal: 2.4 g/kg fuel.
- For paddy husk: 4.89 g/kg fuel.
- For agricultural waste: 4.89 g/kg fuel.
- For LPG: 0.24 g/kg fuel.

Emission factors for TSP and PM_{10} are based on $PM_{2.5}$ EF but are deduced from the EMEP/EEA 2023 guidebook - Tier 1 (Table 3-4, Tier 1 emission factor for NFR source category 1.a.4.b, using gaseous fuels and Table 3-6, Tier 1 emission factor for NFR source category 1.A.4.b, using biomass) using $PM_{2.5}/PM_{10}$ and $PM_{2.5}$/TSP ratios:

- For firewood, charcoal, paddy husk and agricultural waste: 95% for $PM_{2.5}$/TSP and 92.5% for $PM_{2.5}/PM_{10}$.
- For LPG: 100% for $PM_{2.5}$/TSP and $PM_{2.5}/PM_{10}$.

Heavy metal emissions

For solid biomass fuels (firewood, charcoal, paddy husk and agricultural waste), heavy metal emissions were calculated using emission factors from the same reference for both fuel types (and from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion, Table 3-6, Tier 1 emission factor for NFR source category 1.A.4.b, using biomass):

- For lead (Pb): 27 mg/GJ.
- For cadmium (Cd): 13 mg/GJ.
- For mercury (Hg): 0.56 mg/GJ.

Heavy metal emissions were calculated using emission factors from the same reference for LPG and from the EMEP/EEA 2023 Guidebook 1A4 Small Combustion (Table 3-4, Tier 1 emission factor for NFR source category 1.a.4.b, using gaseous fuels):

- For lead (Pb): 11 µg/GJ.
- For cadmium (Cd): 0.9 µg/GJ.
- For mercury (Hg): 100 µg/GJ.

4.8.2.3 Methodological issues

Activity data

It may be a more appropriate approach to calculate emissions from the residential sector from a more accurate reference, for example, energy supply tables for the Northern Region or even better for the Chang Mai province itself.

4.8.2.4 Ways of improvements

Activity data

It may be a more appropriate approach to calculate emissions from the residential sector from a more accurate reference, for example energy supply tables for the Northern Region or even better for the Chang Mai province itself.

The fuel consumption data doesn’t distinguish between different uses that may have different emission factors.

Emission factors

It may be a more appropriate approach to use country-specific emission factors associated with a more detailed disaggregation of residential fuel use.

4.8.3 Agriculture/Forestry/Fishing (1A4c)

4.8.3.1 Overview of the sector

The current sector covers emissions from non-road vehicles and other machinery used in agriculture and forestry, as well as emissions from fishing boats. It contributes to the total Chiang Mai emissions in 2022 as follows: NOx emissions for 4.5% of the total, emissions of CO for 4.6%, NMVOCs for 0.6%, PM_{10} and $PM_{2.5}$, for 0.62% and 1%, respectively, of the total.

The estimation refers to the following categories:

- 1.A.4.c ii Agriculture/Forestry/Fishing: Off-road vehicles & other machinery.
- 1.A.4.c iii Agriculture/Forestry/Fishing: National fishing.

4.8.3.2 Methodology

Methodology for agriculture:

Emissions from agricultural machinery are calculated according to the equation below:

$$E_{i,j} = \sum_k S_k \times Ratio_k \times EC_{k,j} \times EF_{i,j}$$

Where:

- i = pollutant type.
- j = fuel type (diesel, four stroke gasoline, LPG and two stroke gasoline).
- k = crop type.
- $EF_{i,j}$ Emission Factor per pollutant and type of fuel expressed in [g/GJ fuel].
- $EC_{k,j}$ Energy consumption per cultivated area, type of crops and fuel [GJ/rai].
- S_k Land use area by cultivation type expressed in [Rai].
- $Ratio_k$ Harvested over Land use per crop type.

Methodology for forestry:

Emissions from forestry machinery are calculated according to the equation below:

$$E_{j,i} = \frac{S_{CM}}{S_{Nat}} \times Wood_{prod} \times EC_j \times EF_{j,i}$$

Where:

- i = pollutant type.
- j = fuel type (diesel, four stroke gasoline, LPG and two stroke gasoline).
- S_{CM} Forest land surface in Chang Mai [Rai].
- S_{Nat} Forest land surface in Thailand [Rai].
- $Wood_{prod}$ National wood production [m^3].
- EC_j Energy consumption per harvested wood volume [GJ/m^3].
- $EF_{i,j}$ Emission Factor per pollutant and type of fuel expressed in [g/GJ fuel].

Methodology for fishing:

Emissions from fishing activity are calculated according to the equation below:

$$E = EC \times Q_{fish} \times EF_i$$

Where:

- i = pollutant type.
- EC the energy consumption needed to catch one kg of fish.
- Q_{fish} the quantity of fish caught in Chiang Mai.
- EF an emission factor of pollutant i expressed kg/TJ fuel.

Activity data

Activity data for agriculture:

The data used to estimate energy consumption per cultivated area are based primarily on the statistics of Land Utilization by Region and Province for the years 2012 to 2021 based on OAE statistics for year 2012 to 2021 : *https://www.oae.go.th/* and presented in the below table (Table 38).

TABLE 38: LAND USE AREA (THOUSAND OF RAI)

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Paddy land	Thailand	69,630	69,065	68,839	68,734	68,730	68,728	68,718	68,722	69,070	65,406
Paddy land	Northern Region	15,777	15,748	15,750	15,752	15,751	15,753	15,748	15,748	15,932	15,099
Paddy land	Chiang Mai	542	541	542	542	542	542	542	541	542	510
Upland field crops	Thailand	30,804	30,759	30,763	30,731	30,735	30,734	30,733	30,736	31,282	30,885
Upland field crops	Northern Region	10,275	10,281	10,277	10,283	10,284	10,284	10,283	10,285	10,448	10,374
Upland field crops	Chiang Mai	209	210	209	209	209	209	209	210	236	238
Fruit trees and perennial trees	Thailand	35,548	36,504	36,759	36,925	36,936	36,932	36,933	36,936	38,525	39,378
Fruit trees and perennial trees	Northern Region	4,047	4,001	4,004	4,005	4,008	4,009	4,009	4,010	4,110	3,921
Fruit trees and perennial trees	Chiang Mai	708	708	708	708	708	708	708	708	708	604
Vegetables, cut flowers, and ornamental plants	Thailand	1,397	1,398	1398	1,399	1,402	1,401	1,402	1,402	1,572	1,115
Vegetables, cut flowers, and ornamental plants	Northern Region	446	447	446	447	447	447	448	448	486	420
Vegetables, cut flowers, and ornamental plants	Chiang Mai	123	123	123	123	,123	123	123	123	131	131
Others	Thailand	11,861	11,510	11,466	11,454	11458	11,458	11,459	11,455	8,803	12,961
Others	Northern Region	2,064	1,996	2,014	2,014	2,015	2,014	2,014	2,014	1,539	2,051
Others	Chiang Mai	255	246	248	248	248	248	248	248	194	215

OAE gives also statistics related to major and secondary rice cultivation in Thailand for allowing us to deduce a ratio between the harvested area and the Land use area for rice cultivation which is presented in Figure 23. For the other types of cultivation, the ratio between the harvested area and the Land use area is considered equal to one.

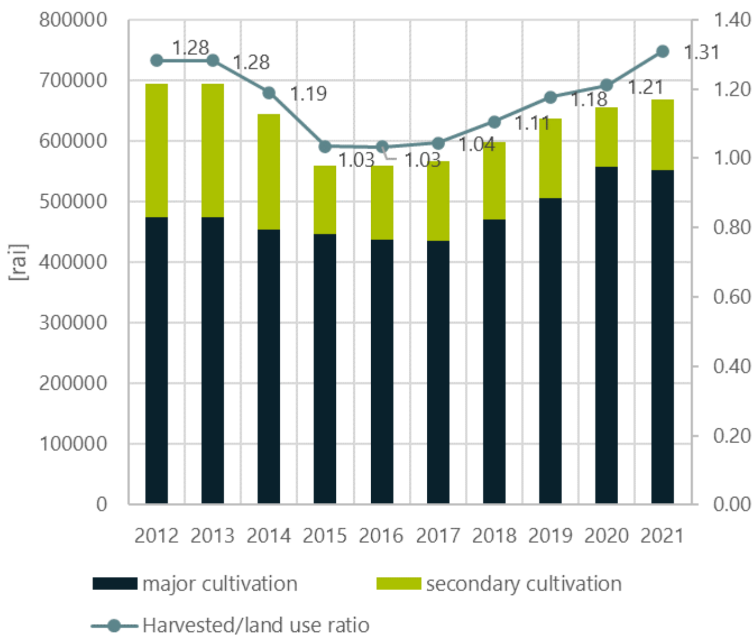


FIGURE 23: MAJOR AND SECONDARY RICE AREA CULTIVATED IN CHIANG MAI ON THE LEFT AXIS. HARVESTED AREA VS LAND USE AREA RATIO ON THE RIGHT AXIS.

The table below illustrates energy consumption by cultivated area and fuel type (Table 39). These were taken from Thambhitaks et al. (2021) for paddy land. For the other types of crops, the energy consumption was taken from Elsoragaby et al. (2019) and expressed par area of the farm covered. Therefore, the values were weighted by a level of mechanization derived from Soni et al. (2016). Note that since only Thambhitaks et al. (2021) distinguish consumption by fuel type (petrol or diesel), the consumption ratio between fuel types has been kept constant for all crop types.

TABLE 39: ENERGY CONSUMPTION PER TYPE OF CROP AND FUEL

Crop type	Fuel type	Fuel consumption (MJ/ha)
Paddy land	Gasoline	620
	Diesel	3,241
Upland field crops	Gasoline	718
	Diesel	3,755
Fruit trees and perennial trees	Gasoline	1,712
	Diesel	8,954
Vegetables, cut flowers, and ornamental plants	Gasoline	153
	Diesel	798
Others	Gasoline	861
	Diesel	4,502

<u>Activity data for forestry:</u>

Energy consumption in forestry was based on wood production. Since wood production in Chiang Mai is not known, Energy consumption has been estimated based on the following data:

- The ratio of forest area between the province and the country was given by OAE statistics.

- National wood production based on government statistics[3].
- Average fuel consumption per volume of harvested timber of 0.8 Liter/m^3 given by Lijewski et al, 2017.

Activity data for national fishing:

Only one activity data is available for fishing activity in Chiang Mai, corresponding to the quantity of fish caught. The value was 3,111 tonnes of fish (Department of Fisheries, Ministry of Agriculture and Cooperatives).
Fuel consumption is directly deduced from the quantity of fish caught, based on French fishing quantity (STECF data base) and emissions (French national inventory report) statistics that lead to a ratio of 2.29 kCO_2/kg of fish caught. This ratio has been validated from Munoz et al, 2022. Please note that only Marine Gas Oil (MGO) fuel has been considered for this activity.

GHG emissions

Carbon dioxide (CO_2):

Carbon dioxide emissions were calculated using emission factors from the same references for all fuel types, namely IPCC Guidelines (Volume 2, Chapter 3: Mobile Combustion). The associated activity data is the fuel consumption.

- For gasoline fuel: 69.3 kg/GJ.
- For diesel fuel: 74.1 kg/GJ.
- For Marine Gas Oil: 74.1 kg/GJ.

Nitrous oxide (N_2O):

Nitrous oxide emissions were calculated using emission factors from the same references for all fuel types, namely IPCC Guidelines (Volume 2, Chapter 3: Mobile Combustion). The associated activity data is the fuel consumption.

- 1.A.4.c ii Agriculture/Forestry/Fishing: Off-road vehicles & other machinery
  - For gasoline fuel: 0.002 kg/GJ.
  - For diesel fuel: 0.029 kg/GJ.
- 1.A.4.c iii Agriculture/Forestry/Fishing: National fishing
  - For Marine Gas Oil: 0.002 kg/GJ.

Methane (CH_4):

Methane emissions were calculated using emission factors from the same references for all fuel types, namely IPCC Guidelines (Volume 2, Chapter 3: Mobile Combustion). The associated activity data is the fuel consumption.

- 1.A.4.c ii Agriculture/Forestry/Fishing: Off-road vehicles & other machinery
  - For gasoline fuel: 0.080 kg/GJ.
  - For diesel fuel: 0.00415 kg/GJ.
- 1.A.4.c iii Agriculture/Forestry/Fishing: National fishing
  - For Marine Gas Oil: 0.007 kg/GJ.

[3] forestinfo.forest.go.th/Content/file/stat2565/forest 2565.pdf

Atmospheric pollutant emissions

Sulphur dioxide (SO_2):

Sulphur dioxide emissions depend directly on the amount of sulfur in the fuel, and therefore on fuel regulations. Sulfur contents in gasoline and diesel fuels, in accordance with the information were provided by the Department of Energy Business, are equal to 50 ppm/wt.

Other pollutants

Pollutant emissions are calculated using emission factors from the same references for all fuel types which is the Tier 1 methodology of the EMEP/EEA 2023 guidebook (1A4cii Agriculture/Forestry/Fishing: Off-road vehicles & other machinery and 1A3d - navigation). The associated activity data is the mass fuel consumption.

4.8.3.3 Results: Off-road vehicles & other machinery and national fishing

The tables below (Table 40 and Table 41) summarizes the emissions from off-road and other machinery as well as national fishing sectors.

Agricultural off-road vehicles & other machinery

TABLE 40: EMISSIONS EXPRESSED IN TONNES FOR AGRICULTURAL MACHINERY

Pollutant	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
SO_2	4.60	4.59	4.52	4.40	4.40	4.41	4.46	4.51	4.47	4.14
CO_2	148,340	147,777	145,667	141,815	141,752	142,051	143,586	145,289	144,159	133,264
CH_4	36	35	35	34	34	34	34	35	35	32
N_2O	48	48	48	46	46	46	47	47	47	43
CO	6,979	6 952	6 862	6 696	6 693	6 706	6 772	6 845	6 786	6 259
NOX	1,354	1,349	1,329	1,294	1,293	1,296	1,310	1,326	1,316	1,217
TSP	73	73	72	70	70	70	71	72	71	66
PM_{10}	73	73	72	70	70	70	71	72	71	66
$PM_{2.5}$	73	73	72	70	70	70	71	72	71	66
BC	42	42	41	40	40	40	40	41	41	38
NH_3	0.3342	0.3330	0.3282	0.3194	0.3193	0.3200	0.3235	0.3273	0.3248	0.3003
NMVOC	294	292	288	281	281	282	284	288	285	263

Forestry off-road vehicles & other machinery

TABLE 41: EMISSIONS EXPRESSED IN TONNES FOR FORESTRY MACHINERY

Pollutant	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
SO_2	0.0009	0.0013	0.0012	0.0013	0.0020	0.0017	0.0017	0.0030	0.0026	0.0025
CO_2	29	41	38	42	64	56	56	98	83	81
CH_4	0.006	0.009	0.008	0.009	0.014	0.013	0.012	0.022	0.018	0.018
N_2O	0.0095	0.0136	0.0126	0.0139	0.0212	0.0187	0.0186	0.0326	0.0275	0.0270
CO	1.2	1.7	1.6	1.8	2.7	2.4	2.4	4.1	3.5	3.4
NOX	0.22	0.32	0.29	0.32	0.49	0.43	0.43	0.76	0.64	0.63
TSP	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.02
PM_{10}	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.02
$PM_{2.5}$	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.02
BC	0.005	0.007	0.006	0.007	0.010	0.009	0.009	0.016	0.013	0.013
NH_3	0.00006	0.00009	0.00009	0.00010	0.00015	0.00013	0.00013	0.00022	0.00019	0.00018
NMVOC	0.04	0.06	0.06	0.06	0.10	0.08	0.08	0.15	0.12	0.12

Fishing off-road vehicles & other machinery

Table 42 summarizes emissions from national fishing.

TABLE 42: EMISSIONS EXPRESSED IN TONNES FOR NATIONAL FISHING

Pollutant	2021
SO_2	4.2
CO_2	7,117
CH_4	0.67
N_2O	0.19
CO	9.9
NOX	91
TSP	2.2
PM_{10}	2.2
$PM_{2.5}$	1.9
BC	0.016
NH_3	0.10
NMVOC	6.0

4.8.3.4 Methodological issues and ways of improvements

Agricultural off-road vehicles & other machinery

High level of uncertainty associated with calculating consumption by surface area. An area for improvement would be to know the number of tractors and machines operating in Chiang Mai. DLT data on the tractor fleet could not be used due to the lack of information on vehicles leaving the fleet.

Forestry off-road vehicles & other machinery

The methodology could be refined by knowing the wood production in Chiang Mai province.

National fishing

At this stage, the methodology could be entirely revised based on the available statistical data. In particular, having detailed information on the fleet of fishing boats in Chiang Mai would be essential for more accurately estimating emissions. The CO_2 emission factor currently used is quite uncertain and is also employed to estimate fuel consumption for the boats. However, this factor is more representative of sea-based activities, which does not apply to Chiang Mai.

4.9 FUGITIVE EMISSIONS (NFR SUBSECTOR 1.B)

4.9.1 Overview of the sector

Fugitive emissions occur throughout the stages of fuel production, from the extraction of fossil fuels to their end use. These emissions primarily result from leaks or irregular releases of gases during the production and processing of solid fuels, oil and gas production, gas transmission and distribution, and oil refining.

4.9.2 Methodology and methodological issues

The following methodological issues including activity data and emission factors used are reported for each category and pollutant estimated in this sub sector.

4.9.2.1 Coal mining and handling (1B1a)

NO (Not Occurring)

4.9.2.2 Solid fuel transformation (1B1b)

NO (Not Occurring)

4.9.2.3 Oil exploration and production (1B2a i)

NO (Not Occurring)

4.9.2.4 Oil transport and storage and refining (1B2a iv)

NO (Not Occurring)

4.9.2.5 Distribution of oil products (1B2a v)

The category includes NMVOC fugitive emissions at service stations. Emission factors are taken from the ABC EIM (Shrestha et al., 2013).

In fact, no data is available in the case of Chiang Mai concerning the implementation of abatement technologies, such as devices for the recovery of vapors or measures on deposits of gasoline. Therefore, it cannot be concluded if such technologies and measures are applied in the province. In a study on emission control for VOC from gasoline stations, Huy et al. (2020) confirmed submerged filling measures were applied for all gasoline stations in Vietnam, in 2011. Therefore, we assume that this is also the case for Chiang Mai. The specific EF for submerged filling from the ABC EIM was hence applied. For the vehicle refueling emissions, no information is available concerning the recovery of vapors, hence the uncontrolled emission factor from ABC EIM (Shrestha et al., 2013) was applied (Table 43).

TABLE 43. EMISSION FACTORS FROM ABC MANUAL USED FOR THE CALCULATIONS

Submerged underground tank filling	0.0011	kg NMVOC/L gasoline consumed/sold
Uncontrolled vehicle refueling	0.0016	kg NMVOC/L gasoline consumed/sold

Fuel energy sales are available for the province of Chiang Mai and for Thailand from 2013 to 2022, particularly gasoline sales are detailed in different fuel specifications, but some data are missing and were completed using the ratio between Chiang Mai and Thailand sales (Table 44).

TABLE 44. FUEL ENERGY SALES IN CHIANG MAI ESTIMATED

Fuel sales in Chiang Mai estimated in thousands of liters	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Gasoline	197,501	199,549	258,164	282,260	280,953	289,352	301,347	286,288	262,715	273,329

Calculation of fugitive NMVOC emissions from service stations employed therefore a Tier 1 methodology as described in the ABC EIM manual:

$$E_{NMVOC} = FS \times EF_{NMVOC}$$

Where E (tonnes) and EF_{NMVOC} (kg NMVOC/L gasoline sold) represent respectively the emissions and emissions rate generated by the service stations (underground tank filling and vehicle refueling) from ABC EIM (Shrestha et al., 2013) and FS represents the gasoline fuel sales in thousands of litters sold per year. Based on this methodology, total fugitive NMVOC emissions from service stations were then estimated from 2013 to 2022 in Chiang Mai (Table 45).

TABLE 45. TOTAL NMVOC EMISSIONS FROM SERVICE STATIONS IN CHIANG MAI (TONNES/YEAR) (1B2A V)

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Fugitive NMVOC emissions (Tonnes)	529	534	691	755	752	774	806	766	703	731

4.9.2.6 Fugitive emissions from natural gas distribution (1.B.2b)

NO (Not Occurring)

4.9.2.7 Flaring in refineries (1B2c)

NO (Not Occurring)

4.9.2.8 Fugitive emissions from geothermal production (1B2d)

NO (Not Occurring)

4.9.3 Ways of Improvement

The estimation of NMVOC fugitive emissions from service stations can be improved with better knowledge of the regulations applied in the province, in terms of tank filling, tank storage and vehicle refilling.

4.10 RESULTS: EMISSIONS FROM ENERGY SECTOR

When focusing only on the Energy sector, the main source of air pollution is road transport for NOx (87% of energy emissions). $PM_{2.5}$ emissions are mainly issued from Residential and Commercial sector (57%) and road transport (35%) (Figure 24).

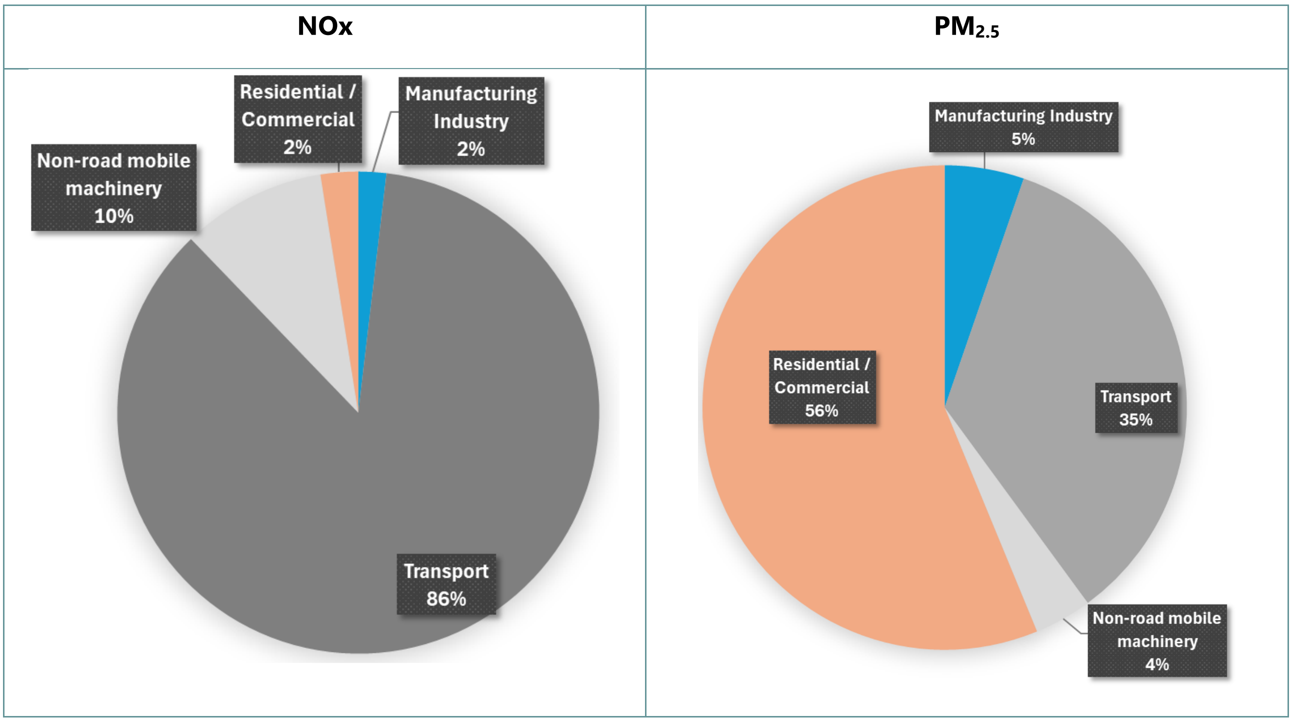


FIGURE 24: MAIN $PM_{2.5}$ AND NOX EMISSION FROM ENERGY SECTOR IN CHIANG MAI PROVINCE (%)

TABLE 46: EMISSIONS OF AIR POLLUTANTS AND GHGS FROM ENERGY SECTOR IN TONNES / YEAR (2022)

Tonnes/ year (2022)	Sector NFR	NOx	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	SO_2	CO_2	CH_4	N_2O
1a2	Manufacturing industries and construction	252.8	395.7	188.3	0.3	95.7	93.5	27.0	242.1	67,499.3	19.3	2.7
1a3a	Aviation	145.0	188.3	27.8		3.3	3.3	1.4	0.4	44,171.8	3.1	1.2
1a3b	Road transport	11,432.6	28,300.6	6,147.7	127.8	789.8	607.4	324.5	88.0	2,752,973.4	707.9	102.0
1a3c	Railways	23.8	4.9	2.1		0.7	0.6	0.3		1,497.9	0.1	0.6
1a4cii	Off-road vehicles and other machinery	1,217.2	6,262.5	263.6	0.3	65.7	65.7	37.6	4.1	133,345.3	31.9	43.5
1a4a	Commercial Institutional	129.2	17.9	44.0		21.7	21.7	2.9	13.8	123,516.4	1.7	7.9
1a4b	Residential	210.5	15,212.0	2,353.9	191.8	996.6	970.6	85.6	350.8	133,344.1	1,243.8	49.8
1a4ciii	Agricultural forestry fishing	90.6	9.9	6.0	0.1	2.2	1.9		4.2	7,117.4	0.7	0.2
1b2a5	Distribution of oil products			731								
Total		13,501.8	50,391.8	9,763.9	320.3	1,975.7	1,764.7	479.3	703.5	3,681,433.4	2,008.4	208.0

5 IPPU - INDUSTRIAL PROCESSES (NFR SECTOR 2)

Emission estimates in this category include emissions from all industrial processes and by-products or fugitive emissions, which originate from these processes. In Industrial sector, emissions can be released simultaneously from the production process and from combustion, as in the cement industry. Emissions from combustion and from processes are estimated separately and included in the appropriate categories, in sector 2 for processes and in sector 1 category 1.A.2 for combustion.

5.1 MINERAL PRODUCTS (NFR 2A)

5.1.1 Quarrying and mining (2A5a)

5.1.1.1 Overview of the sector

This chapter covers dust and particulate matter emissions from non-coal quarrying and mining. Depending on circumstances, this activity can contribute with a significant amount of TSP (total suspended particles), PM_{10} and $PM_{2.5}$. This sector does not include emissions from the combustion of fuels in the quarry and in the plant (drillers, mobile crushers, mobile screeners, electric generators, etc.) or transport machinery (loaders, dumpers, cranes, etc.).

5.1.1.2 Methodology

Activity data

The quarrying and mining sector's data used as activity is the production of minerals in Chiang Mai extracted from the production data of minerals by kind of mineral region and province for the years 2011 to 2020 (Table 47). The activity data was provided by the Department of Primary Industries and Mines, Ministry of industry.

TABLE 47: PRODUCTION OF MINERALS EXTRACTED IN TONNES IN CHIANG MAI PROVINCE

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Andesite							217,466	484,820	52,626	562,221
Limestone	1,538,608	2,051,300	1,966,600	2,141,495	2,703,100	2,811,000	2,052,226	2,963,568	1,397,654	2,226,635
Manganese				500	4,000	400	3,520	500	4,800	1,400
Scheelite	138	130	139	127	42	42	82	48	41	110
Tin Concentrates	228	154	75	100	39	41	36	57	55	110
Total (Tonnes)	1,538,974	2,051,584	1,966,814	2,142,223	2,703,185	2,811,483	2,270,162	3,448,993	1,450,424	2,789,090

Due to the lack of detailed production data for the emissions sources of quarrying and mining (Drilling and blasting, Material processing, internal transport, material handling operations, and wind erosion from stockpiles) and abatement technologies data, the Tier 1 "worst case" approach is used.

GHG emissions

There are no greenhouse gas emissions occurring from the processes of quarrying and mining.

Atmospheric pollutants emissions

The atmospheric pollutants emitted from quarrying and mining activities are dust and particles (TSP, PM_{10}, and $PM_{2.5}$). The methodology used to estimate emissions from the quarrying and mining sector was the Tier 1 methodology from the EMEP/EEA Guidebook 2023, 2.A.5.a quarrying and mining of minerals other than coal.

The total mineral production per year and per mineral in the province of Chiang Mai is multiplied by the default values of emissions factors provided by the EMEP/EEA Guidebook:

$$\mathbf{E}_{\text{pollutant}} = \mathbf{AR}_{\text{production}} \times \mathbf{EF}_{\text{pollutant}}$$

Where:

- $\mathbf{E}_{\text{pollutant}}$: the emission of the specified pollutant,
- $\mathbf{AR}_{\text{production}}$: the activity rate for the quarrying/mining; and
- $\mathbf{EF}_{\text{pollutant}}$: the emission factor for this pollutant.

The emission factors used for emissions estimation for the quarrying and mining sector are default emission factors originating from the EMEP/EEA guidebook 2023 (Table 3-1: Tier 1 emission factors for source category 2.A.5.a Quarrying and mining of minerals other than coal) (Table 48).

TABLE 48: TIER 1 EMISSION FACTORS FOR SOURCE CATEGORY 2.A.5.A QUARRYING AND MINING

Pollutant	Emission factor (g/Mg)
TSP	102
PM_{10}	50
$PM_{2.5}$	5

5.1.1.3 Methodological issues and ways of improvements

The estimation of dust and particulate matter emissions from quarries and mines can be improved with a better knowledge of the different parameters characterizing the processes that are sources of emissions (Drilling and blasting, Material processing, internal transport, material handling operations and wind erosion from stockpiles).

It may be a more appropriate approach to elaborate a list of default values for the different parameters described in the EMEP guidebook for quarrying and mining, to estimate emissions more accurately using the Tier 2 methodology.

5.1.2 Construction and demolition (2A5b)

5.1.2.1 Overview of the sector

This chapter discusses emissions from the construction sector. The construction of infrastructure and buildings constitutes an important source of fugitive particulate matter (PM) emissions. It is frequently observed that elevated PM_{10} concentrations are around construction works. A significant proportion of construction activities takes place in urban and other densely populated areas. Consequently, many people may be exposed to PM emitted from construction activities.

Construction and demolition activities may emit other pollutants, besides being a source of fugitive PM emissions, such as NOx, CO_2 and NMVOC emissions from the use of products and combustion. This chapter only considers fugitive PM emissions, all combustion and product use emissions are estimated elsewhere (Sector 1 – Energy).

5.1.2.2 Methodology

Activity data

The construction and demolition sector's data used as activity is the area of building construction by type of building in Chiang Mai province in 2021. The types of construction considered for the construction emission estimation are four:

- Construction of houses.
- Construction of apartment building.
- Non-residential construction.
- Road construction.

The area of building in Chiang Mai province was obtained using the area of building in the Northern region, divided by a population ratio between the Northern region and the province of Chiang Mai (

Table 49). The population data is provided by the dashboard from the National Office of Statistics (NSO).

TABLE 49: AREA OF BUILDINGS FOR CONSTRUCTION AND DEMOLITION ACTIVITIES IN CHIANG MAI FOR 2021

	Municipal areas (m^2)		Non-municipal areas (m^2)		
Type of construction	New construction	Addition, Alteration	New construction	Addition, Alteration	Total (m^2)
Construction of houses	517,260.6	6,346.9	262,921.8	5,173.6	791,702.9
Construction of apartment buildings	8,894.6	1,920.8	1,323.0	37.5	12,175.9
Non-residential construction	138,615.2	34,241.1	114,077.9	2,215.3	289,149.5
Road construction	-	-	-	-	-

GHG emissions

There are no greenhouse gas emissions occurring from the processes of construction and demolition.

Atmospheric pollutants emissions

The methodology used to estimate emissions from the construction and demolition sector is Tier 1 methodology from the EMEP/EEA guidebook 2023, 2.A.5.b construction and demolition. The method involves multiplication of a specific emission factor for each type of construction with the total area affected by that specific type of construction (e.g., the area of the bare construction site) and the average duration of the construction. The method offers the further option to correct for the soil moisture content and the soil particle size distribution (which both affect dust sensitivity).

$$\mathbf{EM_{pollutant} = EF_{pollutant} \times A_{affected} \times d \times (1\text{-}CE) \times (24/PE) \times (s/9\%)}$$

Where:

- $EM_{pollutant}$: pollutant emissions (kg/year),
- $EF_{pollutant}$: emission factor for the pollutant (kg/[m^2.year]),
- $A_{affected}$: area affected by construction activity (m^2),
- d: duration of construction (year),
- CE: efficiency of emission control measures (-),
- PE: Thornthwaite precipitation-evaporation index (-); and
- S: soil silt content (%).

The emission factors (EF) and the other parameters used for emissions calculation were default values originating from the EMEP/EEA guidebook 2023, 2A5b Construction and Demolition (Table 50).

TABLE 50: PM DEFAULT EMISSIONS FACTORS BY TYPES OF CONSTRUCTION

Type of construction	TSP (kg/ [m^2. year])	PM_{10} (kg/ [m^2. year])	$PM_{2,5}$ (kg/ [m^2. year])
Construction of houses	0.29	0.086	0.0086
Construction of apartment buildings	1	0.3	0.03
Non-residential construction	3.3	1	0.1
Road construction	7.7	2.3	0.23

The duration of the construction activity (d) for a type of construction is the total duration of all activities from land clearing and/or demolition to the finishing structure. The following average values were used for the emission calculation (Table 51).

TABLE 51: DEFAULT VALUES FOR ESTIMATED DURATION BY TYPE OF CONSTRUCTION (D)

Type of construction	Estimated duration (year)
Construction of houses	0.5 (6 months)
Construction of apartment buildings	0.75 (9 months)
Non-residential construction	0.83 (10 months)
Road construction	1 (12 months)

The control efficiency factor (CE) of applied emission reduction techniques was used in the emissions estimation. In fact, watering of temporary unpaved roads is a simple and effective emission control measure that is widely used in construction, especially during dry periods.

The effect of watering is the highest directly after spraying and then decreases again as the road surface dries. It is assumed that in general watering routinely takes place in heavy construction activities during dry periods, resulting in an overall emission reduction of 50%. This translates to the following control efficiencies default values by type of construction (Table 52).

TABLE 52: CONTROL EFFICIENCY OF APPLIED EMISSION REDUCTION MEASURES (CE)

Type of construction	Control efficiency (-)
Construction of houses	0
Construction of apartment buildings	0
Non-residential construction	0.5
Road construction	0.5

The Thornthwaite precipitation-evaporation (PE) index is used for emission estimation for construction in Chiang Mai as an indicator of the soil moisture content. One of the parameters that has the strongest influence on soil dust sensitivity is the soil moisture content.

The Tier 1 EMEP EEA guidebook methodology provides the following default values for the PE. The mean PE index is calculated to have a specified value per type of climate (Table 53). It is considered that the Chiang Mai province has a humid climate in general, and that the mean PE index used for emissions estimation is the PE index for humid climate (95.5).

TABLE 53: THORNTHWAITE PRECIPITATION-EVAPORATION INDEX (PE)

Climate	PE Index	Mean PE Index
Wet	More than 128	128
Humid	64 - 127	95.5
Sub-Humid	32 - 63	47.5
Semi-arid	16 - 31	23.5
Arid	Less than 16	16

Another parameter used for the sector's emission calculation is the soil silt content (s). Silt is soil with particles sized between 0.002 and 0.075 mm, and the soil silt content is the weight fraction of these particles. Silt is the fraction of the soil that is the most dust sensitive and therefore the estimated construction emissions must be corrected for the average silt content of the topsoil of the affected area.

The following table shows the default values for soil silt content (s). It is considered that the soil type in Chiang Mai is of clay type, and the silt content used for calculations is 29% (Table 54).

TABLE 54: SOIL SILT CONTENT (S) PER SOIL TYPE

Soil type	Silt content (%)
Silt loam	52%
Sandy load	33%
Sand	12%
Loamy sand	12%
Clay	29%
Clay loam	29%
Loam	40%

5.1.2.3 Methodological issues and ways of improvements

The construction data for Chiang Mai province in the year 2022 is not available. Duration for construction and demolition, soil content, CE and PE values are not available. It could be a more precise approach to emission calculation if a specific list of these parameters is developed based on the true characteristics of the Chiang Mai province.

5.2 CHEMICAL PRODUCTS (NFR 2B)

NE – Not estimated – Lack of Data.

5.3 METAL PRODUCTS (NFR 2C)

NE – Not estimated – Lack of Data.

5.4 SOLVENT AND OTHER PRODUCT USE (NFR SECTOR 2D3)

5.4.1 Overview of the sector

In this sector, all non-combustion emissions from other industrial sectors than manufacturing and energy industry are reported.

Emissions are related to the use of solvent in paint application, degreasing and dry cleaning, chemical products manufacture and processing, and other solvent use, including emissions from road paving with asphalt and asphalt roofing activities. The categories included in the sector are specified in the following:

- 2D3a - Domestic solvent use: includes emissions from the use of solvent in household cleaning and car care products as well as cosmetics.
- 2D3b - Road paving with asphalt: includes emissions from the production and use of asphalt for road paving.
- 2D3c - Asphalt roofing: includes emissions from the manufacturing of roofing products and the blowing of asphalt.
- 2D3d - Coating application: includes emissions from all paint-consuming activities in the industry (i.e. motor vehicle construction, vehicle repair, building and construction, pre-painting, boat building and other industrial paint applications) and the domestic use of paints.
- 2D3e – Degreasing: includes emissions from the use of solvents for metal degreasing and cleaning.
- 2D3f - Dry cleaning: includes emissions from the use of solvent in cleaning machines.
- 2D3g - Chemical products manufacture and processing: covers the emissions from the implementation of polyester, polyvinyl chloride (PVC), polyurethane (PU), polystyrene foam (PS), and rubber as well as the manufacture of pharmaceutical products, adhesive supports and other chemical products, paints, inks, and glues.
- 2D3h – Printing: includes emissions from the use of solvent in the printing industry.
- 2D3i - Other solvent use: addresses emissions from the use of solvent for coating of glass wool and other mineral fibers, edible and non-edible oil extraction, preservation of wood, application of glues and adhesives, and vehicles dewaxing.

However, due to a lack of data on solvent production, consumption, import, and export in Chiang Mai for the different categories, only three categories (2D3a, 2D3d, and 2D3i) will be presented in this report.

5.4.2 Methodology

NMVOC emissions from solvent use are typically calculated based on per capita data for only three subsectors (2D3a, 2D3d, and 2D3i). The calculations employ a simple Tier 1 method, as described in the ABC EIM by Shrestha et al. (2013):

$$E_{NMVOC} = \sum AR \times EF$$

Where E (tonnes) and EF (tonnes/capita) represent, respectively, NMVOC emissions and emission factor due to solvent use in each category, and AR (capita) is the activity rate represented in terms of population number in the Chiang Mai province.

The following paragraphs provide a detailed description of the applied method to calculate activity data, NMVOC emissions, and indirect CO_2 emissions per category.

5.4.2.1 Activity Data

Domestic Solvent Use (2D3a)

Domestic solvent use includes a lot of activities and solvent applications, such as household cleaning, the use of car care products, and cosmetics.

Due to a lack of activity data on domestic solvent use in the Chiang Mai province, a survey conducted in 2010 by Jiawkok et al. (2012) was utilized. This survey investigated detergent consumption in 400 households in the peri-urban area of Bangkok, providing information on the daily consumption per person of four household products: liquid soap, shampoo, liquid dishwashing detergent, and laundry powder detergent. The activity data are expressed as the sum, in tonnes, of the consumption of these four products in mL (for liquids) or g per person per day. Subsequently, this value is multiplied by the population of Chiang Mai and the number of days per year to estimate the annual consumption of household products in the province from 2010 to 2021 (Table 55). Activity data for the year 2022 were not estimated as population data for Chiang Mai province was unavailable.

TABLE 55. POPULATION (INHABITANT) AND CALCULATED ACTIVITY DATA (TONNES/YEAR) FOR DOMESTIC SOLVENT USE (2D3A) IN CHIANG-MAI PROVINCE.

YEAR	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Population	1,172,928	1,646,144	1,655,642	1,666,888	1,678,284	1,728,242	1,735,762	1,746,840	1,763,742	1,779,254	1,784,370	1,789,385
Liquid soap consumption	2,862	4,017	4,040	4,068	4,095	4,217	4,236	4,263	4,304	4,342	4,354	4,367
Shampoo consumption	2,684	3,767	3,789	3,815	3,841	3,955	3,972	3,998	4,036	4,072	4,084	4,095
Liquid dish washing detergent consumption	3,537	4,964	4,993	5,027	5,061	5,212	5,234	5,268	5,319	5,366	5,381	5,396
Powder laundry detergent consumption	6,850	9,613	9,669	9,735	9,801	10,093	10,137	10,202	10,300	10,391	10,421	10,450
Total consumption	**15,934**	**22,362**	**22,491**	**22,644**	**22,798**	**23,477**	**23,579**	**23,730**	**23,959**	**24,170**	**24,240**	**24,308**

Coating Application (2D3d)

The category includes the paint and coating application in the industrial section.

A market research study (Frost and Sullivan, 2017) on paint and coating consumption per capita in 2016 in various countries, including Thailand, showed that paint and coating consumption in Thailand was estimated at 8 Liters per capita per year. This is equivalent to 9.6 kg per capita [considering the average density of paint and coating as 1.2 g/mL (Bremmer and van Engelen, 2007; EPA 1986)].

The same methodology, as for domestic solvent use (2D3a), was then applied to estimate paint and coating consumption in Chiang Mai between 2010 and 2021 using the available population data.

TABLE 56. ACTIVITY DATA (TONNES/YEAR) FOR COATING APPLICATION (2D3D) IN CHIANG MAI PROVINCE.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Paint and Coating consumption	11,252	15,792	15,883	15,991	16,100	16,579	16,651	16,758	16,920	17,068	17,118	17,166

Other Solvent Use (2D3i)

The category includes NMVOC emissions from several activities, including coating of glass wool and other mineral fibers, edible and non-edible oil extraction, preservation of wood, application of glues and adhesives, and vehicles dewaxing.

This report will focus solely on the use of solvent in the application of glues and adhesives, based on the provided data.

According to a market research study on adhesives in Thailand (Mordor Intelligence 2021), adhesives are primarily based on epoxy, acrylic, cyanoacrylate, silicone, and polyurethane, with polyurethane holding the largest market share at 24.75%. In 2017, 124.5 kt of glues and adhesives were introduced to the Thai market, with the packaging industry emerging as the largest consumer. However, adhesive consumption in Thailand experienced an 11.6% decline in 2020 due to the impact of the COVID-19 sanitary crisis, followed by a subsequent 10% increase in 2021. This resulted in approximately 110 and 121 kt of glues and adhesives being introduced to the Thai market in 2020 and 2021, respectively.

The estimated activity data for glues and adhesives applications at the national level was then used to calculate VOC emission factors (kg/capita) at the national level for the years 2017, 2020, and 2021. These factors, in addition to the provided population data for Chiang Mai province, allowed us to estimate VOC emissions from this sector in Chaing Mai (see section 5.4.3.3).

5.4.2.2 NMVOC Emissions

In addition to the previously determined activity data, default VOC content per type of consumer product taken from the literature was used to estimate NMVOC emissions from domestic solvent use (2D3a) and coating applications (2D3d). Therefore, NMVOCs were considered to be 100% emitted from these products. To estimate NMVOC emissions from glues and adhesives (2D3i), a default emission factor provided by the ABC EIM (Shrestha et al., 2013) was utilized for the 2D3i category.

5.4.2.3 Indirect CO_2 Emissions

Indirect CO_2 emissions were estimated by applying a CO_2 emission factor to the determined NMVOC emissions of each category. The CO_2 emission factor considers the average carbon content of NMVOCs in each sector, based on a bibliographic study conducted by Citepa in 2005 (Citepa, 2005). The following equation is applied:

$$Indirect\ CO_2 emissions = \frac{NMVOC\ emissions\ x\ M_{CO2}}{M_C\ x\ CO_2 emission\ factor}$$

Where M_{CO2} is the molar mass of CO_2 (44 g/mol), and M_C is the molar mass of carbon (12 g/mol). CO_2 emission factor is 0.62, 0.65, and 0.8 for domestic solvent use, other solvent use, and coating applications, respectively.

5.4.3 Results: Emissions from the Solvent and other product use

5.4.3.1 Domestic Solvent Use (2D3a)

NVMOC Emissions

The VOC content in the liquid soap, shampoo, dishwashing detergent, and powder laundry detergent was estimated to be 2.6%, 3.2%, 5%, and 1.6%, respectively (Bremmer et al., 2006). Table 57 shows the estimated NMVOC emissions from domestic solvent use in Chiang Mai province over the years.

TABLE 57. NMVOC EMISSIONS (TONNES/YEAR) FOR DOMESTIC SOLVENT USE (2D3A) IN CM PROVINCE.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Liquid soap	74	104	105	106	106	110	110	111	112	113	113	114
Shampoo	86	121	121	122	123	127	127	128	129	130	131	131
Liquid dishwashing detergent	177	248	250	251	253	261	262	263	266	268	269	270
Powder laundry detergent	110	154	155	156	157	161	162	163	165	166	167	167
Total emissions	**447**	**627**	**631**	**635**	**639**	**658**	**661**	**665**	**672**	**678**	**680**	**682**

Indirect CO_2 Emissions

The average carbon content of NMVOCs used for domestic solvent is estimated to be 62% (Citepa, 2005). Table 58 shows the estimated indirect CO_2 emissions from domestic solvent use in Chiang Mai province over the years.

TABLE 58. INDIRECT CO_2 EMISSIONS (TONNES/YEAR) FOR DOMESTIC SOLVENT USE (2D3A) IN CM PROVINCE.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Liquid soap	170	238	240	241	242	250	251	253	255	258	258	259
Shampoo	196	275	277	279	280	289	290	292	295	297	298	299
Liquid dish washing detergent	403	566	570	573	577	595	597	601	607	612	614	616
Powder laundry detergent	250	351	353	355	358	368	370	372	376	379	380	381

Total emissions	1,019	1,431	1,439	1,449	1,458	1,502	1,508	1,518	1,533	1,546	1,551	1,555

5.4.3.2 Coating Application (2D3d)

NVMOC Emissions

The VOC content in a solvent-rich coating and solvent-rich paint is 40 and 45%, respectively (Bremmer and van Engelen 2007; EPA Guideline 1986). Estimated NMVOC emissions from coating applications are shown in Table 59.

TABLE 59. NMVOC EMISSIONS (TONNES/YEAR) FOR COATING APPLICATION (2D3D) IN CHIANG MAI PROVINCE

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Paint and Coating consumption	4,782	6,711	6,750	6,796	6,842	7,046	7,077	7,122	7,191	7,254	7,275	7,295

Indirect CO_2 Emissions

The average carbon content of NMVOCs in domestic solvent use is estimated to be 80% (Citepa, 2005). Estimated indirect CO_2 emissions from coating applications are shown in Table 60.

TABLE 60. INDIRECT CO_2 EMISSIONS (TONNES/YEAR) FOR COATING APPLICATION (2D3D) IN CHIANG MAI PROVINCE

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Paint and Coating consumption	13,972	19,609	19,722	19,856	19,991	20,587	20,676	20,808	21,009	21,194	21,255	21,315

5.4.3.3 Other Solvent Use (2D3i)

NVMOC Emissions

NMVOC emissions resulting from adhesive and glue application in Thailand are estimated for the years 2017, 2020, and 2021, as these are the years for which activity data is available.

The NMVOC emission factor for adhesives and glues applications, as provided by the ABC EIM, is 600 kg/tonne of used product. This EF was used to calculate NMVOC emissions from adhesives and glues applications in Thailand.

Subsequently, using the national population data in Thailand, an emission factor of emitted NMVOC due to adhesive use per capita is calculated for these three years Table 61.

TABLE 61. NMVOC EMISSIONS (TONNES/YEAR) AND EMISSION FACTOR FOR ADHESIVES USE (2D3I) IN THAILAND

Year	2017	2020	2021
NMVOC emissions from adhesive and glues use (tonnes)	74,700	66,035	72,638
Population in Thailand (capita)	66,188,503	66,186,727	66,171,439
NMVOC EF for adhesives and glues use (kg VOC/ capita)	1.129	0.998	1.098

The calculated NMVOC emission factors per capita are then used to determine NMVOC emissions in the Chiang Mai province for the years 2010 to 2021, using Chiang Mai population data (Table 62).

TABLE 62. NMVOC EMISSIONS (TONNES/YEAR) FOR ADHESIVES USE (2D3I) IN CHIANG MAI.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Adhesive and glues use	1,324	1,858	1,869	1,881	1,894	1,950	1,959	1,971	1,991	2,008	1,780	1,964

Indirect CO_2 Emissions

The average carbon content of NMVOCs used for domestic solvent use is estimated to be 65% (Citepa, 2005). Table 63 shows the estimated CO_2 emissions from glues and adhesives use.

TABLE 63. INDIRECT CO_2 EMISSIONS (TONNES/YEAR) FOR ADHESIVES USE (2D3I) IN CHIANG MAI.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Adhesive and glues use	3,176	4,458	4,484	4,514	4,545	4,680	4,701	4,731	4,777	4,819	4,272	4,713

5.4.4 Methodological Issues

The sector is characterized by a multitude of activities, which implies that collecting activity data and emission factors is laborious. Consequently, NMVOC emissions in Chiang Mai province were only partially estimated due to the lack of provided activity data for various applications across different categories.

5.5 WAYS OF IMPROVEMENT

5.5.1 Mineral products, chemical products and metal products

Emissions from these sectors have not been calculated in this emissions inventory due to lack of data. To improve Chiang Mai's emissions inventory, it is essential to obtain information on industrial production in these sectors, if possible, on a provincial scale, but data on a national scale would already be valuable information. In the longer term, it would be better to have production data by facility for the largest plants.

5.5.2 Solvent and other products use

NMVOC emissions resulting from solvent use in the Chiang Mai province were estimated for only a few categories and specific applications within each category. To enhance the emissions inventory for Chiang Mai, it is crucial to acquire additional information on activity data related to solvent use in various applications across different categories. Statistical data encompassing production, product consumption, imports, and exports would facilitate a more precise and inclusive estimation of emissions. Information on the VOC content of various consumer products containing solvents is also essential.

Precise data aids in identifying major NMVOC-emitting sectors (key sources) and estimating their impact on total provincial emissions. This assessment allows for the implementation of adequate mitigation measures to reduce NMVOC emissions from key sources.

5.6 RESULTS: EMISSIONS FROM THE INDUSTRIAL PROCESSES SECTOR

Due to the lack of data on industrial processes, only few sectors are considered in this inventory: Quarrying and mining, construction and demolition, domestic solvent, paint and coating application and other solvent use.

Quarrying and mining as well as construction and demolition are significant sources of particles. Solvent use is a strong source of NMVOCs (Table 64).

TABLE 64: EMISSIONS OF AIR POLLUTANTS AND GHGS FROM INDUSTRIAL PROCESSES IN TONNES / YEAR (2022)

Tonnes/year (2022)	Sector NFR	NMVOCs	PM_{10}	$PM_{2.5}$	CO_2
2a5a	Quarry and Mining		139.5	14.0	
2a5b	Construction and demolition		127	12.7	
2d3a	Domestic solvent	681.6			1,555.0
2d3d	Paint and Coating Application	7,295.4			21,314.8
2d3i	Other solvent use	1,964.3			4,713.4
Total		9,941.2	266.5	26.7	27,483.3

6 AGRICULTURE (NFR SECTOR 3)

6.1 OVERVIEW OF THE SECTOR

Emissions addressed in this chapter include emissions from the subcategories:

- 3.A Enteric Fermentation.
- 3.B Manure Management.
- 3.C Methane from Rice Cultivation.
- 3.D Agricultural Soils.
- 3.F Field Burning of Agricultural Residues.
- 3.H CO_2 emissions from urea application

This chapter includes information on the methodologies applied for estimating emissions of air pollutants, activity data, and emission factors applied.

6.2 GLOBAL METHODOLOGY

Emissions from agricultural activities in Chiang Mai were calculated following IPCC guidelines[4] (2019 refinement) for CO_2, N_2O, CH_4 emissions and EMEP 2019 guidelines[5] for atmospheric pollutants (especially NH_3 and NOx for agriculture). The EMEP emission factor database[6] was used for most emission factors, and when possible, country-specific emission factors were extracted from different literature.

A Tier 2 approach was implemented for enteric fermentation and manure management for CH_4 and NH_3 emissions. For other emissions from agriculture, a Tier 1 approach was used.

Activity data and calculation parameters were collected from official statistics of different Thailand Government Departments such as the Department of Livestock Development (DLD) and the Office of Agricultural Economics (OAE). When national data were unavailable, international databases such as FAOSTAT[7] or IFASTAT[8] were used as well as data intro/extrapolated from published literature.

6.2.1 Enteric fermentation (3A)

6.2.1.1 Methodology

Methane emissions from animals are calculated according to the 2019 IPCC guidelines using a Tier 2 method for ruminants and Tier 1 method for other animals.

6.2.1.2 Activity Data

Livestock population

Livestock population statistics of 8 different categories chicken, cow, buffalo, pig, duck, goat, sheep, and other (quail, donkey, mule, elephant, horse, geese, and turkey) were collected from the DLD's reports on annual animal numbers[9] for years from 2012 - 2022. The detailed data by gender, and animal raising purpose (egg-

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[4] https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

[5] https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

[6] https://efdb.apps.eea.europa.eu

[7] FAOSTAT – *Food and Agriculture data*

[8] IFASTAT – *International Fertilizer Association*

[9] https://ict.dld.go.th/webnew/index.php/th/service-ict/report/355-report-thailand-livestock/animal-book

laying chicken, meat chicken, milk cow, meat cow, etc.) were also collected whenever such data were available from the statistics.

Calculation parameters

Default parameters from the IPCC were collected using the closest regional value (generally Asia or Southeastern Asia) and based on assumption for agricultural systems (productivity / feeding situation). The correspondence between Thai statistics on livestock and the assumed IPCC system used to derive default parameters is given in Table 65.

The bodyweights for several animal categories were reviewed in different studies (Jaturasitha et al., 2008; Thanapongtharm et al., 2016; Preechajarn 2018; Wattanachant, 2008; Feed and Livestock Magazine, 2022; Faarungsang, 2003; Srisakdi et al., 2019; Chaiwatanasin et al., 1998). In case animal body weights aren't available, IPCC default values were used.

Milk yield from dairy cows has been collected from FAOSTAT[10] statistics. Finally, the fat content of milk was assumed to be 3.59% according to Wongpom, et. al (2017).

The IPCC methodology is based on the estimation of Gross energy intake for each animal category involving multiple intermediate parameters. From these parameters, nitrogen excretion rate per animal type was also calculated which is used under section 3B and 3D.

[10] https://www.fao.org/faostat/fr/#data

TABLE 65. CORRESPONDENCE TABLE BETWEEN THAI STATISTICS CATEGORIES AND IPCC SYSTEMS

Animal category in Thai	General category	Animal category in English	IPCC System (affectation of parameters)
โคนม – ผู้	Dairy cattle (Cow)	Dairy Cattle - Male breeders	Non-dairy cattle - Mature Males - high productivity systems
โคนม - แรกเกิดถึง 1 ปี		Dairy Cattle (Newborn -1 year)	Non-dairy cattle - Calves on forage - high productivity systems
โคนม - 1 ปี ถึงตั้งท้องแรก		Dairy cattle - 1 year to first pregnancy	Non-dairy cattle - Growing/Replacement - high productivity systems
โคนม – โคกำลังรีดนม		Dairy Cattle - > 2 years, Dairy Cattle Milking	Dairy cows - high productivity systems
โคนม – โคแห้งนม		Old dairy cows, cannot collect milk/dry cow	Dairy cows - high productivity systems
โคพื้นเมือง - ผู้ (ตัว)	Non-dairy cattle (cow), Native breed (male)	Native Breed Cattle - Male (Unit: Body)	Non-dairy cattle - Mature Males-Farming - low productivity systems
โคพื้นเมือง – แรกเกิดถึงโคสาว		Native Breed Cattle - Newborn to Heifer (0 - 1 year)	Non-dairy cattle - Calves on forage - low productivity systems
โคพื้นเมือง – ตั้งท้องแรกขึ้นไป		Native breed cattle - First pregnancy and above (1-3 years)	Non-dairy cattle - Growing/Replacement - low productivity systems
โคพันธุ์แท้ - ผู้ (ตัว)	Non-dairy cattle (cow), Purebred (male)	Purebred Cattle – Male (Unit: Body)	Non-dairy cattle - Mature Males - high productivity systems
โคพันธุ์แท้ – แรกเกิดถึงโคสาว		Purebred Cattle - Newborn to Heifer (0 - 1 year)	Non-dairy cattle - Calves on forage - high productivity systems
โคพันธุ์แท้ – ตั้งท้องแรกขึ้นไป		Purebred Cattle – Heifers or young males up to first mating	Non-dairy cattle - Growing/Replacement - high productivity systems
โคลูกผสม - ผู้ (ตัว)	Non-dairy cattle (cow), hybrid (male)	Dairy Steer Fattening Beef – Male (Unit: Body)	Non-dairy cattle - Mature Males - high productivity systems
โคลูกผสม – แรกเกิดถึงโคสาว		Dairy Steer Fattening Beef - Newborn to Heifer (0 - 1 year)	Non-dairy cattle - Calves on forage - high productivity systems
โคลูกผสม – ตั้งท้องแรกขึ้นไป		Dairy Steer Fattening Beef – Heifers or young males up to first mating	Non-dairy cattle - Growing/Replacement - high productivity systems

Animal category in Thai	General category	Animal category in English	IPCC System (affectation of parameters)
โคขุน - จำนวน (ตัว)	Non-dairy cattle, fattening (number)	Fattened Cattle (Cow for meat) - Quantity (Unit: Body)	Non-dairy cattle - Mature Males - high productivity systems
กระบือ - ผู้ (ตัว)	Buffalos	Male buffalo (Unit: Body)	Buffalos - Mature Males - total Asia
ตั้งท้องแรกขึ้นไป		Female buffalo (first pregnancy to up)	Buffalos - Mature Females - total Asia
แรกเกิดถึงกระบือสาว		Female buffalo (newborn to first pregnancy/young female)	Buffalos - Calves - total Asia
แพะ (ตัว)	Goats	Goat - males (Unit: Body)	Goats - Average - total Asia
แรกเกิดถึงแพะสาว		Female goat - newborn to first pregnancy/young female)	Goats - Average - total Asia
ตั้งท้องแรกขึ้นไป		Female goat (first pregnancy to up)	Goats - Average - total Asia
แกะ - ผู้ (ตัว)	Meat sheep	Male meat sheep (Unit: Body)	Sheep - Average - total Asia
แรกเกิดถึงแกะสาว		Female meat sheep (newborn to first pregnancy/young female)	Sheep - Average - total Asia
ตั้งท้องแรกขึ้นไป		Female meat sheep (first pregnancy to up)	Sheep - Average - total Asia
แกะ (ตัว)	Dairy sheep	Dairy sheep (Unit: Body)	Sheep - Average - total Asia
แรกเกิดถึงแกะสาว		Female sheep (newborn to first pregnancy/young female)	Sheep - Average - total Asia
ตั้งท้องแรกขึ้นไป		Female sheep (first pregnancy to up)	Sheep - Average - total Asia
สุกร (ตัว)	Swine	Native pigs (Unit: Body)	Swine - Average - low productivity systems

Animal category in Thai	General category	Animal category in English	IPCC System (affectation of parameters)
พ่อพันธุ์ (ตัว)		Male breeder (Boar) (Unit: Body)	Swine - Average - low productivity systems
แม่พันธุ์ (ตัว)		Female breeder (Sow) (Unit: Body)	Swine - Average - low productivity systems
ลูกสุกรเพศผู้ (ตัว)		Male piglet (Unit: Body)	Swine - Average - low productivity systems
ลูกสุกรเพศเมีย (ตัว)		Female piglet (Unit: Body)	Swine - Average - low productivity systems
สุกรขุน (ตัว)		Swine for meat (Fattening pigs) (Unit: Body)	Swine - Finishing - low productivity systems
ลูกสุกรขุน (ตัว)		Fattening piglet/Young pigs (baby swine for meat) (Unit: Body)	Swine - Average - low productivity systems
ไก่ไข่	Poultry and ducks	Laying hens (Chicken for eggs, including pullets)	Poultry - Hens - total Asia
ไก่เนื้อปู่, ย่าพันธุ์		Broiler breeders (grandparent stock, for meat)	Poultry - Hens - total Asia
ไก่เนื้อพ่อ, แม่พันธุ์		Broiler breeders (parent stock, for meat)	Poultry - Hens - total Asia
ไก่ไข่ปู่, ย่าพันธุ์		Layer breeders (grandparent stock, for eggs)	Poultry - Hens - total Asia
ไก่ไข่พ่อ, แม่พันธุ์		Layer breeders (parent stock, for eggs)	Poultry - Hens - total Asia
ไก่เนื้อ		Broilers	Poultry - Broilers - low productivity systems
ไก่ลูกผสม		Hybrid chicken	Poultry - Broilers - low productivity systems
ไก่พื้นเมือง		Native chicken (assumed free range dual-purpose)	Poultry - Broilers - low productivity systems
เป็ด / รวม		Ducks	
นกกระทา	Other animals	Quails	
ลา		Donkey	

Animal category in Thai	General category	Animal category in English	IPCC System (affectation of parameters)
ล่อ		Mule	
ช้าง		Elephant	
ม้า		Horse	
ห่าน		Geese	
ไก่งวง		Turkey	

6.2.1.3 Results: Emissions of methane from enteric fermentation

In 2022, it is estimated that **14,389 tonnes of methane** were emitted from enteric fermentation, mostly due to non-dairy cattle, buffalos and dairy cattle (Table 66).

TABLE 66. ENTERIC METHANE EMISSIONS IN CHIANG MAI (IN TONNES OF CH_4)

Animal category	2021	2022
Dairy cattle	3,085	3,039
Non-dairy cattle	6,899	7,664
Buffalo	3,469	3,354
Goat	1	2
Sheep	24	38
Swine	384	284
Poultry	0	0
Other animals	10	10
Total	**13,872**	**14,389**

6.2.2 Manure management (3B)

Organic nitrogen inputs to agricultural soils mainly come from animal manure.

6.2.2.1 Methodology

Emissions were calculated according to the IPCC 2019 guidelines for GHGs and EMEP 2019 guidelines for pollutants.

For NH_3 and CH_4 from 3B, the Tier 2 methodology has been implemented for all livestock categories. All other pollutants are estimated using Tier 1 methodology.

6.2.2.2 Activity Data

Livestock population and nitrogen excretion

Livestock populations (from DLD) and nitrogen excretion are coming from the enteric methane calculation spreadsheet.

Calculation parameters

Average waste management systems (AWMS) are coming both from IPCC 2019 default parameters and Thailand's national GHG inventory (1994)[11] which seemed more country-specific for cattle and buffalos. These parameters have a great influence over nitrogen-based emissions (NH_3, N_2O, NOx) as well as for methane emissions (through Methane Correction Factor - MCF) and it is recommended that they are updated frequently to ensure a more robust estimation of air emissions. Nitrogen excretion can be separated between house, yard and grazing according to AWMS parameters (Figure 25).

[11] *Thailand's national GHG inventory 1994,* https://unfccc.int/sites/default/files/resource/Thailand%20GHG_0.pdf

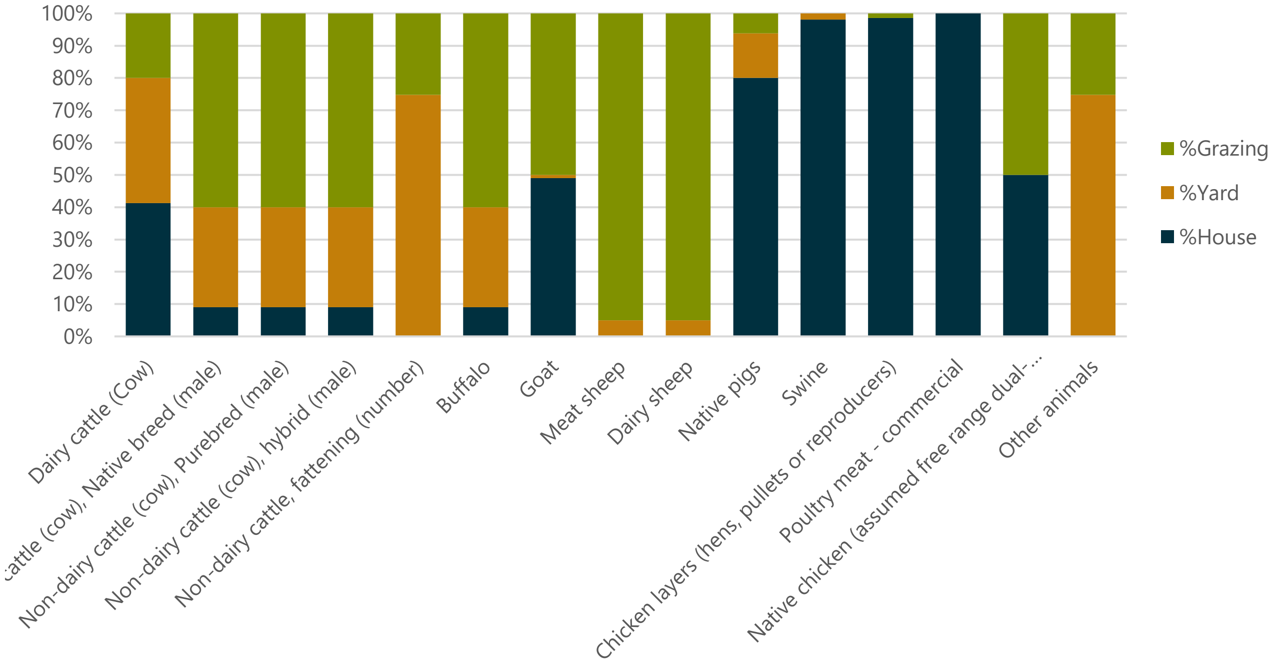


FIGURE 25. DISTRIBUTION OF NITROGEN EXCRETION AT HOUSE, IN YARD AND AT PASTURE BASED ON CHOSEN AWMS (AVERAGE WASTE MANAGEMENT SYSTEMS) PARAMETERS FOR CHIANG MAI

The IPCC climate zone for Chiang Mai is assumed to be 100% Tropical Moist as a measure of simplification even though a small part of the area falls in the Tropical Montane according to the IPCC climate map[12]. The MCF is reported in Table 67.

TABLE 67: METHANE CORRECTION FACTOR (MCF) FOR CHIANG MAI PROVINCE

AWMS	MCF - Chiang Mai
Lagoon	76%
Liquid /Slurry	59%
Solid storage	5%
Drylot	2%
Pasture/ Range/ Paddock	0%
Daily spread	1%
Digester	13%
Burned for fuel	10%
Pit < 1	18%
Pit > 1	59%
Poultry manure with litter	2%
Other	3%

[12] https://abc-map.users.earthengine.app/view/next-ipcc-climate-zones

6.2.2.3 Results: Emissions from Manure management

Table 68 presents the results of the emissions (in tonnes/year) of GHGs and air pollutants from NRF 3b (manure management) by different species in 2021 and 2022 in Chiang Mai province.

TABLE 68. EMISSIONS OF POLLUTANTS AND GHG FROM NFR 3B (MANURE MANAGEMENT), IN TONNES OF POLLUTANT

Pollutant	2021	2022
CH_4	4,241	3,764
N_2O	272	261
NH_3	5,138	4,658
NO_2	14	14
TSP	1,217	1,101
PM_{10}	302	287
$PM_{2.5}$	39	38

6.2.3 Methane from Rice cultivation (3C)

6.2.3.1 Methodology

Emissions of methane from rice cultivation in Chiang Mai were calculated using a Tier 1 approach based on the 2019 IPCC guidelines[13] (volume 4 chapter 5). We were not able to retrieve country-specific scaling factors for soil type or rice cultivars, other country-specific parameters to estimate rice emission factors such as Tier 1 scaling factors, duration of cropping season, and water regime were extracted from literature (Thambhitaks and Kitchaicharoen (2021); Yodkhum et al., 2017; Katoh et al., 1999). Equation 5.2 from the "Cropland" chapter was used:

$$\boldsymbol{EF = EF_c \times SF_w \times SF_p \times SF_o}$$

Where:

- EF: adjusted daily emission factor for a particular harvested area.
- EF_c: baseline emission factor for continuously flooded fields without organic amendment.
- SF_w: scaling factor to account for the differences in water regime during the cultivation period (from Table 67).
- SF_p: scaling factor to account for the differences in water regime in the pre-season before the cultivation period (from Table 67).
- SF_o: scaling factor should vary for both type and amount of organic amendment applied (from Equation 5.3 and Table 67).

6.2.3.2 Activity Data

With a Tier 1 approach, activity data for rice methane emission estimation include planted area and a range of practice data (organic amendment application, water regime, duration of cropping season…).

For the annual planted and harvested areas of rice cultivation in Chiang Mai, the statistics from the OAE (Office of Agricultural Economics[14]) were used, distinguishing between major rice and off-season rice production.

[13] https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

[14] https://www.oae.go.th

Statistics also distinguish between irrigated and non-irrigated rice. This study considered all rice production in Chiang Mai as continuously flooded (Rungcharoen et al., 2014; Yodkhum et al., 2017).

No data on organic amendment were available within the scope of the study, however, we included rice residues after harvest in the calculation of the application rate of the organic amendment (ROA), based on crop residue calculation detailed in the section on agricultural soils (NFR 3D).

All parameters are reported in the table below with references (Table 69).

TABLE 69. PARAMETERS FOR RICE METHANE EMISSION CALCULATION IN CHIANG MAI IN 2021

Parameter	Unit	Major rice	Off season rice	Source
EFc	-	1.22	1.22	IPCC methodology (Southeastern Asia)
SFw	-	1.40	1.40	Thambhitaks et al., 2021
SFp	-	0.68	0.68	Yodkhum et al., 2017
ROA	-	1.18	1.18	IPCC residue calculation
CFOA (straw incorporated < 30 days)	-	1.00	1.00	IPCC methodology
SFo	-	1.58	1.58	IPCC methodology
Cultivation period	(days)	113	114	Katoh et al., 1999
Emission factor	(kg CH_4 / ha / year)	208	210	IPCC methodology
Harvested area	(ha)	88,380	18,530	OAE
CH_4 emissions	(tonnes CH_4/year)	18,272	2,865	IPCC methodology

CFOA: Conversion Factor for Organic Amendment

6.2.3.3 Results: Emissions of methane from rice cultivation

Results showed emission factors ranging from 208 to 210 kg CH_4 / ha / year applying country-specific parameters to the Tier 1 approach. Using only default IPCC values, the calculation shows a lower emission factor mainly due to lower SFw and SFp parameters (Table 70).

TABLE 70. METHANE EMISSIONS FROM RICE CULTIVATION IN CHIANG MAI, IN TONNES OF CH_4

	2019	2020	2021	2022
CH_4 emissions from rice cultivation	21,303	21,834	22,237	21,137

6.2.4 Agricultural Soils (3D)

6.2.4.1 Methodology

Emissions are calculated according to the IPCC 2019 guidelines and the EMEP 2019 guidelines with a Tier 1 approach.

6.2.4.2 Activity Data

Within the agricultural soils category, most emissions are linked to the nitrogen inputs to soils by type (animal manure, chemical fertilizer, crop residues, etc.).

Animal manure inputs to agricultural soils

Organic N inputs to agricultural soils mainly come from animal manure. This data has been estimated using the IPCC guidelines within the manure management section (NFR 3B). In 2022, manure applied to agricultural soils in Chiang Mai has been estimated at 11,425 tN and urine and dung deposited on pastures and yards has been estimated at 6,204 tN.

Synthetic fertilizer inputs to agricultural soils

Total nitrogen inputs to agricultural soils from synthetic fertilizer were calculated based on an estimate of fertilization rate per major crop type in Chiang Mai. Several sources of data were used. The OAE provides statistics on the total mass of synthetic fertilizer used per major crop category[15] per year. However, the nitrogen content of the mix of fertilizers used is unknown. It was calculated based on import data for Thailand by type of product (Urea, DAP, Ammonium, Sulphate…) assuming a homogenous distribution of fertilizers by province. The average calculated nitrogen content is reported in Table 71 below for years 2021 and 2022. The distribution of N application was based on IFASTAT data for Thailand and shown in Figure 26 for year 2021.

TABLE 71. SYNTHETIC FERTILIZER IMPORT (TONNES/YEAR) IN THAILAND AND AVERAGE NITROGEN CONTENT

Fertilizer type	% N content	2021	2022
Urea	46%	1,967,029	1,514,854
DAP	18%	530,841	417,465
Potash	0%	903,788	710,249
Ammonium Sulfate	21%	433,220	330,621
Ammonium Phosphate	16%	316,822	231,758
NPK 16-16-8 compound	16%	2,057	3,354
NPK 15-15-15 compound	15%	407,567	23,316
Others	16%	941,046	662,207
TOTAL		**5,502,370**	**3,893,824**
% N content		24.5%	25.3%

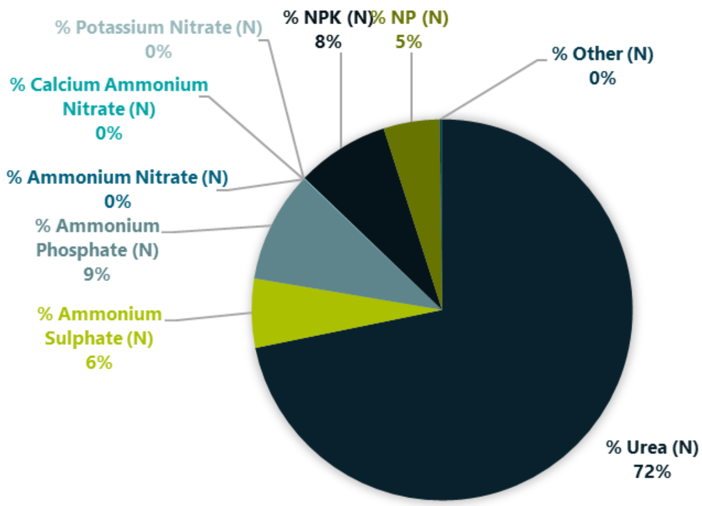


FIGURE 26. FERTILIZER APPLICATION BY FORM IN CHIANG MAI (IN % OF TOTAL N) BASED ON IFASTAT DATA FOR THE WHOLE KINGDOM IN 2021

The amount of N from synthetic fertilizer applied to agricultural soils in Chiang Mai was then calculated using this data, the statistics on fertilizer quantities and harvested areas. Fertilizer quantities are not reported for Longan fruit trees even though they represent about 28% of Chiang Mai planted area in 2022. We used data from FAO[16] and Prasittikhet et al. (2003) with an average nitrogen rate per tree of 0.7 kgN / tree and an assumed

[15] *Rice, Maize, Soybean, Cassava*

[16] *FAO, 2000, Longan production in Asia*

plant density of 50 trees / ha to calculate the average nitrogen rate per hectare (33.8 kgN/ha) which was then multiplied by the harvested area of Longan trees.

TABLE 72. ESTIMATION OF SYNTHETIC FERTILISER INPUT TO AGRICULTURAL SOILS IN CHIANG MAI IN 2022

Crops	Harvested area	Fertilization rate		N application
	rai	*kgN / rai / year*	*kgN / ha / year*	*tonnes N*
Maize	285,976	16.9	105.6	4,833
Rice	635,361	8.1	50.6	5,148
Major rice	549,895	7.7	48.3	4,247
Secondary rice	85,466	10.5	65.9	901
Soyabean	4,317	5.1	31.6	22
Cassava	6,711	7.5	46.8	50
Coffee	32,688	NE	NE	NE
Oil palm	352	NE	NE	NE
Tangerine	33,829	NE	NE	NE
Longan	444,767	5.4	33.8	2,402
Lychee	40,396	NE	NE	NE
Other perennial	22,865	NE	NE	NE
Weighted average		**6.2**	**38.7**	
Total Chiang Mai	**1,507,262**			**12,456**

Other inputs to agricultural soils

Other inputs to agricultural soils are crop residues returning to soils, compost, sewage sludge, wastewater effluent and mineralization of soil organic matter. Only crop residues returning to soils have been estimated following the IPCC guidelines and production data from OAE.

The choice of parameters for Chiang Mai has been based by order of priority on:

- Cheewaphongphan et al. (2018); Liam (2023); Khonpikul et al. (2017).
- The national inventory audited within the scope of this study[17].
- Phairuang et al., 2017.
- IPCC 2019 default values.

The selected parameters are reported in the table below (Table 73):

TABLE 73. CALCULATION PARAMETERS TO ESTIMATE CROP RESIDUE NITROGEN RETURNED TO SOILS AND AGRICULTURAL RESIDUE BURNING FOR CHIANG MAI

	NAG	NBG	RAG	RS	DRY	Cf	FracBurnt	FracRemove	FracRenew
Maize	0.006	0.007	2.000	0.220	0.400	0.920	30%	70%	100%
Rice	0.007	0.007	1.190	0.160	0.850	0.890	22%	58%	100%
Major rice	0.007	0.007	1.190	0.160	0.850	0.890	22%	58%	100%
Secondary rice	0.007	0.007	1.190	0.160	0.850	0.890	22%	58%	100%
Soyabean	0.008	0.008	0.210	0.190	0.710	0.680	0%	0%	100%
Cassava	0.019	0.014	0.500	0.200	0.710	0.680	0%	0%	100%

[17] *PCD, 2020, Report on the results of the development of a data linkage system for air pollution accounting management. [report translated by google translate]*

6.2.4.3 Results: Emissions from Agricultural soil

The amount of pollutants from Agricultural soil, emitted in 2022, is summarized in Table 74 below.

TABLE 74. EMISSIONS OF POLLUTANTS AND GHG FROM NFR 3D (AGRICULTURAL SOILS), IN TONNES OF POLLUTANT

Pollutant	2021	2022
N_2O	689	675
NH_3	4,877	4,638
NOx	1,230	1,203
PM_{10}	408	391
$PM_{2.5}$	16	15
NMVOC	1,426	1,399

6.2.5 Field burning of agricultural residues (3F)

6.2.5.1 Methodology

Emissions from field burning of agricultural residues have been calculated based on Tier 2 emission factors from IPCC, EMEP 2023 and Phairuang *et al.*, 2017 (Table 74).

TABLE 75. EMISSION FACTORS FOR NFR 3F - AGRICULTURAL RESIDUE BURNING (KG / KGDM)

Pollutants and GHG		Maize	Rice	Soyabean	Cassava
Greenhouse gases (IPCC 2019 - Vol4. Ch2. Table 2.5)	CO_2	1.515 (biogenic)	1.515 (biogenic)	1.515 (biogenic)	1.515 (biogenic)
	CH_4	0.0027	0.0027	0.0027	0.0027
	N_2O	0.00007	0.00007	0.00007	0.00007
Main pollutants (Phairuang et al., 2017; EMEP 2023)	SOx	0.0004	0.00048	0.0004	0.0004
	NOx	0.00305	0.00343	0.0017	0.0017
	NMVOC	0.0045	0.0063	0.0005	0.0005
	NH_3	0.0024	0.0024	0.0024	0.0024
	CO	0.0388	0.0589	0.0667	0.0667
Particulate matter (Phairuang et al., 2017; EMEP 2023)	PM_{10}	0.00872	0.0091	0.0039	0.0039
	$PM_{2.5}$	0.00872	0.0083	0.0039	0.0039
	BC	0.00075	0.0005	0.0005	0.0005
Heavy metals (EMEP 2023)	Pb	0.000000007	0.000000072	0.00000011	0.00000011
	Cd	0.000000036	0.00000016	0.00000088	0.00000088
	Hg	0.000000028	0.000000033	0.00000014	0.00000014

The quantity of residues available for burning has been estimated using IPCC 2019 methodology for crop residues estimation (see Table 75 for chosen parameters).

Moreover, agricultural residue burning was estimated only for annual crops (Maize, Rice, Soybean and Cassava) accounting for 63% of Chiang Mai harvested area.

6.2.5.2 Activity Data

Production levels for each annual crop, harvested area and dry matter content have been collected within calculations for 3D Agricultural soils sector based on OAE data.

6.2.5.3 Results: Emissions from Agricultural field burning

CO_2 emission from agricultural burning is a biogenic source. It is reported for information in the Table 76 below.

TABLE 76. CHIANG MAI EMISSIONS OF POLLUTANTS AND GHG FROM AGRICULTURAL RESIDUE BURNING, IN TONNES OF POLLUTANT

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2 (biogenic)	209,530	203,771	189,007	153,051	151,676	169,689	174,771	192,493	208,950	218,747	208,905
CH_4	373	363	337	273	270	302	311	343	372	390	372
N_2O	10	9	9	7	7	8	8	9	10	10	10
SOx	64	62	57	47	46	51	53	58	62	65	62
NOx	463	450	417	338	332	373	383	422	455	476	454
NMVOC	817	793	732	595	579	651	669	736	785	819	778
NH_3	332	323	299	242	240	269	277	305	331	347	331
CO	7,539	7,315	6,749	5,492	5,320	5,988	6,150	6,760	7,189	7,496	7,113
PM_{10}	1,247	1,212	1,124	911	900	1,008	1,038	1,143	1,237	1,295	1,236
$PM_{2.5}$	1,161	1,129	1,048	848	843	942	971	1,070	1,164	1,219	1,166
BC	77	75	70	56	57	64	66	73	81	85	81
Pb	0.0080	0.0077	0.0070	0.0058	0.0053	0.0061	0.0062	0.0068	0.0069	0.0071	0.0067
Cd	0.0184	0.0178	0.0163	0.0133	0.0125	0.0142	0.0145	0.0159	0.0163	0.0169	0.0158
Hg	0.0044	0.0043	0.0040	0.0032	0.0032	0.0035	0.0036	0.0040	0.0043	0.0045	0.0043

6.2.6 CO_2 emissions from Urea application (3H)

6.2.6.1 Methodology

Urea fertilization leads to a loss of CO_2 that was calculated for Chiang Mai using a Tier 1 approach from IPCC 2006 guidelines[18].

$$CO2\ emissions = M\ \times EF\ \times \frac{44}{12}$$

With M annual amount of urea fertilisation, tonnes urea / year and EF the emission factor (0.2 tC / tUrea).

6.2.6.2 Activity Data

The total amount of nitrogen from urea applied to soils was estimated within the calculations for NH_3 emissions (Section 3D) based on the amount of fertilizer use in Chiang Mai and fertilizer mix from Thailand imports collected in OAE statistics (see section 3D).

The total mass of urea applied to soils was then recalculated based on a N content of 46% (19,441 tonnes of urea in 2022 for Chiang Mai).

6.2.6.3 Results: Emissions from urea application

The table below summarizes emissions of CO_2 from 2012 to 2022 from Urea application (Table 77).

TABLE 77. CO_2 EMISSIONS IN CHIANG MAI FROM UREA APPLICATION (IN TONNES OF CO_2)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2	12,222	12,013	10,956	9,521	10,723	11,217	12,848	14,501	14,933	14,191	14,257

[18] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf

6.3 RESULTS: TOTAL EMISSIONS FROM AGRICULTURAL SECTOR

Agricultural activities contribute differently to the emissions of air pollutants in Chiang Mai province (Figure 27). Results from this inventory show that methane emissions mostly come from rice cultivation, enteric fermentation, and manure management. N_2O emissions mostly come from agricultural soils through the application of organic and synthetic fertilizers as well as from manure management. On the other hand, particulate matter emissions (PM_{10}, $PM_{2.5}$) are mainly emitted by agricultural residue burning.

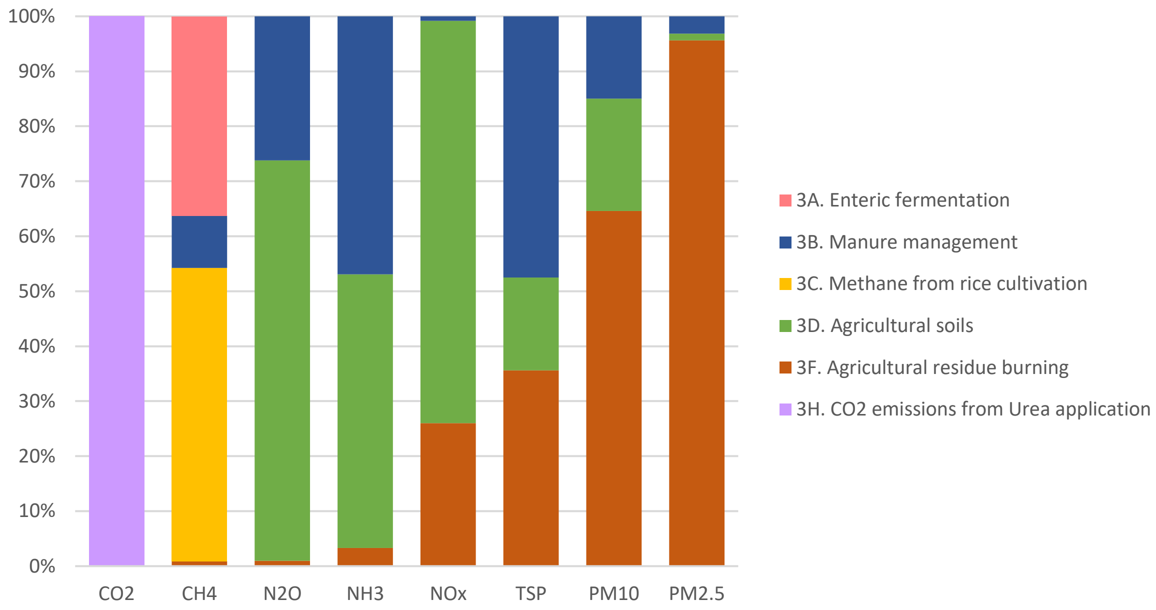


FIGURE 27. CONTRIBUTION OF AGRICULTURAL SECTORS TO THE EMISSIONS OF MAIN GHG AND POLLUTANTS IN 2021 (FOR CO_2, ONLY ANTHROPOGENIC SOURCES ARE TAKEN INTO ACCOUNT IN THIS CHART).

6.4 WAYS OF IMPROVEMENTS

Several ways of improvement exist for the agricultural sector.

Parameters used in the Tier 2 calculation for sectors 3A and 3B were mainly coming from IPCC default and may be improved based on more accurate statistics in Chiang Mai. The milk yield per dairy cow was taken from FAOSTAT but some more country or province-specific data may be available in official statistics. Moreover, data on the evolution of livestock weight per animal type may be estimated from slaughterhouse statistics which could result in a better monitoring of gross energy intake, nitrogen excretion and related emissions. Data on manure management systems could also be updated (most being either IPCC or Thailand 1994 inventory).

Methane emissions from rice cultivation (sector 3C) were calculated based on a Tier 1 approach and using some country-specific data extracted from literature. Disaggregating the calculus per each rice season (major / off-season) and irrigation practices could lead to a better understanding of mitigation options. Moreover, considering the importance of methane emission from rice, it is considered good practice to try and develop a Tier 2 or Tier 3 methodology to better monitor emissions and impacts from management practices. If not possible, try to discuss uncertainties related to different site-specific variables, such as soil texture, cultivars, growing season, or planting method, that may impact emissions but are not entirely captured by the existing estimation model, as pointed out by Nikolaisen et al., 2023.

For sector 3D, the synthetic fertilizer application levels by type of fertilizer were estimated using both national and provincial data with an average N content estimation. However, statistics on the total amount of fertilizer applied per each crop type suggest that more information may be available that could improve the inventory (especially expressing statistics as N content and not total mass or distinguishing by the form of fertilizer).

Alternatively, knowledge of crop needs in terms of fertilizer form may also be a way to cross-reference these data. Other sources of N input to soils (sewage sludge, wastewater…) were not estimated due to a lack of data on these sources.

Regarding agricultural residues burning (3F), it is worth noting that the $Frac_{Burnt}$ was based on Cheewaphongphan et al., 2018, Khonpikul et al., 2017 and the Asean Cassava Center[19], with lower values than those of Phairuang et al., 2017 or the PCD report. This suggests a lower frequency of open burning in Chiang Mai compared to the rest of Thailand. Complementary and interannual data on agricultural burning would help monitor residue burning emissions.

[19] *[1] ASEAN Cassava Centre, « Harnessing Cassava Residues for Sustainability | Asean Cassava ». last accessed February 12th, 2024. Available on:* https://sustainablecassava.org/information-hub/articles/CassavaWasteHandbook2/#:~:text=These%20residues%20make%20up%2024,%2C%20compost%2C%20and%20charcoal%20production.

7 WASTE (NFR SECTOR 5)

7.1 OVERVIEW OF THE SECTOR

This section concerns emissions from solid waste treatment and wastewater treatment and discharge.

The solid waste treatment processes generate sometimes significant atmospheric emissions of substances such as CH_4 from solid waste disposal sites, and certain pollutants from incineration and open burning as particulate matter, carbon monoxide or nitrogen oxides. Solid waste is generated by households, local authorities and businesses (commercial, industrial, construction and public works, agricultural facilities, etc.). Some waste from local authorities and businesses is treated in facilities that receive household waste and is treated as household waste.

Wastewater treatment and discharge generate mainly greenhouse gases emissions and more particularly methane and nitrous oxide.

7.2 METHODOLOGY

7.2.1 Activity data: quantity of waste generated and the associated treatment processes

The total amount of municipal solid wastes (MSW) generated in Chiang Mai was collected from Reports of current status of municipal solid waste management in Thailand for different years published by PCD. We have differentiated between the quantity of waste generated in rural and urban areas. The total amount of solid waste generated for each type of area is given in Table 78 and Figure 28 below:

TABLE 78. GENERAL DATA ABOUT WASTE IN CHIANG MAI

Chiang Mai	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Population data (10^6 inhabitant)	1.66	1.67	1.68	1.73	1.74	1.75	1.76	1.78	1.78	1.79	1.79
Population distribution (%): rural area	63.5	62.3	62.3	62.1	62.1	61.7	61.9	62.0	62.2	62.3	62.4
Population distribution (%): urban area	36.5	37.7	37.7	37.9	37.9	38.3	38.1	38.0	37.8	37.7	37.6
Generation rate of MSW per inhabitant (kg/cap/day): rural areas	0.55	0.56	0.59	0.54	0.51	0.51	0.37	0.36	0.36	0.36	0.36
Generation rate of MSW per inhabitant (kg/cap/day): urban areas	1.89	1.82	1.71	1.64	1.68	1.67	1.86	1.85	1.85	1.85	1.85
Total amount of MSW generated (kt)	627	627	620	603	606	609	604	602	602	602	602

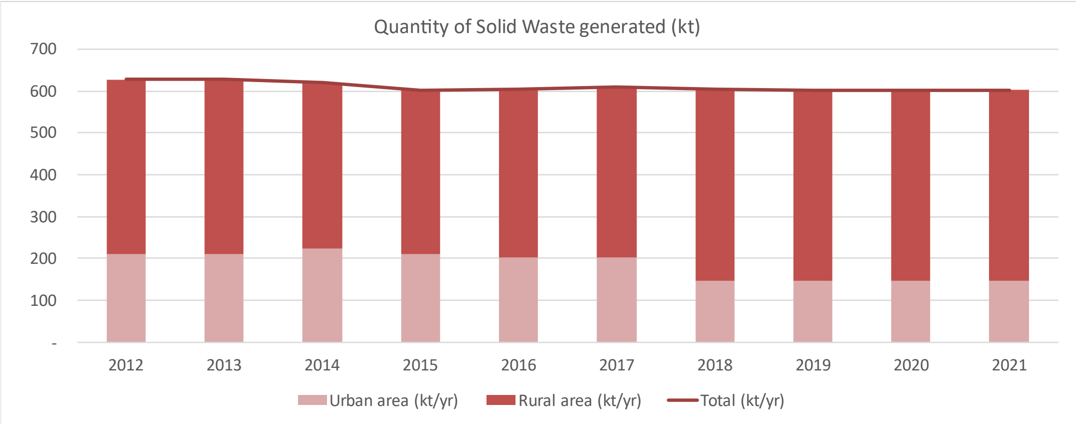


FIGURE 28: TOTAL AMOUNT OF MUNICIPAL SOLID WASTE GENERATED IN CHIANG MAI PER YEAR

Assumptions about solid waste generation were based on data from the PCD, and distribution by type of treatment are based in a large part on Pansuk et al. (2018). Then in the waste section, activity data and results are compared with results from Pansuk et al. (2018) when it is relevant. About the total amount of MSW, this study's estimates were consistent with Pansuk et al. (2018) which consider that Chiang Mai generates between 501 and 1,000 kt of MSW each year. The spatial distribution of the amount of household solid waste generated per year is shown in Figure 29.

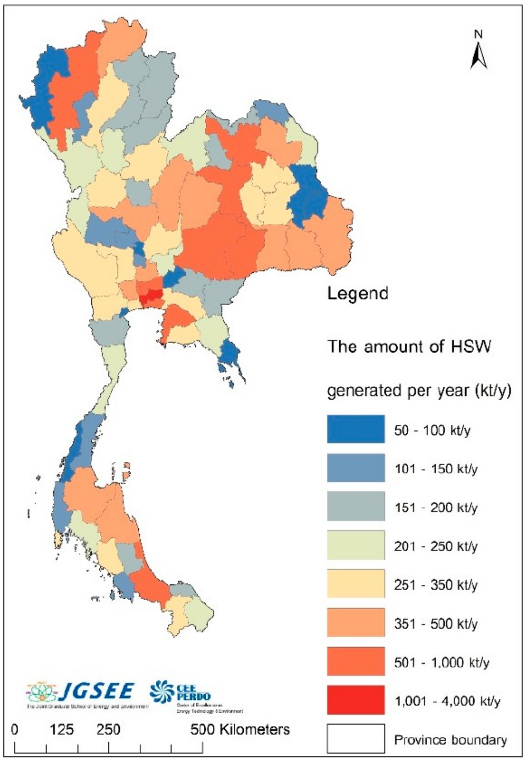
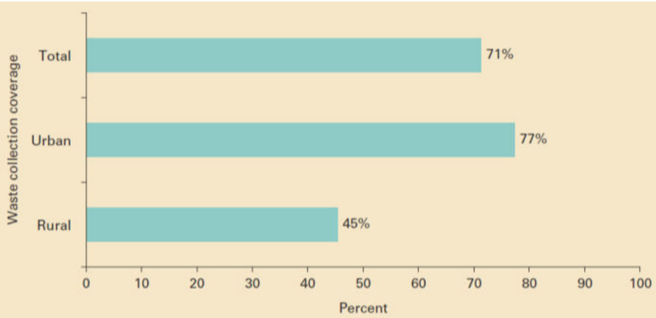


FIGURE 29: SPATIAL DISTRIBUTION OF THE AMOUNT OF HOUSEHOLD SOLID WASTE GENERATED PER YEAR (PANSUK ET AL., 2018)

The MSW can be collected or uncollected. According to Pansuk et al. (2018), it is assumed for the Chiang Mai inventory that the collected part is approximately 75% and the uncollected part is approximately 25%. This repartition between collected and uncollected (75% / 25%) is considered constant.



It is consistent with the "*What a Waste*[20]" *report* from the World Bank which considers that 71% of the waste generated are collected in the East Asia and Pacific Region (Figure 30).

In parallel, it's consistent with the *Action plan on Plastic waste management - Phase II (2023 - 2027)*[21] which considers that 78% of the waste generated are collected in Thailand.

FIGURE 30: WASTE COLLECTION COVERAGE IN EAST ASIA AND PASIFIC (WORLD BANK)

About the collected part of MSW, it is assumed (consistently with the Action plan on Plastic waste management) that a part (21%) is utilized before disposal (recycling), a part is treated correctly (48%) and finally, the last part is treated incorrectly (32%) (Figure 31).

It is assumed that the total amount of waste treated correctly is completely disposed of in the landfill. It's assumed that there is no incinerator of MSW in the province of Chiang Mai.

For the incorrectly treated part, it is assumed that the total amount of waste treated incorrectly is completely disposed of in the open dump. It is assumed that there is no open burning about the collected MSW.

Recycling is not included in the inventory, as it is not an emission process (IPCC).

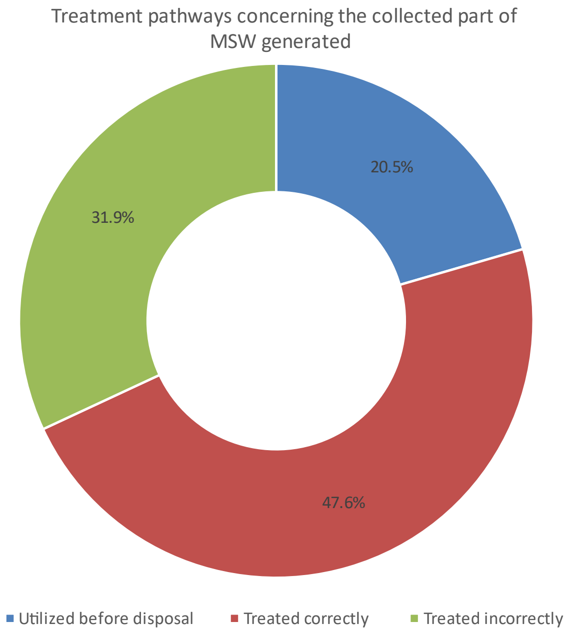


FIGURE 31: TREATMENT PATHWAYS CONCERNING THE COLLECTED PART OF MSW GENERATED

Then, concerning the uncollected part of MSW, it is assumed there are a total of 15 methods employed by the households (consistent with Pansuk et al., 2018). These methods have been identified from the results of interviews with 4,300 households (including the entire Thailand) who resided in areas without MSW collection and disposal services. The methods of household solid waste management are:

1. collection of solid waste in bags and dumping thereof on authorized sites (23.7%),
2. burning of solid waste on their property (34.4%),
3. burning of solid waste outside their property (19.3%),
4. dumping of solid waste on their property (1.7%),
5. dumping of solid waste on the roadside (2.2%),
6. dumping of solid waste into a trench or small canal (0.5%),
7. dumping of solid waste on abandoned lands (0.8%),
8. burial of solid waste on their property (0.8%),
9. burial of solid waste outside their property (0.3%),

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[20] What a Waste (worldbank.org)

[21] Plastic Waste Management Action Plan on Phase 2 (2023-2027) - ศูนย์องค์ความรู้ด้านทรัพยากรธรรมชาติและสิ่งแวดล้อม (mnre.go.th)

10. dumping of solid waste into a river, canal, or swamp (0.5%),
11. segregation of solid waste for sale (2.08%),
12. segregation of hazardous waste to be dumped on authorized sites provided by LAOs or municipalities (0.02%),
13. composting of solid waste (0.4%),
14. segregation of food waste for animal feed (8.6%); and
15. others (4.7%).

It is assumed that 1. and 12. correspond to landfill disposal, 2. and 3. correspond to open burning, 4. to 10. correspond to open dump, 11. and 14. correspond to recycling, 13. corresponds to composting and 15. corresponds to unknown (Figure 32).

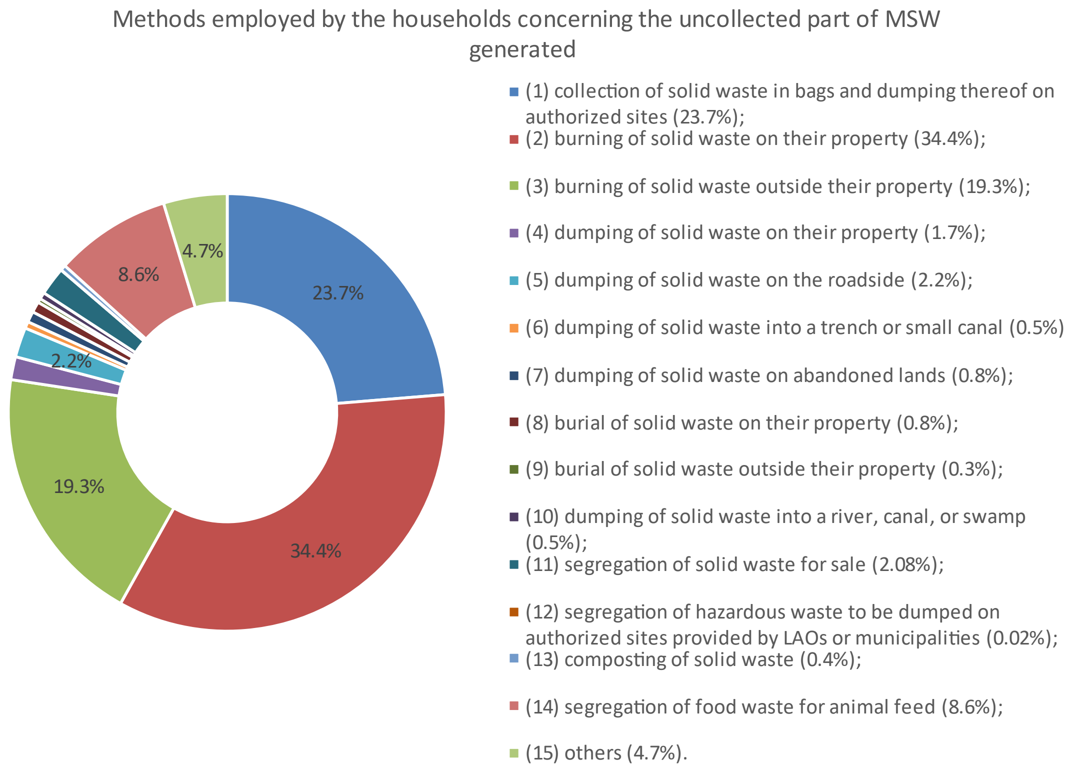


FIGURE 32: METHODS EMPLOYED BY THE HOUSEHOLDS CONCERNING THE UNCOLLECTED PART OF MSW GENERATED (PANSUK ET AL., 2018)

Finally, it is assumed that the total amount of MSW process management (collected and not collected, correctly treated and incorrectly treated) is summarized in Table 79 and illustrated in Figure 33.

TABLE 79. GENERAL OVERVIEW ABOUT SOLID WASTE TREATMENT IN CHIANG MAI (KT)

MSW treated (kt)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
5.A - Solid Waste Disposal Sites	422	422	417	406	407	410	406	405	405	405	405
5.B - Biological treatment	0.63	0.63	0.62	0.60	0.60	0.61	0.60	0.60	0.60	0.60	0.60
5.C - Incineration and open burning	84	84	83	81	81	82	81	81	81	81	82
Without emissions (recycling or unknown treatment)	121	121	119	116	116	117	116	116	116	116	116

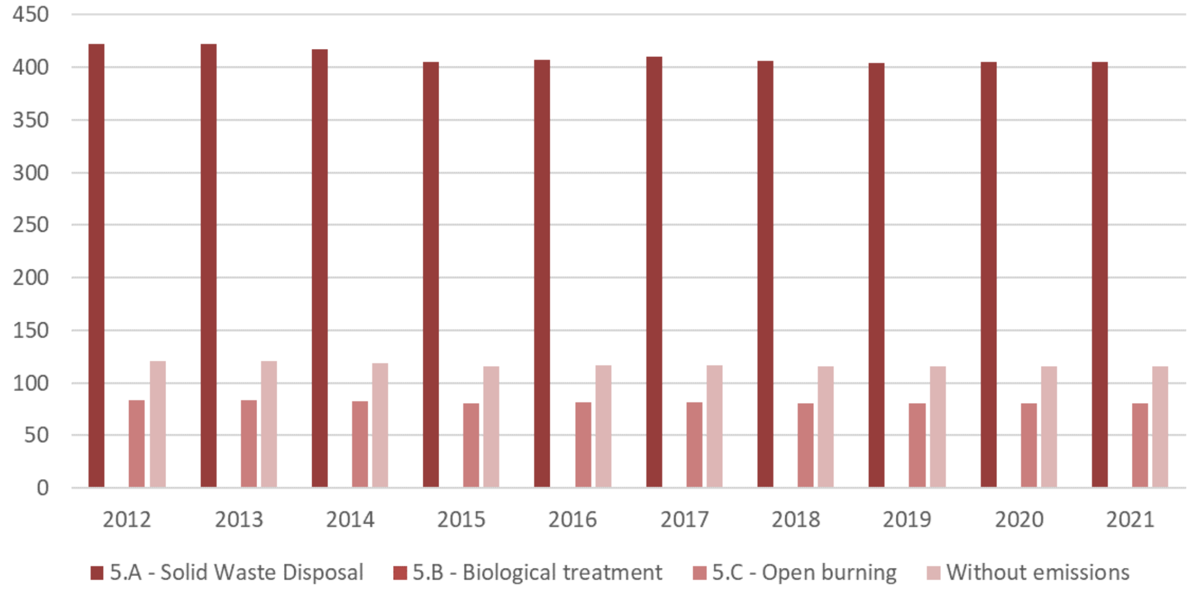


FIGURE 33: TOTAL AMOUNT OF MUNICIPAL SOLID WASTE TREATED (KT)

7.2.2 Solid waste disposal on land (5A)

7.2.2.1 Overview of the sector

This section refers to Solid Waste Disposal Sites (SWDS). IPCC guidelines distinguish a few types of SWDS, managed, unmanaged, and uncategorized.

Unmanaged (deep or shallow) SWDS, also known as "open dumps", are depots of waste on the ground, in a cavity, a ravine, or any other depression in the ground.

- Deep: all SWDS not meeting the criteria of managed SWDS, and which have depths greater than or equal to 5 metres and/or high-water table at near ground level. The latter situation corresponds to filling inland water, such as pond, river or wetland, by waste.
- Shallow: all SWDS not meeting the criteria of managed SWDS, and which have depths of less than 5 metres.

Managed (anaerobic or semi-aerobic) SWDS is a management method to limit the many nuisances caused by open dumps. Management consisted of taking a few basic precautions to limit the proliferation of animals (flies, rats, etc.) and pathogenic germs.

- Anaerobic: these must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging, and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) levelling of the waste.
- Semi-aerobic: these must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging, and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) levelling of the waste.

Uncategorized SWDS: if countries cannot categorize their SWDS into above four categories of managed and unmanaged SWDS, the MCF for this category can be used.

7.2.2.2 Activity data

The total amount of MSW going into landfills between 2012 and 2021 was estimated based on the annual waste mass flow extracted from the reports of the Pollution Control Department, Ministry of Natural Resource and Environment (waste generated) and information provided by *Pansuk and al.* (2018) and by the *Action plan on Plastic waste management - Phase II (2023 - 2027)* as presented previously and in Table 80.

TABLE 80. TOTAL AMOUNT OF WASTE GOING IN LANDFILLS PER YEAR

Municipal Solid Wastes treated (kt)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
5.A.1 - Managed Solid Waste Disposal Sites (SWDS)	224	224	221	215	216	217	216	215	215	215
5.A.2 - Unmanaged SWDS	161	161	159	155	155	156	155	154	154	155
5.A.3 - Uncategorized SWDS	37	37	37	36	36	36	36	36	36	36

The methodology used for estimating GHG emissions from SWDS was based on a mathematical model which requires activity data for a long period. The total amount of MSW going in landfills has been estimated since 1950.

It is assumed that there are three landfills in Chiang Mai and the oldest one was opened in 1998 (Table 81).

TABLE 81. SOLID WASTE DISPOSAL SITES IDENTIFIED

Operator	Landfill's name	Year of operation	Location	Waste amount (tonnes/day)
THA CHIANG THONG CO, LTD.	Tha Chiang Thong (Ban Tan)	1998 - now	209 Moo.7, Ban Tan Subdistrict, Hot District, Chiang Mai Province 50240	600
Wiang Fang Municipality	Wiang Fang Municipality	2004 - now	617 Wiang Subdistrict, Fang District, Chiang Mai Province 50110	70
Chiang Mai Provincial Administrative Organization	Chiang Mai Provincial Administrative Organization	2009 - now	Ban Pa Tung Noi, Moo.1, Pa Pong Subdistrict, Doi Saket District, Chiang Mai Province 50220	90

As a result, we assume that the quantities of MSW stored in landfills have increased since the opening of the SWDS. The amount of MSW disposed of in unmanaged landfills is considered proportional to the population. Finally, the total quantity of MSW landfilled is assumed to be as follows (Figure 34).

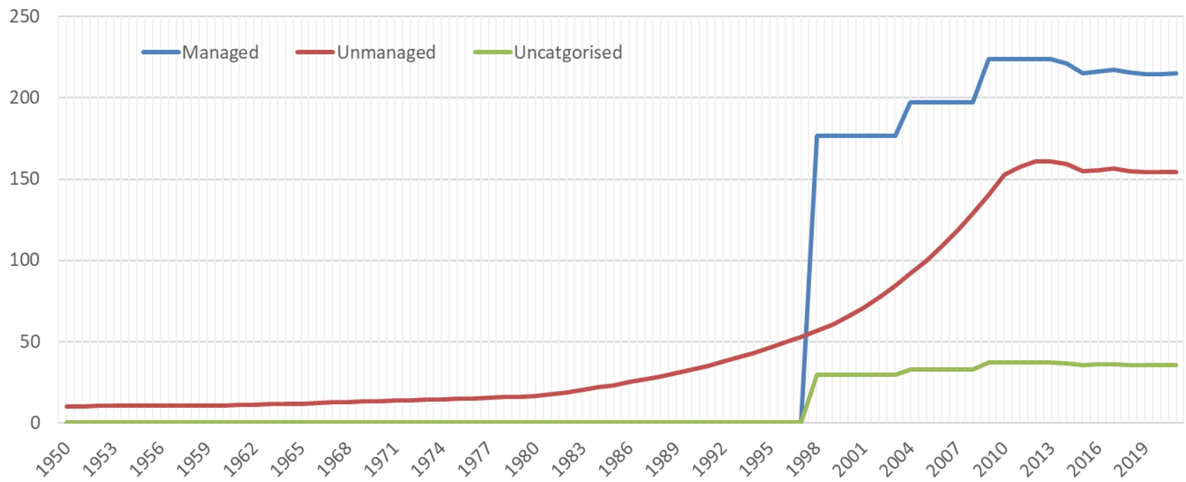


FIGURE 34: TOTAL AMOUNT OF MSW GOING IN LANDFILLS (KT)

Concerning the composition of the MSW, two possible options are available:

- option « bulk waste », when few data are available; and
- option « waste composition » when the knowledge of waste is accurate.

The first approach assumes that the decomposition of different waste types in a SWDS is completely independent of each other. The second approach assumes that the decomposition of all types of waste is completely dependent on each other. No evidence exists that one approach is better than the other.

When the waste composition is relatively stable, both options give similar results. However, when rapid changes in waste composition occur, options might give different outputs. For example, changes in waste management, such as bans on disposing of food waste or degradable organic materials, can result in rapid changes in the composition of waste disposed in SWDS.

For Chiang Mai, the composition of MSW generated is known only for the year 2020. So, it is assumed to consider the bulk option in this inventory.

7.2.2.3 GHG emissions

The IPCC methodology for estimating GHG emissions from SWDS is based on the First Order Decay (FOD) method. This method assumes that the degradable organic component (degradable organic carbon, DOC) in waste decays slowly throughout a few decades, during which CH_4 and CO_2 are produced. Transformation of degradable material in the SWDS to CH_4 and CO_2 occurs through a chain of reactions and parallel reactions.

Methane emissions (CH_4)

<u>First Order Decay (FOD) Model</u>

If conditions are constant, the rate of CH_4 production depends solely on the amount of carbon remaining in the waste. As a result, emissions of CH_4 from waste deposited in a disposal site are the highest in the first few years after deposition, then gradually decline as the degradable carbon in the waste is consumed by the bacteria responsible for the decay.

Half-lives for different types of waste vary from a few years to several decades or longer. The FOD method requires data to be collected or estimated for historical disposals of waste over a period of 3 to 5 half-lives to achieve an acceptably accurate result. It is therefore good practice to use disposal data for at least 50 years as this time frame provides an acceptably accurate result for most typical disposal practices and conditions.

The CH_4 emissions from SWDS for a single year are estimated using the methodology recommended by the IPCC guidelines from 2006 and calculated by using the following equation:

$$CH_4 Emissions = [\sum_x CH_4 generated - R_T] \times (1 - OX_T)$$

Where:

- CH_4 Emissions = CH_4 emitted in year T, Gg (or Ktonnes).
- T = inventory year.
- x = waste category or type/material.
- R_T = recovered CH_4 in year T, Gg (or Ktonnes).
- OX_T = oxidation factor in year T, (fraction).

Part of the CH_4 generated is oxidized in the cover of the SWDS or can be recovered for energy or flaring. The CH_4 emitted from the SWDS will hence be smaller than the amount generated. The CH_4 recovered must be subtracted from the CH_4 amount generated. Only the fraction of CH_4 that is not recovered will be subject to oxidation in the SWDS cover layer. The tool developed by the IPCC is used to calculate emissions.

The total amount of methane generated is calculated by using this equation:

$$CH_4generated_T = DDOC_{m\ decompT} \times F \times \frac{16}{12}$$

Where:

- CH_4 generated$_T$ = amount of CH_4 generated from decomposable material.
- $DDOC_{m\ decompT}$ = $DDOC_{m\ decomposed}$ in year T, Gg (or Ktonnes).
- F = fraction of CH_4, by volume, in generated landfill gas (fraction).
- 16/12 = molecular weight ratio CH_4/C (ratio).

Degradable organic carbon (DOC) is the organic carbon in waste that is accessible to biochemical decomposition and depends on the composition of the category of waste.

Decomposable Degradable Organic Carbon (DDOC) is the part of the organic carbon that will degrade under the anaerobic conditions in SWDS.

With a first order reaction, the amount of product is always proportional to the amount of reactive material. This means that the year in which the waste material was deposited in the SWDS is irrelevant to the amount of CH_4 generated each year. It is only the total mass of decomposing material currently in the site that matters.

This implies that once the amount of decomposing material in the SWDS at the beginning of the year is known, each subsequent year can be treated as the first year in the estimation method. The basic first-order calculations can be performed using these two simple equations, with the decay reaction starting on January 1st of the year following deposition.

$$DDOCma_T = DDOCmd_T + (DDOCma_{T-1} \times e^{-k})$$

$$DDOCm\ decomp_T = DDOCma_{T-1} \times (1 - e^{-k})$$

Where:

- T = inventory year.
- $DDOCma_T$ = DDOCm accumulated in the SWDS at the end of year T, Gg (or Ktonnes).
- $DDOCma_{T-1}$ = DDOCm accumulated in the SWDS at the end of year (T-1), Gg (or Ktonnes).
- $DDOCmd_T$ = DDOCm deposited into the SWDS in year T, Gg (or Ktonnes).
- DDOCm $decomp_T$ = DDOCm decomposed in the SWDS in year T, Gg (or Ktonnes).
- k = reaction constant, k = ln(2)/$t_{1/2}$ (y-1).
- $t_{1/2}$ = half-life time (y).

The half-life value, $t_{1/2}$ is the time taken for the DOC_m in waste to decay to half its initial mass. The half-life is affected by a wide variety of factors related to the composition of the waste, climatic conditions at the site where the SWDS is located, characteristics of the SWDS, and waste disposal practices.

<u>Climatic zone</u>
For the Province of Chiang Mai, the "moist and wet tropical" climate zone was chosen.

<u>Reaction constant k</u>
The default rate constants proposed by the 2006 IPCC guidelines for the selected climate zone were applied.

<u>Degradable organic carbon (DOC)</u>
The degradable organic carbon values proposed for each waste category in the 2006 IPCC Guidelines were applied.

Decomposed DOC fraction (DOC_f)
The fraction of degradable organic carbon that decomposes (DOC_f) is considered constant (0.5) and is provided by the 2006 IPCC guidelines.

Methane Correction Factor (MCF)
The default methane correction factors (MCF) proposed in the 2006 guidelines were assigned to the different types of landfill facilities existing in Chiang Mai:

- MCF = 1 for managed SWDS.
- MCF = 0.4 for unmanaged shallow SWDS.
- MCF = 0.6 for uncategorized SWDS.

Oxidation Factor (Ox)
The default value provided by the 2006 IPCC guidelines for SWDS not covered with aerated material was considered (0).

Fraction of CH_4 in generated biogas (F)
The CH_4 fraction in generated biogas (F) of 0.5 recommended by default in the 2006 IPCC Guidelines was applied.

Biogas recovered (R_T)
Without information about the amount of biogas recovered, it was assumed that there is no biogas recovery in Chiang Mai.

Carbon dioxide (CO_2)

As CO_2 is of biogenic origin, it is accounted for a different way to other substances. As a result of these rules, CO_2 emissions from SWDS in CRF reporting formats (category 5.A) are not included in the inventory total.

Biogenic CO_2 emissions are based on the quantities of CH_4 not recovered that are oxidized to CO_2 when passing through the cover.

Nitrous oxide (N_2O)

No emissions of this substance are expected.

7.2.2.4 Atmospheric pollutants emissions

It is assumed that only NMVOC emissions are significant, while other air pollutants are considered insignificant or non-existent.

Non-methane volatile organic compounds (NMVOCs)

NMVOC emissions are considered proportional to methane emissions, calculated at a rate of 3.6 kg of NMVOCs per Mg (or tonnes) of CH_4 emissions. This emission factor is based on the 2023 EMEP guidelines.

7.2.2.5 Ways of improvement

Composition
Emissions from SWDS are influenced in large part by the composition of waste and the evolution of the composition. The biological process that drives emission is a long-term process. The waste stored in a year is emitted for a period of more than thirty years. A change in the composition of waste (due to an evolution of the practices or the national regulations) can massively impact emissions from SWDS. Due to a lack of information, it is assumed that emissions are estimated with the bulk option. It would be a good practice to consider the regional composition of waste going into landfills and its evolution between 1950 and now.

Amount of MSW stored

The total amount of MSW disposed in landfills should be estimated based on information relating to the SWDS in operation, to the national practices, and to the national population. It would be a good practice to consider the total amount of waste in each landfill for each year.

7.2.3 Biological treatment of waste (5B)

This section refers to the biological treatment of waste and includes composting and anaerobic digestion.

7.2.3.1 Composting

Composting is a biological treatment of fermentable organic matter in an aerobic environment (in the presence of oxygen). The raw organic matter is decomposed and placed in a heap (this decomposition can be natural or controlled). The micro-organisms then begin the decomposition process, which can be divided into two phases: the active phase and the hardening phase.

During the active phase, the temperature rises rapidly due to the metabolism of the micro-organisms. This increase sanitizes the material by killing pathogens and weed seeds and breaking down phytotoxic compounds. The active phase lasts several weeks.

Once all the easily degradable or digestible matter has been consumed, the activity of the thermophiles diminishes, and the maturation phase begins. The organic matter continues to decompose into humic substances. There is no clearly defined time for maturation (it depends on the raw material, the composting method, and the management).

Composting is complete when the raw materials are no longer actively decomposing and are biologically and chemically stable.

7.2.3.2 Anaerobic digestion

Methanization involves treating organic matter in an anaerobic environment (in the absence of oxygen). All organic waste can be treated by methanization, except for wood waste. The main types of waste treated are industrial effluents and urban or industrial sewage sludge, the fermentable fraction of household waste and agricultural waste.

Anaerobic digestion of organic matter produces biogas (55 to 60% CH_4) and digestate (comprising a solid fraction and a liquid fraction) that can be used as fertilizer.

7.2.3.3 Activity data

It is assumed that there is no anaerobic digestion in Chiang Mai.

Concerning composting, it is assumed that a small part of the uncollected MSW is composted by households (consistent with Pansuk et al., 2018). The emission results are presented in Figure 35.

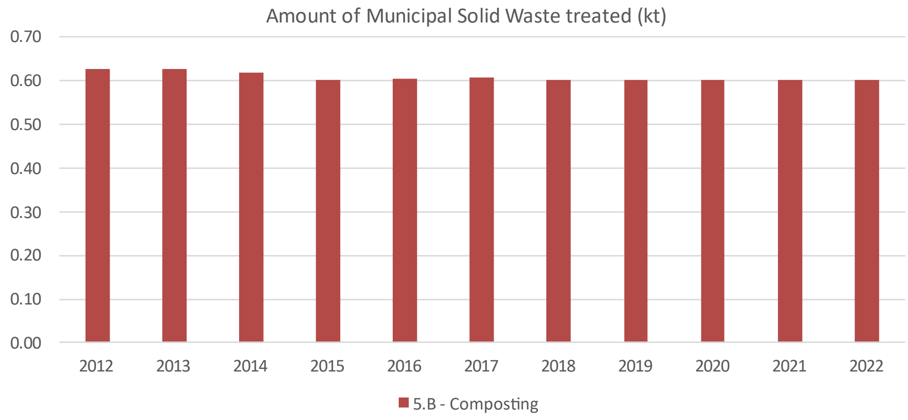


FIGURE 35: TOTAL AMOUNT OF MSW COMPOSTED PER YEAR (KT)

7.2.3.4 GHG emissions

Carbon dioxide emissions

As CO_2 is of biogenic origin, it is accounted for in a different way to other substances in GHGs Emissions Inventory. As a result of these rules, CO_2 emissions from biological treatment in CRF reporting formats (category 5.B) should not be included in the inventory total.

Methane emissions

Methane emissions from composting of waste were estimated based on the default equation proposed in the 2006 IPCC Guidelines:

$$CH_4 Emissions = \sum_i (M_i \times EF_i) \times 10^{-3} - R$$

Where:

- CH_4 Emissions = total CH_4 emissions in inventory year, Gg (or Ktonnes) CH_4
- M_i = mass of organic waste treated by type of waste i, Gg (or Ktonnes)
- EF_i = emission factor for the type of waste i, g CH_4/kg waste treated
- i = type of waste,
- R = total amount of CH_4 recovered in inventory year, Gg (or Ktonnes) CH_4

Emission factor for CH_4 is the default value provided by 2006 IPCC Guidelines; 4 g CH_4/kg waste treated (on a wet weight basis). The emission results are presented in Figure 36.

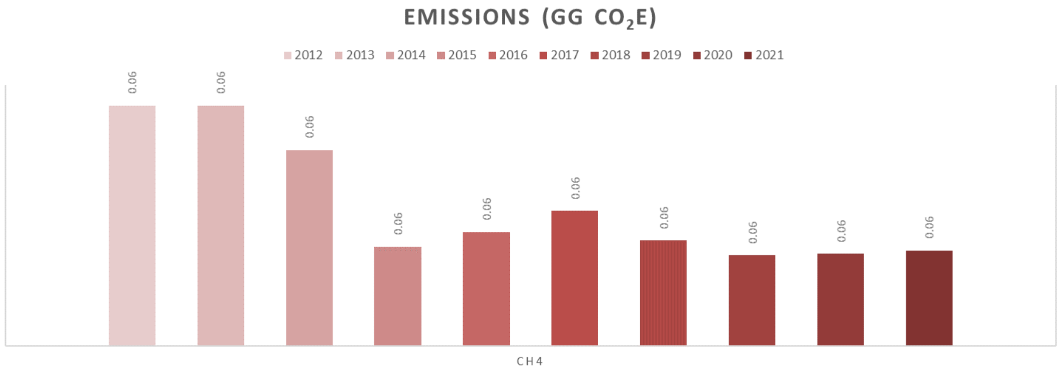


FIGURE 36: CH_4 EMISSIONS (GG OR KTONNES OF CO_2E[22]) FROM COMPOSTING

Nitrous oxide emissions

Nitrous oxide emissions from composting of waste were estimated based on the default equation proposed in the 2006 IPCC Guidelines:

$$N_2O\ Emissions = \sum_i (M_i \times EF_i) \times 10^{-3}$$

Where:

- N_2O Emissions = total N_2O emissions in inventory year, Gg (or Ktonnes) N_2O.
- Mi = mass of organic waste treated by type of waste i, Gg (or Ktonnes).
- EF = emission factor for treatment i, g N_2O/kg waste treated.
- i = type of waste.

Emissions factor for N_2O is the default value provided by 2006 IPCC Guidelines; 0.3 g N_2O/kg waste treated (on a wet weight basis).

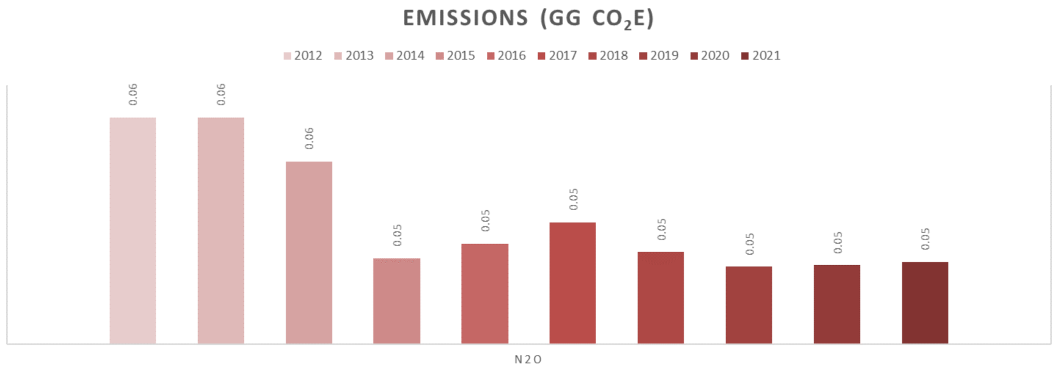


FIGURE 37: N_2O EMISSIONS (GG OR KTONNES OF CO_2E) FROM COMPOSTING

7.2.3.5 Atmospheric pollutants

It is assumed that only NH_3 emissions are significant, while other substances are considered as insignificant or non-existent.

[22] *CO_2E: emissions of GHG in CO_2 equivalent*

Ammonia (NH_3)

Emission factor for NH_3 is the default value provided by 2023 EMEP guidelines, 0.24 kg NH_3/Mg (or tonnes) waste treated. The emission results are presented in Figure 38.

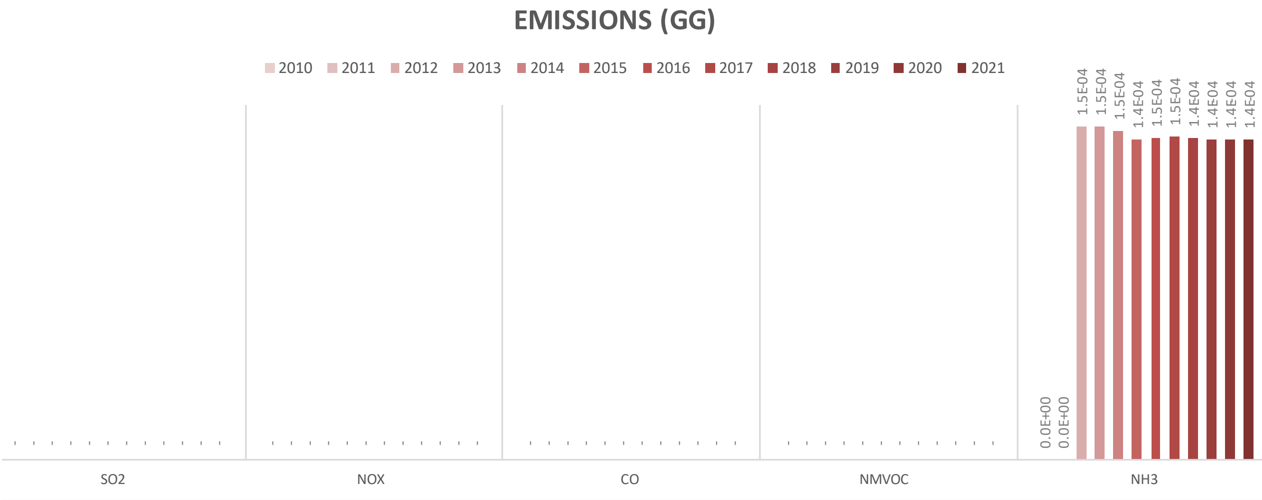


FIGURE 38: SO_2, NOX, CO, NMVOC AND NH_3 EMISSIONS (GG OR KTONNES) FROM COMPOSTING

7.2.3.6 Ways of improvement

Amount of MSW composted

The total amount of MSW composted was estimated based on information relating to the total waste generated in Chiang Mai and to the national practices. It would be a good practice to consider the total amount of waste composted each year in Chiang Mai.

Emissions factor

Atmospheric pollutants were estimated with EF from EMEP 2023. It would be a good practice to use country specific EF (or regional EF).

7.2.4 Waste Incineration (5C1a – 5C1b)

This section refers to the incineration of waste. It includes municipal solid waste, industrial waste, and clinical waste.

7.2.4.1 Activity data

Based on available information, it was assumed that there is no incineration of municipal solid waste in Chiang Mai. The total amount of MSW collected is going into managed or unmanaged landfills. Concerning the uncollected part, it is assumed that there is only open burning of MSW and no incineration.

It is assumed that there is no incineration of industrial solid waste too.

Research from Chiang Mai University indicates that Chiang Mai Municipality uses incineration to dispose of infectious waste. This study notes that they have the capacity to dispose of approximately 1.5 tonnes of waste per day using this method. It is assumed that 1.5 tonnes of infectious waste per day are incinerated.

7.2.4.2 GHG emissions

Carbon dioxide emissions

Carbon dioxide emissions from incineration waste were estimated based on the default equation proposed in the 2006 IPCC Guidelines:

$$CO_2Emissions = SW \times \sum_j (WF_j \times dm_j \times CF_j \times FCF_j \times OF_j) \times \frac{44}{12}$$

Where:

- CO_2 Emissions = CO_2 emissions in inventory year, Gg (or ktonnes)/yr.
- W = total amount of solid waste as wet weight incinerated or open-burned, Gg (or ktonnes)/yr.
- WF_j = fraction of waste type/material of component j in the waste (as wet weight incinerated or open burned).
- dm_j = dry matter content in the component j of the waste incinerated or open-burned, (fraction).
- CF_j = fraction of carbon in the dry matter (i.e. carbon content) of component j.
- FCF_j = fraction of fossil carbon in the total carbon of component j.
- OFj = oxidation factor, (fraction).
- 44/12 = conversion factor from C to CO_2.
- with: $\sum_j WF_j = 1$.
- j = component of the waste incinerated/open-burned such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, other inert waste, clinical waste.

Considering the parameters presented below (Table 82), the EF_{CO2} is 238.3 kg CO_2/Mg (or tonnes) of MSW.

TABLE 82. PARAMETERS CONSIDERED FOR INCINERATION OF CLINICAL WASTE

Type of waste	%	dm (% of wet weight)	FC (% of dry weight)	FCF (% of total carbon)	OF (oxidation factor)
Clinical	100	65 %	40 %	25 %	100 %
Reference	Research in Chiang Mai	IPCC GL	IPCC GL	IPCC GL	IPCC GL

Methane emissions

It is assumed that CH_4 emissions are not significant.

Nitrous oxide emissions

Nitrous oxide emissions from incineration of waste were estimated based on the default equation proposed in the 2006 IPCC Guidelines:

$$N_2O\ Emissions = \sum_i (IW_i \times EF_i) * 10^{-6}$$

Where:

- N_2O Emissions = N_2O emissions in inventory year, Gg (or ktonnes)/yr.
- IW_i = amount of solid waste of type i incinerated or open-burned, Gg (or ktonnes)/yr.
- EF_i = aggregate N_2O emission factor, kg N_2O/Gg (or ktonnes) of waste.
- 10^{-6} = conversion factor from kilogram to gigagram.
- i = category or type of waste incinerated/open-burned, specified as follows: MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste, CW: clinical waste, SS: sewage sludge, others (that must be specified).

The total amount of waste open burned is considered as MSW, so the emissions factor considered is 100 g N_2O/ Mg (or tonnes) MSW (wet weight) as presented in the 2006 IPCC guidelines. It corresponds to the EF for industrial waste.

7.2.4.3 Atmospheric pollutants emissions

SO_2, NOx, NMVOCs and CO emissions

Emissions factors of these substances come from the ABC EIM (Table 10.8: Emission Factors for Solid waste incineration) as shown in Table 83 and the emission results are presented in Figure 39.

TABLE 83. EMISSION FACTORS CONSIDERED FOR INCINERATION OF CLINICAL WASTE

Substance	Value	Unit	Reference
SO_2	0.07	g/kg	• ABC EIM (Shrestha et al., 2013) • Table 8.2: Emission Factors for MSW Open Burning
NOx	2.5	g/kg	
NMVOCs	7.40	g/kg	
CO	0.13	g/kg	
NH_3	-	g/kg	

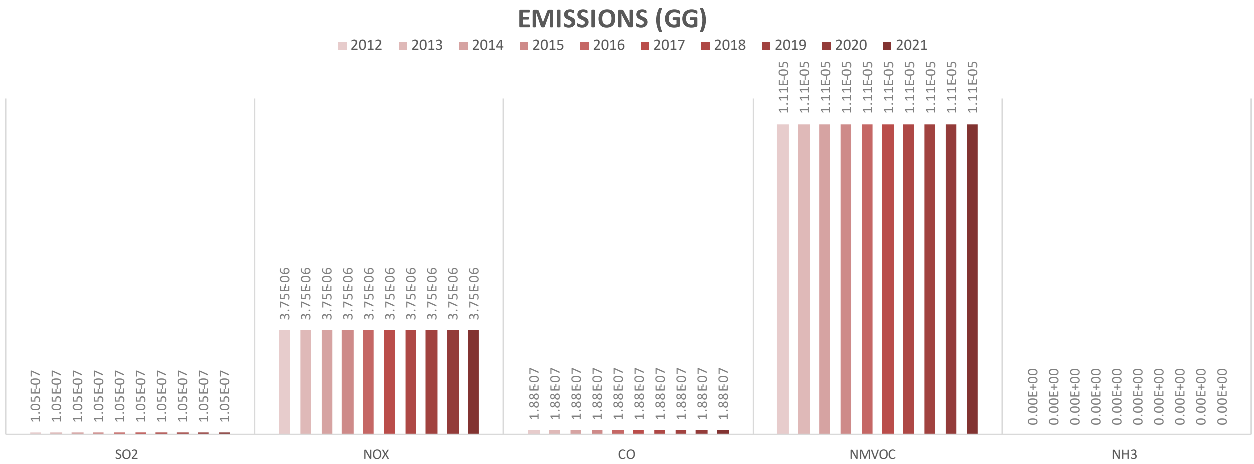


FIGURE 39: SO_2, NOX, CO, NMVOC AND NH_3 EMISSIONS (GG OR KTONNES) FROM WASTE INCINERATION

Particulate emissions

Emission factors of particles come from the ABC EIM (Table 10.8: Emission Factors for Solid waste incineration). This document does not provide any EF for TSP. It is assumed that the ratio between TSP and PM_{10} (and $PM_{2.5}$) is the same that in the EMEP 2023 guidelines as shown in Table 84 and the emission results are presented in Figure 40.

TABLE 84. EMISSION FACTORS CONSIDERED FOR INCINERATION OF CLINICAL WASTE

Substance	Value	Unit	Reference
TSP	2.33	g/kg	• ABC EIM (Shrestha et al., 2013) - Table 10.8: Emission Factors for medical waste Open Burning • EMEP 2023 - 5.C.1.b.i Industrial waste incineration, 5.C.1.b.ii hazardous waste incineration and 5.C.1.b.iv sewage sludge incineration
PM_{10}	1.63	g/kg	
$PM_{2.5}$	0.93	g/kg	
BC	0.044	g/kg	• ABC EIM (Shrestha et al., 2013) - Table 10.8: Emission Factors for medical waste Open Burning
OC	0.0013	g/kg	

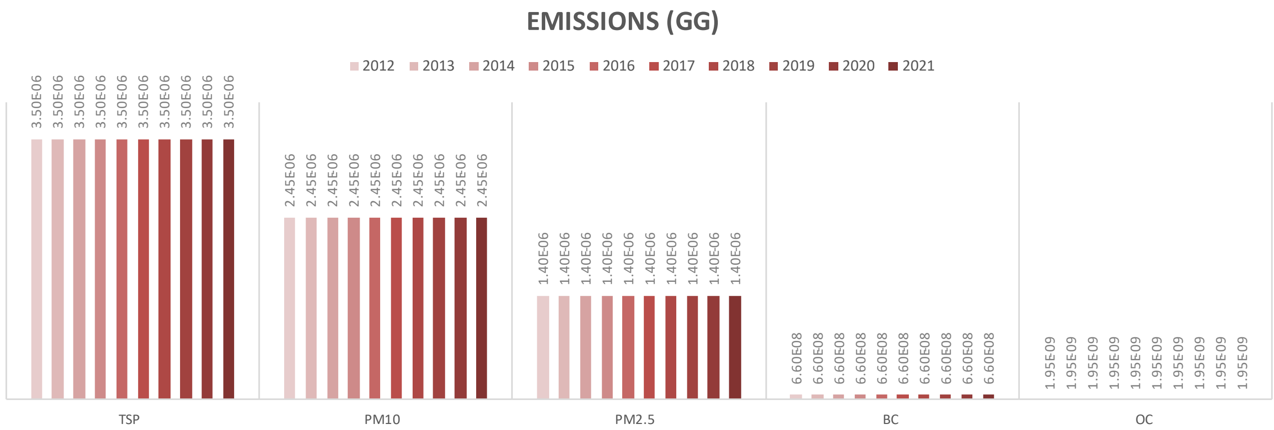


FIGURE 40: PARTICULATE EMISSIONS (GG OR KTONNES) FROM WASTE INCINERATION

Heavy metals emissions

Emission factors of heavy metals come from the EMEP 2023 guidelines (Table 3-1 Tier 1 emission factors for source category 5.C.1.b.i Industrial waste incineration, 5.C.1.b.ii hazardous waste incineration and 5.C.1.b.iv sewage sludge incineration) as shown in Table 85 and the emission results are presented in Figure 41.

TABLE 85. EMISSION FACTORS CONSIDERED FOR INCINERATION OF CLINICAL WASTE

Substance	Value	Unit	Reference
Pb	1.3	g/Mg	• EMEP 2023 • 5.C.2 - Open burning of waste • Table 3-1 - Tier 1 emission factors for source category 5.C.1.b.i Industrial waste incineration, 5.C.1.b.ii hazardous waste incineration and 5.C.1.b.iv sewage sludge incineration
Cd	0.10	g/Mg	

Mg = tonnes

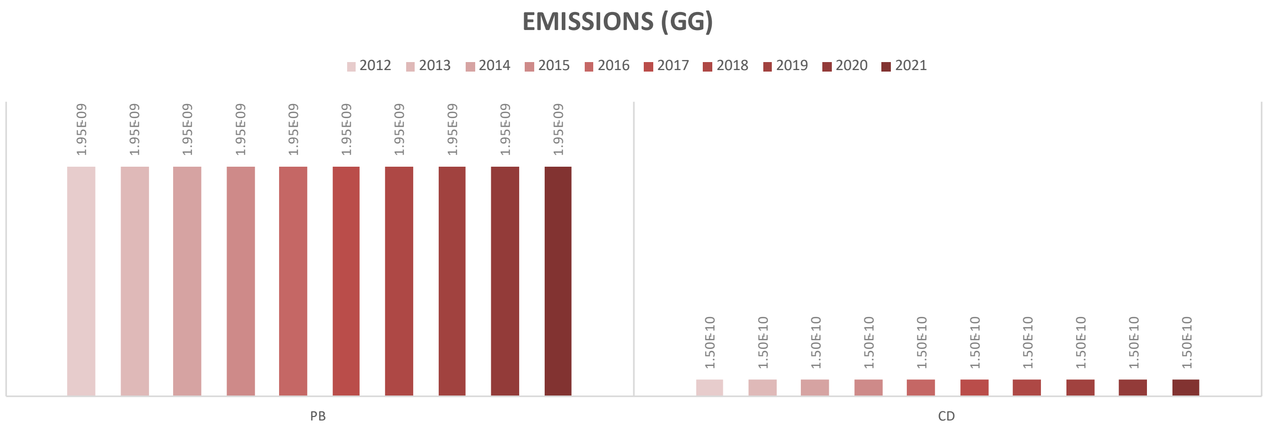


FIGURE 41: HEAVY METALS (GG OR KTONNES) FROM WASTE INCINERATION

7.2.4.4 Ways of improvement

Amount of Solid Waste incinerated

The total amount of solid waste incinerated was based on hypothesis. It would be a good practice to estimate a total amount and composition of solid waste incinerated each year in Chiang Mai province.

Emission factors

Emission factors for heavy metals are based on EMEP 2023. It would be a good practice to use country-specific EF (or regional EF).

7.2.5 Cremation of corpses (5C1bv)

This section refers to the cremation of human bodies.

7.2.5.1 Activity data

The level of activity corresponds to the number of bodies cremated annually. There is no national cremation society in Thailand. All information is provided by "The Cremation Society[23]" from the UK. 80% of Thai people are Buddhist and therefore cremation is the usual method of disposal. In the Northern Region, open-air cremation in a cemetery is still the custom. So, it was assumed that 80% of deaths in Chiang Mai are subjected to cremation. In parallel, the number of deaths each year comes from NSO Interactive Dashboard (Figure 42).

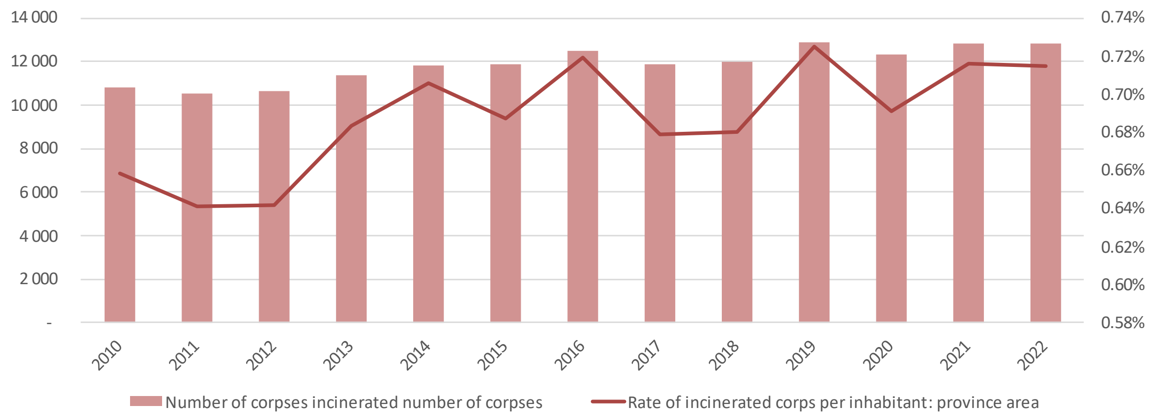


FIGURE 42: NUMBER OF CORPSES INCINERATED PER YEAR IN CHIANG MAI?

[23] *https://www.cremation.org.uk/thailand-2017*

7.2.5.2 GHG emissions

No emissions of these substances are expected.

7.2.5.3 Atmospheric pollutants emissions

SO2, NOx, NMVOCs and CO emissions

Emissions factors of these substances come from the EMEP 2023 guidelines (5.C.1.b.v Cremation, cremation of human bodies) as shown in Table 86. The emission results are presented in Figure 43.

TABLE 86. EMISSION FACTORS CONSIDERED FOR CREMATION

Substance	Value	Unit	Reference
SO_2	0.113	kg/body	• EMEP 2023 • 5.C.1.b.v – Cremation • Table 3-1 - Tier 1 emission factors for source category 5.C.1.b.v Cremation, cremation of human bodies
NOx	0.825	kg/body	
NMVOCs	0.013	kg/body	
CO	0.140	kg/body	

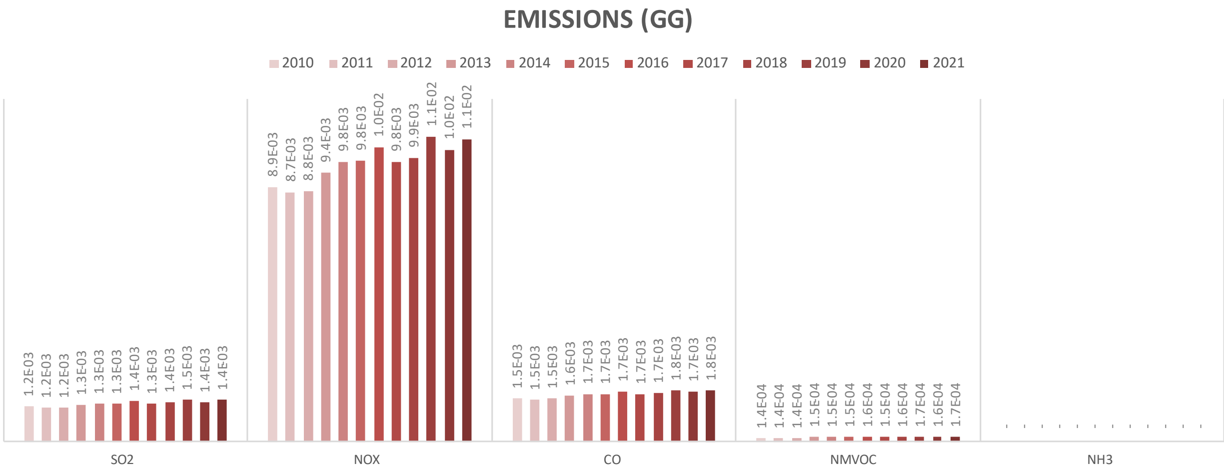


FIGURE 43: SO_2, NOX, CO, NMVOC AND NH_3 EMISSIONS (GG OR KTONNES) FROM CREMATION

Particulate emissions

Emissions factors of these substances come from the EMEP 2023 guidelines (5.C.1.b.v Cremation, cremation of human bodies) as shown in Table 87. The emission results are presented in Figure 44.

TABLE 87. EMISSION FACTORS CONSIDERED FOR CREMATION

Substance	Value	Unit	Reference
TSP	38.56	g/body	• EMEP 2023 • 5.C.1.b.v – Cremation • Table 3-1 - Tier 1 emission factors for source category 5.C.1.b.v Cremation, cremation of human bodies
PM_{10}	34.70	g/body	
$PM_{2.5}$	34.70	g/body	

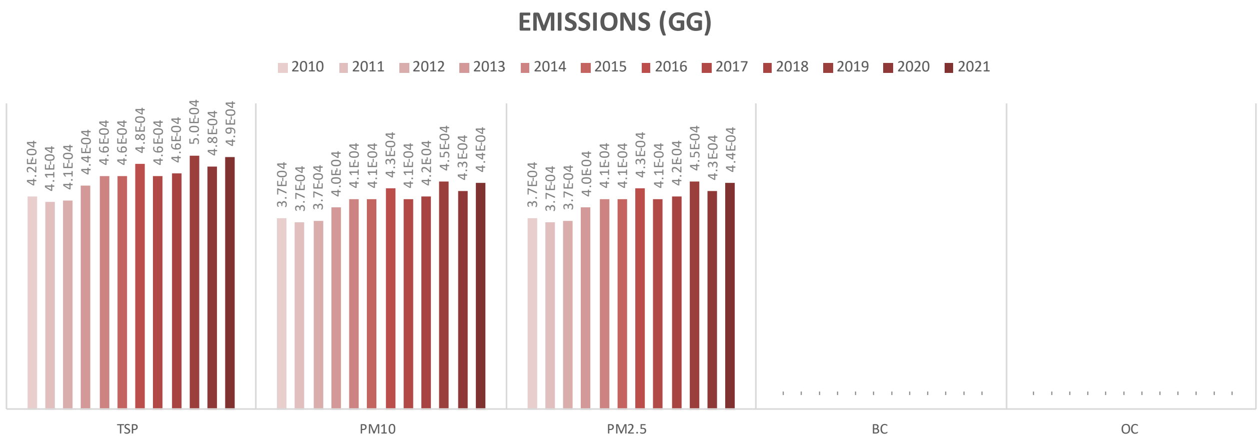


FIGURE 44: PARTICULATE EMISSIONS (GG OR KTONNES) FROM CREMATION

Heavy metals emissions

Emission factors of these substances come from the EMEP 2023 guidelines (5.C.1.b.v Cremation, cremation of human bodies), as presented in Table 88. The emission results are presented in Figure 45.

TABLE 88. EMISSION FACTORS CONSIDERED FOR CREMATION

Substance	Value	Unit	Reference
Pb	30.03	mg/body	• EMEP 2023 • 5.C.1.b.v – Cremation • Table 3-1 - Tier 1 emission factors for source category 5.C.1.b.v Cremation, cremation of human bodies
Cd	1.49	mg/body	

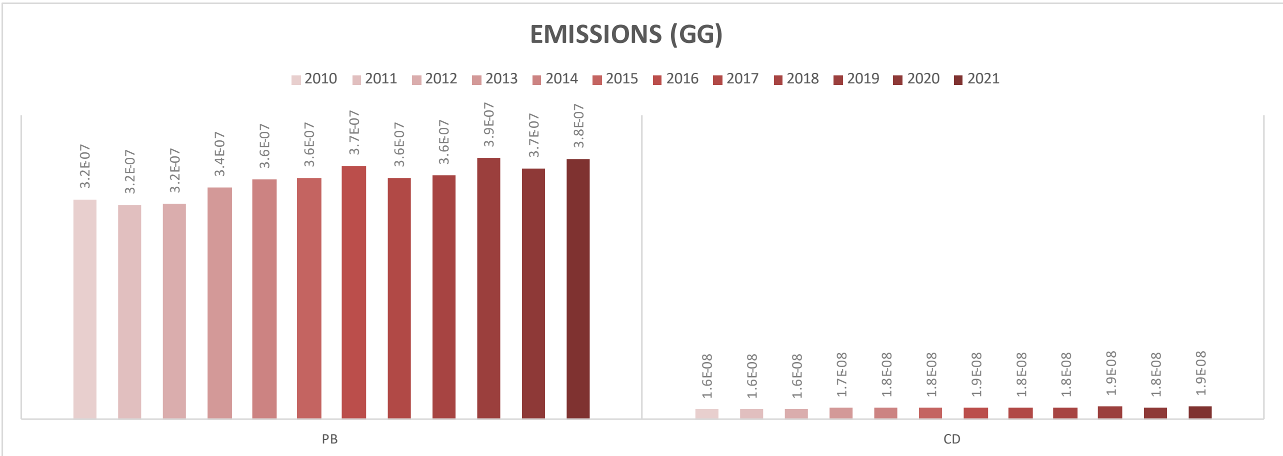


FIGURE 45: HEAVY METALS (GG OR KTONNES) FROM CREMATION

7.2.5.4 Ways of improvement

Number of corpses

The number of corpses was estimated with a simple hypothesis based on the annual number of deaths in Chiang Mai province. It would be a good practice to use specific data and estimate the real number of corpses incinerated each year.

7.2.6 Open burning of waste (5C2)

This section refers to the open burning of waste. Open burning of waste can be defined as the combustion of unwanted combustible materials such as paper, wood, plastics, textiles, rubber, waste oils, and other debris in nature (open-air) or in open dumps, where smoke and other emissions are released directly into the air without passing through a chimney or stack.

7.2.6.1 Activity data

The total amount of MSW open burned was estimated considering a fraction of the uncollected MSW (Figure 46). As previously mentioned, it is assumed that more than a half (53.7%) of the uncollected MSW is open burned:

- burning of solid waste on their property (34.4%); and
- burning of solid waste outside their property (19.3%).

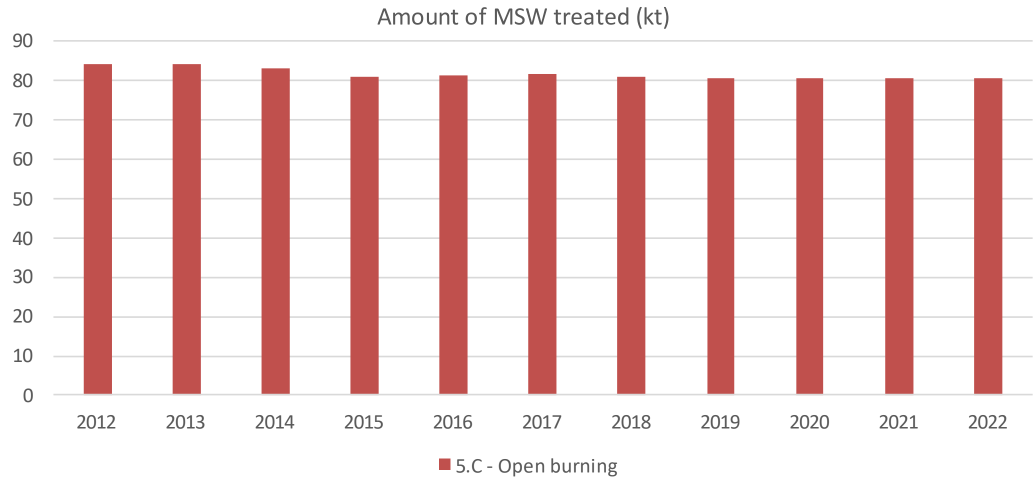


FIGURE 46: TOTAL AMOUNT OF MSW OPEN BURNED PER YEAR

Therefore, it was estimated that approximately 80 kt of MSW is open burned each year in Chiang Mai province. This accounts for 13.4% of the total MSW generated in the province, which appears consistent with national figures. Pansuk et al. (2018) suggest that 3.43 Mt of MSW (out of a total of 26.20 Mt generated) is burned annually in Thailand, equivalent to 13.1% of the total. For Chiang Mai Province, Pansuk et al. (2018) report that the total MSW open burned ranges from 27 kt/year to 60 kt/year. The estimate provided in this study amounts to around 80 kt/year, representing a slightly higher figure. The spatial distribution of the amount of household solid waste burnt in open areas and the amount of MSW burnt in open-dump sites is illustrated in Figure 47.

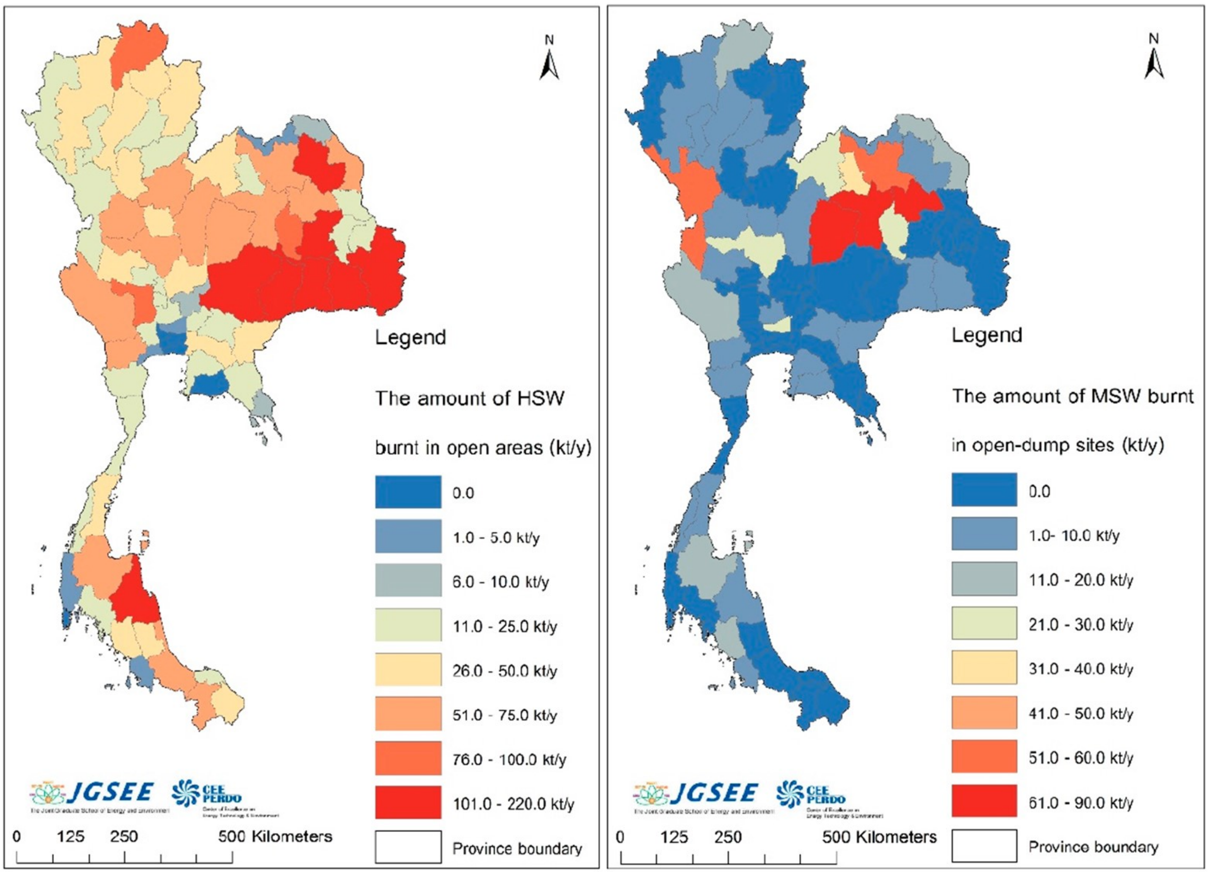


FIGURE 47: SPATIAL DISTRIBUTION OF: (LEFT) THE AMOUNT OF HOUSEHOLD SOLID WASTE BURNT IN OPEN AREAS; AND (RIGHT) THE AMOUNT OF MSW BURNT IN OPEN-DUMP SITES – PANSUK ET AL. (2018)

The composition of the MSW was extracted from Ayutthaya et al. (2021) and is presented in Table 89 and Figure 47, and are considered as constant:

TABLE 89. COMPOSITION OF WASTE IN CHIANG MAI

Type of waste	%
Plastics	14.9
Paper/cardboard	12.5
Textiles	0.0
Food	59.0
Wood	0.6
Garden and Park waste	1.1
Nappies	2.3
Rubber and leather	0.0
Other, inert waste	9.6

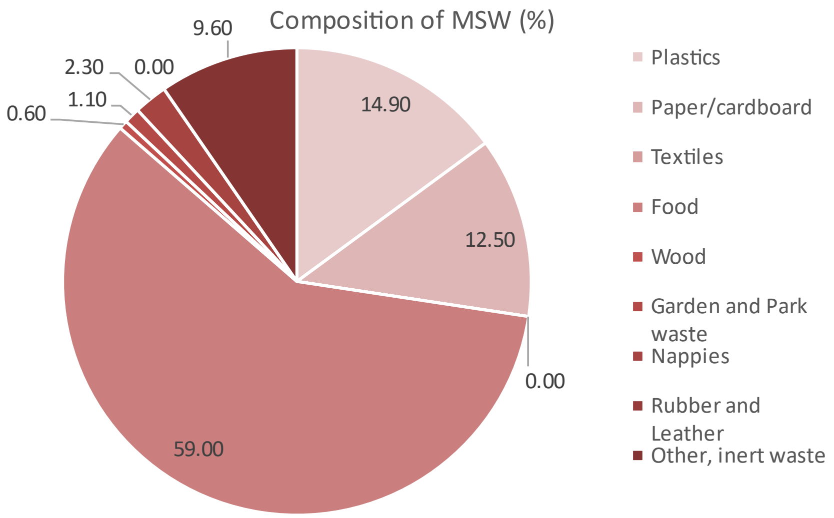


FIGURE 48: COMPOSITION OF WASTE IN CHIANG MAI (AYUTTHAYA ET AL., 2021)

7.2.6.2 GHG emissions

Carbon dioxide emissions

Carbon dioxide emissions from open burning of waste are estimated based on the default equation proposed in the 2006 IPCC Guidelines:

$$CO_2Emissions = MSW \times \sum_j (WF_j \times dm_j \times CF_j \times FCF_j \times OF_j) \times \frac{44}{12}$$

Where:

- CO_2 Emissions = CO_2 emissions in inventory year, Gg (or Ktonnes)/yr.
- MSW = total amount of municipal solid waste as wet weight incinerated or open-burned, Gg (or Ktonnes)/yr.
- WF_j = fraction of waste type/material of component j in the MSW (as wet weight incinerated or open burned).
- dm_j = dry matter content in the component j of the MSW incinerated or open-burned, (fraction).
- CF_j = fraction of carbon in the dry matter (i.e., carbon content) of component j.
- FCF_j = fraction of fossil carbon in the total carbon of component j.
- OF_j = oxidation factor, (fraction).
- 44/12 = conversion factor from C to CO_2.
- with: $\sum_j WF_j = 1$.
- j = component of the MSW incinerated/open-burned such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, other inert waste.

Considering the parameters presented below (Table 90), the EF_{CO2} is 300.7 kg CO_2/Mg (or tonnes) of MSW.

TABLE 90. PARAMETERS CONSIDERED FOR THE OPEN BURNING

Types of waste	%	dm (% of wet weight)	FC (% of dry weight)	FCF (% of total carbon)	OF (oxidation factor)
Plastics	14.9	100 %	75 %	100 %	0.71
Paper/cardboard	12.5	90 %	46 %	1 %	0.71
Textiles	0.0	80 %	50 %	20 %	0.71
Food	59.0	40 %	38 %	0%	0.71
Wood	0.6	85 %	50 %	0 %	0.71
Garden and Park waste	1.1	40 %	49 %	0 %	0.71
Nappies	2.3	40 %	70 %	10 %	0.71
Rubber and leather	0.0	84 %	67 %	20 %	0.71
Other, inert waste	9.6	90 %	3 %	100 %	0.71
Reference	Ayutthaya et al. (2021)	IPCC GL	IPCC GL	IPCC GL	IPCC GL

Methane emissions

Methane emissions from open burning of waste are estimated based on the default equation proposed in the 2006 IPCC Guidelines:

$$CH_4 Emissions = \sum_i (IW_i \times EF_i) * 10^{-6}$$

Where:

- CH_4 Emissions = CH_4 emissions in inventory year, Gg (or Ktonnes)/yr.
- IW_i = amount of solid waste of type i incinerated or open-burned, Gg (Ktonnes)/yr.
- EF_i = aggregate CH_4 emission factor, kg CH_4/Gg (or Ktonnes) of waste.
- 10^{-6} = conversion factor from kilogram to gigagram.
- i = category or type of waste incinerated/open-burned, specified as follows: MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste, CW: clinical waste, SS: sewage sludge, others (that must be specified).

The total amount of waste open burned is considered as MSW, so the emissions factor considered was 6,500 g CH_4/ Mg (or tonnes) MSW (wet weight) as presented in the 2006 IPCC guidelines.

Nitrous oxide emissions

Nitrous oxide emissions from open burning of waste were estimated based on the default equation proposed in the 2006 IPCC Guidelines:

$$N_2O\ Emissions = \sum_i (IW_i \times EF_i) * 10^{-6}$$

Where:

- N_2O Emissions = N_2O emissions in inventory year, Gg (or Ktonnes)/yr.
- IW_i = amount of solid waste of type i incinerated or open-burned, Gg (or Ktonnes)/yr.
- EF_i = aggregate N_2O emission factor, kg N_2O/Gg (or Ktonnes) of waste.
- 10^{-6} = conversion factor from kilogram to gigagram.

- i = category or type of waste incinerated/open-burned, specified as follows: MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste, CW: clinical waste, SS: sewage sludge, others (that must be specified).

The total amount of waste open burned is considered as MSW, so the emissions factor considered was 150 g N_2O/ Mg (or tonnes) MSW (wet weight) as presented in the 2006 IPCC guidelines.

7.2.6.3 Atmospheric pollutants

SO_2, NOx, NMVOCs and CO emissions

Emission factors of these substances come from the ABC EIM (Table 8.2: Emission Factors for MSW Open Burning), as shown in Table 91. The emission results are shown in Figure 49.

TABLE 91. EMISSION FACTORS CONSIDERED FOR OPEN BURNING

Substance	Value	Unit	Reference
SO_2	0.5	g/kg	• ABC EIM (Shrestha et al., 2013) • Table 8.2: Emission Factors for MSW Open Burning
NOx	3.0	g/kg	
NMVOCs	15.0	g/kg	
CO	42.0	g/kg	
NH_3	0.94	g/kg	

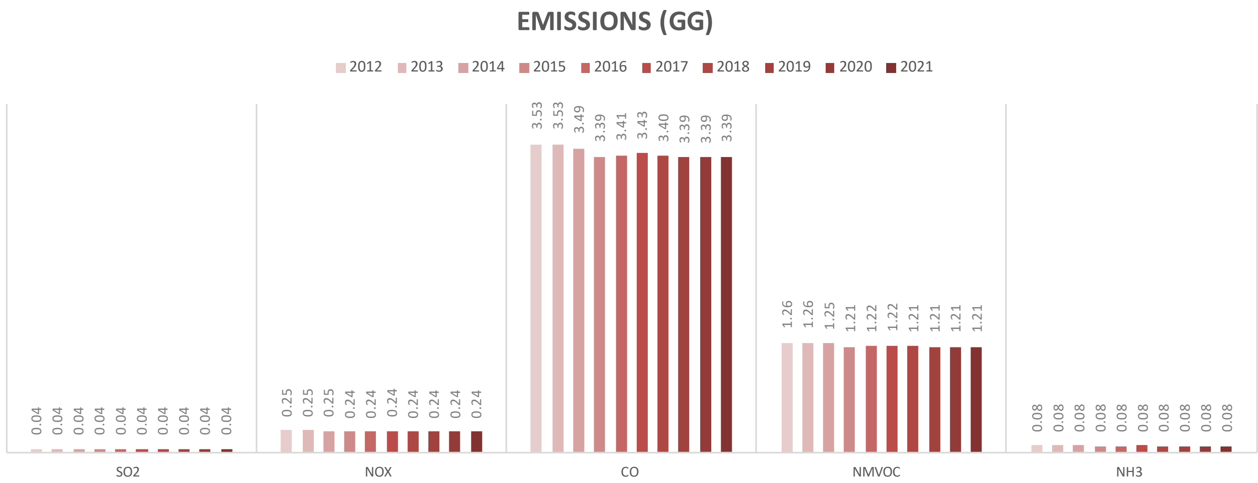


FIGURE 49: SO_2, NOX, CO, NMVOC AND NH_3 EMISSIONS (GG OR KTONNES) FROM OPEN BURNING OF WASTE

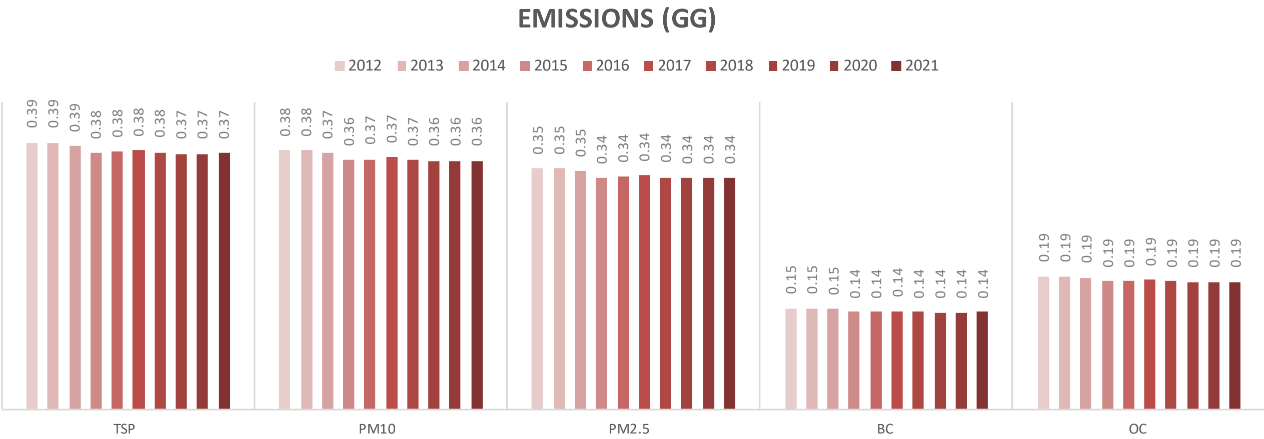
Particulate emissions

Emission factors of these substances come from the EMEP 2023 guidelines (Table 3-1 Tier 1 emission factors for source category 5.C.2 Small-scale waste burning) and the ABC EIM (Table 8.2: Emission Factors for MSW Open Burning) as shown in Table 92. This document does not provide any EF for TSP. The emission results are shown in Figure 50.

TABLE 92. EMISSION FACTORS CONSIDERED FOR OPEN BURNING

Substance	Value	Unit	Reference
TSP	4.64	g/kg	• EMEP 2023 • 5.C.2 - Open burning of waste • Table 3-1 Tier 1 emission factors for source category 5.C.2 Small-scale waste burning
PM_{10}	4.51	g/kg	
$PM_{2.5}$	4.19	g/kg	
BC	42%	$\%PM_{2.5}$	
OC	55%	$\%PM_{2.5}$	• ABC EIM (Shrestha et al., 2013) • Table 8.2: Emission Factors for MSW Open Burning

Pansuk and al. (2018) estimate that total $PM_{2.5}$ emissions amount in Chiang Mai are between 0.51 and 1.00 kt/year. The results with this inventory are a bit lower with an estimation around 0.35 kt $PM_{2.5}$/year.



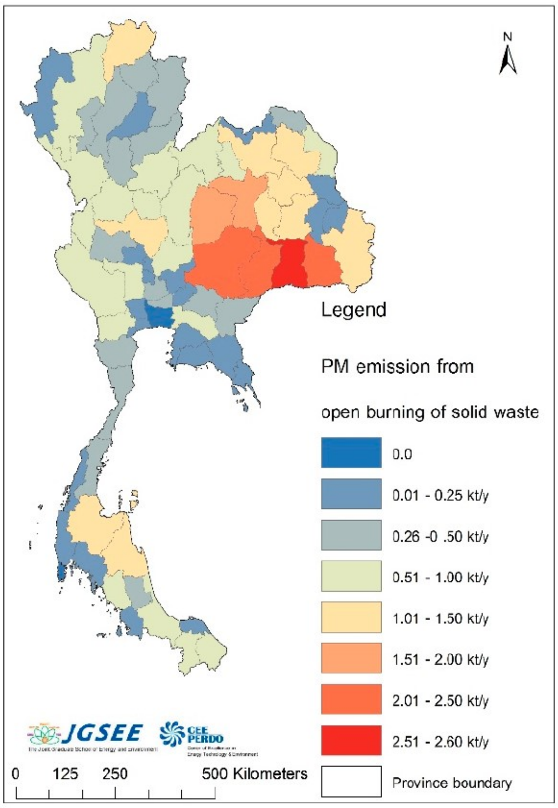


FIGURE 50: PARTICULATE EMISSIONS (GG OR KTONNES) FROM OPEN BURNING OF WASTE (PANSUK ET AL., 2018)

Heavy metals emissions

Emission factors of these substances come from the EMEP 2023 guidelines (Table 3-1 Tier 1 emission factors for source category 5.C.2 Small-scale waste burning) as shown in Table 93 and the emission results are illustrated in Figure 51.

TABLE 93. EMISSION FACTORS CONSIDERED FOR OPEN BURNING

Substance	Value	Unit	Reference
Pb	0.49	g/Mg	• EMEP 2023 • 5.C.2 - Open burning of waste • Table 3-1 Tier 1 emission factors for source category 5.C.2 Small-scale waste burning
Cd	0.10	g/Mg	

Mg = tonnes

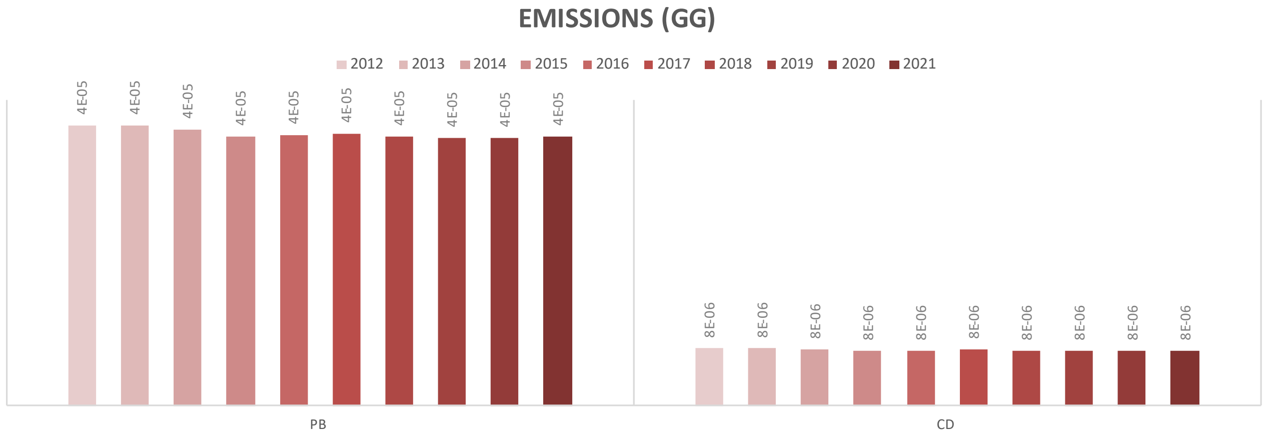


FIGURE 51: HEAVY METALS (GG OR KTONNES) FROM OPEN BURNING OF WASTE

7.2.6.4 Ways of improvement

Composition

Composition is specific to the province of Chiang Mai. However, it is assumed that the composition does not evolve each year. It would be a good practice to consider an evolution of the composition for the CO_2 emissions.

Amount of MSW burned

The total amount of MSW burned was based on the total amount of MSW generated in Chiang Mai and the national practices. It would be a good practice to estimate a rate of MSW burned specific to Chiang Mai.

Emission factors

Emission factors for heavy metals are based on EMEP 2023. It would be a good practice to use country specific EF (or regional EF).

7.2.7 Wastewater treatments (5D)

This section refers to wastewater treatment and discharge.

7.2.7.1 Activity data

Emissions related to wastewater depend on the population, the total amount of organic matter in the wastewater, the nitrogen content in the wastewater effluent, and the methods of treatment (or lack thereof). The population data for the province of Chiang Mai was extracted from NSO, as shown in Figure 52.

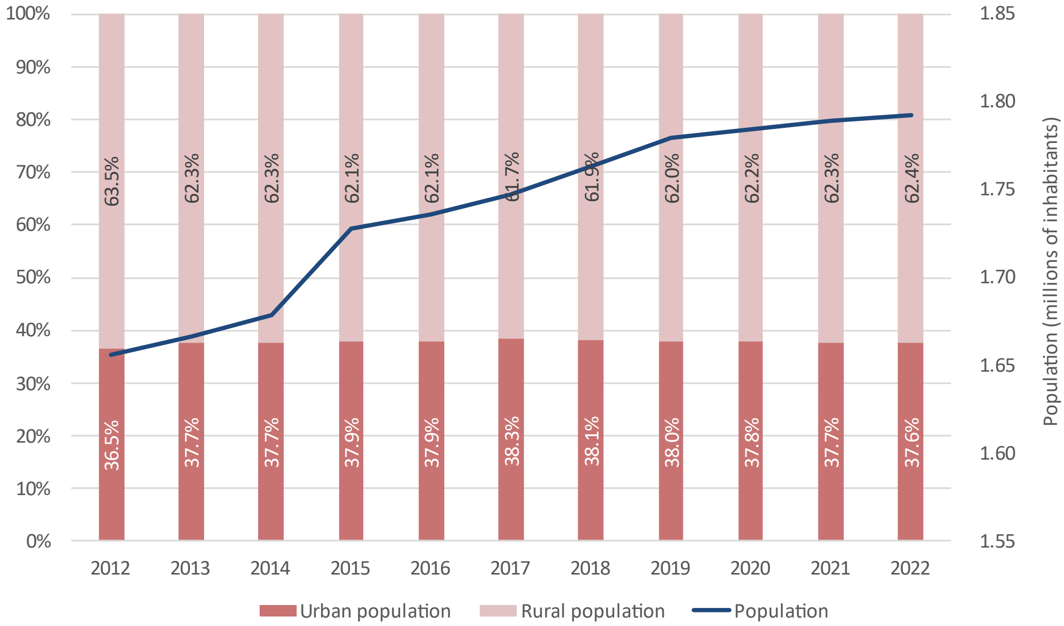
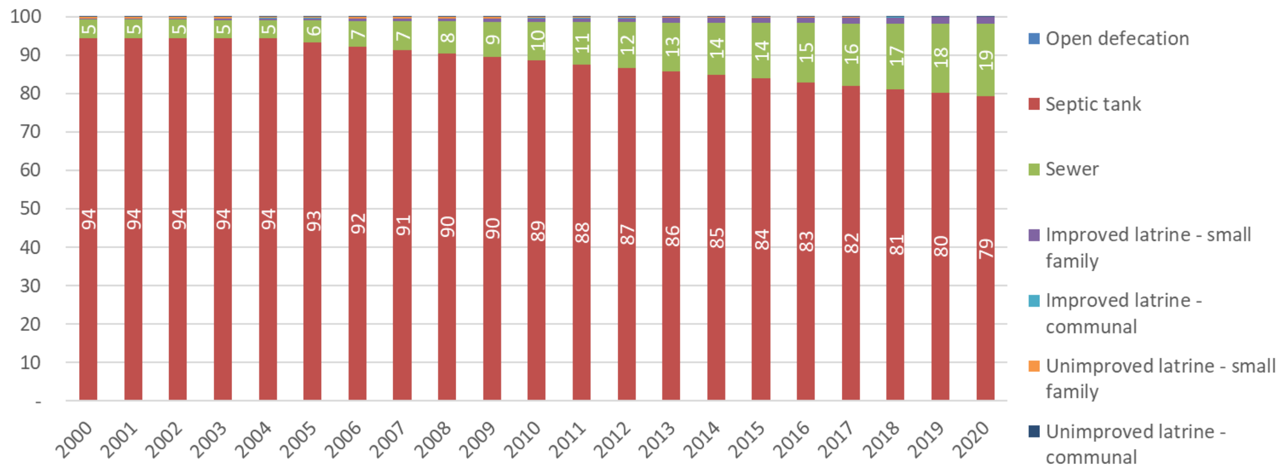


FIGURE 52: SPLIT BETWEEN URBAN POPULATION AND RURAL POPULATION IN CHIANG MAI (NSO)

Regarding the usage level of the treatment system or discharge pathway for each area, it was assumed that the national situation is comparable to that of Chiang Mai. The distribution (Figure 53 and 54) is as follows:

FIGURE 53: DEGREE OF TREATMENT OR DISCHARGE PATHWAY OR METHOD – RURAL SCOPE FOR THAILAND (UN WATER)



United Nations - UN Water

FIGURE 54: DEGREE OF TREATMENT OR DISCHARGE PATHWAY OR METHOD – URBAN SCOPE FOR THAILAND (UN WATER)

The total amount of organically degradable material in domestic wastewater was estimated considering this equation from 2006 IPCC guidelines:

$$TOW = P \times BOD \times 0.001 \times I \times 365$$

Where:

- TOW = Total Organics in Wastewater in inventory year, kg BOD/year.
- P=country population in inventory year (person).
- BOD = country-specific per capita Biochemical Oxygen Demand (BOD) in inventory year, in g/person/day.
- 0.001 = conversion from additional BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.0).

The biochemical oxygen demand (BOD) is a default value from 2006 IPCC guidelines, 40 g/person/day. Without information relating to industrial wastewater, it is assumed that “I” is equal to 1, the default value from 2006 IPCC guidelines.

7.2.7.2 GHG emissions

Carbon dioxide emissions

As CO_2 is of biogenic origin, it is accounted for in a different way to other substances. As a result of these rules, CO_2 emissions from wastewater treatment and discharge in CRF reporting formats (category 5.D) are not included in the inventory total.

Methane emissions

The general equation to estimate CH_4 emissions from domestic wastewater is as follows:

$$CH_4\ Emissions = \left[\sum_{i,j} (U_i \times T_{i,j} \times EF_j)\right] \times (TOW - S) - R$$

Where:

- CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr.
- TOW = total organics in wastewater in inventory year, kg BOD/yr.
- S = organic component removed as sludge in inventory year, kg BOD/yr.

- U_i = fraction of population in income group i in inventory year, See Table 6.5 of IPCC.
- $T_{i,j}$ = degree of utilization of treatment/discharge pathway or system, j, for each income group fraction i in inventory year, See Table 6.5.
- i = income group: rural, urban high income and urban low income.
- j = each treatment/discharge pathway or system.
- EF_j = emission factor, kg CH_4 / kg BOD.
- R = amount of CH_4 recovered in inventory year, kg CH_4/yr.

The emission factor for a wastewater treatment and discharge pathway and system is a function of the maximum CH_4 producing potential (B_0) and the methane correction factor (MCF) for the wastewater treatment and discharge system. The B_0 is the maximum amount of CH_4 that can be produced from a given quantity of organics (as expressed in BOD or COD) in the wastewater. The MCF indicates the extent to which the CH_4 producing capacity (B_0) is realized in each type of treatment and discharge pathway and system.

$$EF_j = B_0 \times MCF$$

Where:

- EF_j = emission factor, kg CH_4/kg BOD.
- j = each treatment/discharge pathway or system.
- B_0 = maximum CH_4 producing capacity, kg CH_4/kg BOD.
- MCF_j = methane correction factor (fraction).

The maximum CH_4 producing capacity (B_0) is a default value from 2006 IPCC guidelines, 0.6 kg CH_4/kg BOD.

The following MCF are considered in the inventory consistently with the IPCC guidelines:

- Latrines: 0.7,
- Septic tank: 0.5,
- Untreated - Sea, river and lake discharge: 0.11; and
- Untreated - Flowing sewer (open or closed): 0.

The organic component removed as sludge (S) and the amount of CH_4 recovered (R) are considered null.

Nitrous oxide emissions

The general equation to estimate N_2O emissions from domestic wastewater is as follows:

$$N_2O\ Emissions = N_{effluent} \times EF_{effluent} \times \frac{44}{28}$$

Where:

- N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr.
- $N_{effluent}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr.
- $EF_{effluent}$ = emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N.
- The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

The activity data that are needed for estimating N_2O emissions are nitrogen content in the wastewater effluent, country population and average annual per capita protein generation (kg/person/yr). Per capita protein generation consists of intake (consumption) which is available from the Food and Agriculture Organization (FAO), multiplied by factors to account for additional ‘non-consumed’ protein and for industrial protein discharged into the sewer system. Food (waste) that is not consumed may be washed down the drain (e.g., as result of the use of garbage disposals in some developed countries) and also, bath and laundry water can be expected to contribute to nitrogen loadings. The total nitrogen in the effluent is estimated as follows:

$$N_{effluent} = \left(P \times Protein_{supply} \times FPC \times F_{NPR} \times N_{HH} \times F_{NON-CON} \times F_{I\,ND-CON}\right) - N_{sludge}$$

Where:

- $N_{effluent}$ = total annual amount of nitrogen in the wastewater effluent, kg N/yr.
- P = human population.
- $Protein_{supply}$ = annual per capita protein supply, kg/person/yr.
- FPC = fraction of protein consumed.
- F_{NPR} = fraction of nitrogen in protein, default = 0.16 kg N/kg protein.
- N_{HH} = additional nitrogen from household products added to the wastewater, default is 1.1.
- $F_{NON\text{-}CON}$ = factor for non-consumed protein added to the wastewater.
- $F_{IND\text{-}COM}$ = factor for industrial and commercial co-discharged protein into the sewer system.
- N_{sludge} = nitrogen removed with sludge (default = zero), kg N/yr.

The default value for FPC is 0.96. The default value for non-consumed protein discharged to wastewater pathways is 1.02. Wastewater from industrial or commercial sources that is discharged into the sewer may contain protein (e.g., from grocery stores and butchers). The default value for this fraction is 1.25 N_{sludge} is assumed null.

Data relating to the protein supply (Thailand) come from the Food and Agriculture Organization (FAO) and are considered relevant for Chiang Mai (Figure 55).

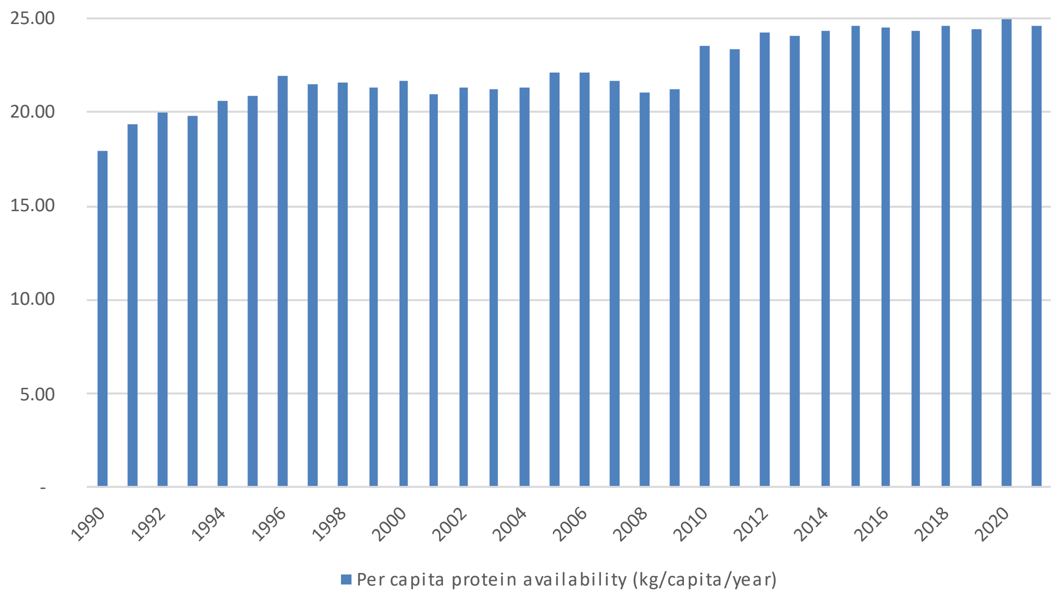


FIGURE 55: PROTEIN AVAILABILITY IN THAILAND PER YEAR (FAO)

7.2.7.3 Atmospheric pollutants

No emissions of these substances are estimated.

7.2.7.4 Ways of improvement

Domestic wastewater

The degree of use of the treatment system or discharge pathway for each area (rural or urban) is considered as the same than the national one. It would be a good practice to estimate this repartition for Chiang Mai.

The total amount of protein supply comes from FAO Stat. It would be a good practice to use country-specific data.

Industrial wastewater

Due to a lack of information, emissions from industrial wastewater are not considered.

8 NATURAL SOURCES (NFR SECTOR 11)

The emission sources of air pollutants are divided into anthropogenic (human-made) and natural sources, as presented in this section. Natural sources can represent a high proportion of total emitted pollutants but are accounted for separately in the emissions inventory.

This category includes emissions from forest fires (NFR Code 11B), which are responsible for a large part of $PM_{2.5}$ emissions, for example, during smoke-haze episodes in Thailand (Chansuebsri et al, 2024). Natural sources sector also includes emissions from volcanoes (NFR code 11A), mostly responsible for SO_2 emissions, and other natural sources (NFR code 11C) such as emissions from wild animals, vegetation, and oceans, which contribute, among other pollutants, around 45% of total global emissions of ammonia (Shrestha et al. 2013).

Only emissions from forest fires have been estimated in this sector for the emissions inventory for Chiang Mai. This chapter describes the methodologies applied for estimating emissions of air pollutants, activity data, and emission factors applied.

8.1 FOREST AND OTHER VEGETATION FIRES (11B)

8.1.1 Overview of the sector

Forest fires include all on-site burning of forest and other vegetation because of a natural occurrence or due to human-induced burning. This section also covers fires on other land cover categories such as grassland, savannah, shrubland but excludes agricultural residues burning which is estimated in agriculture sector (NFR code 3F).

8.1.2 Methodology

The estimation of emissions from forest fires is based on spatial data set from Moderate Resolution Imaging Spectroradiometer (MODIS) provided by the Fire Information for Resources Management System (FIRMS). Into a Geographic Information System (QGIS), fire hotspots are intersected with a land use map (ESA-CCI-LandCover edition 2015) to match burned areas with land cover categories and associated biomass loads. Hotspots identified on cropland are not included in the burned area as wildfire but are considered as agricultural residue burning estimated elsewhere (3B NFR category). Based on burned areas, biomass loss, and related emissions are calculated for each pixel based on country-specific emission factors, the EMEP guidelines 2009, and IPCC guidelines.

The calculation of atmospheric pollutant and greenhouse gas emissions is carried out using the Tier 2 IPCC method. The general equation for calculating emissions is the following:

$$E = Area \times Mb \times Cf \times EF$$

Where:

- E is the annual emission of pollutant (kg/year).
- Area is the area annually burnt (ha/year).
- Mb is the mass of fuel available for combustion expressed as the amount of Dry Matter (kgDM/ha).
- Cf is the combustion factor (dimensionless).
- EF is the emission factor (kg/kgDM/year).

8.1.3 Activity data

The estimation of the burned area is derived from Moderate Resolution Imaging Spectroradiometer (MODIS) MCD14 - Collection 6, this product provides near-real-time information on fires. The dataset was downloaded from the Fire Information for Resources Management System (FIRMS) website for Thailand on a yearly basis. This dataset provides a list of active fire locations as pixel hotspots, along with geographic information, date and other attributes. This information is available either as csv file or shapefile format (refer to the list of attributes for each data table provided in the Excel sheet).

The method used to estimate the burned area is based on (Giglio et al., 2006). It is assumed that the burned area is proportional to simple counts of fire pixels using the following equation:

$$A = Np \; x \; Rp$$

Where:

- A = Actual burned area.
- Np = Number of hotspot pixels of burned area product.
- Rp = Resolution of product.

The MODIS thermal band detects hotspots with a resolution of 1,000 meters per pixel resulting in an average area of hectares (10,000 m^2) per MODIS pixel.

8.1.4 Spatial distribution

8.1.4.1 Avoiding potential double counting

A limitation of the previous methodology lies in the potential overestimation of burned areas throughout the entire fire season. If a fire persists around a hotspot, new pixels may be added, resulting in multiple active fire locations overlapping. Similarly, if a fire is detected at the same location several months after another fire, additional pixels could be recorded in the same place by MODIS.

The method used to estimate emissions is based on the combustion of organic matter stock (Mb) according to a combustion efficiency factor (Cf). Therefore, it is unlikely that this same stock will be burned again within the same dry season, which in Thailand lasts a maximum of 6 months from December to May.

To eliminate the possibility of double counting of burned areas within the fire season, active fire locations from MODIS are processed using a GIS environment. Each pixel is associated with a square buffer of 1 km on each side, corresponding to the average resolution of each pixel size provided in the MODIS database (SCAN attribute). From the initial points, polygons are created, resulting in a unique coverage of burned areas.

8.1.4.2 Distribution of fires by land cover categories

As vegetation and biomass properties vary across regions, fires occurring in each area exhibit different behavior, biomass loads, and emission factors. By overlaying the geographic coordinates of each fire polygon obtained from the previous GIS treatment with a land cover map of the region, it is possible to spatially distribute fires into different land cover categories. For this operation, the ESA CCI Land Cover map edition 2015 is used and the area of each polygon is calculated and grouped by land use category. A cartographic representation of this operation is presented in Figure 56.

The total burned areas used for further calculations are presented in Table 94. Only the burned areas, within the forestland and grassland, land cover categories are considered. Burned areas within other categories do not contribute to the calculation of pollutant emissions.

TABLE 94: TOTAL BURNED AREA (HA) AFTER GIS BASED TREATMENT, CLASSIDIED BY LAND COVER CATEGORY FROM 2020 TO 2022.

Year	Forestland	Cropland	Grassland	Wetland	Settlements	Other land	TOTAL
2020	150,103	12,471	51,485	177	20	-	214,255
2021	53,768	8,395	24,957	62	-	-	87,181
2022	18,155	4,421	9,086	22	-	-	31,685

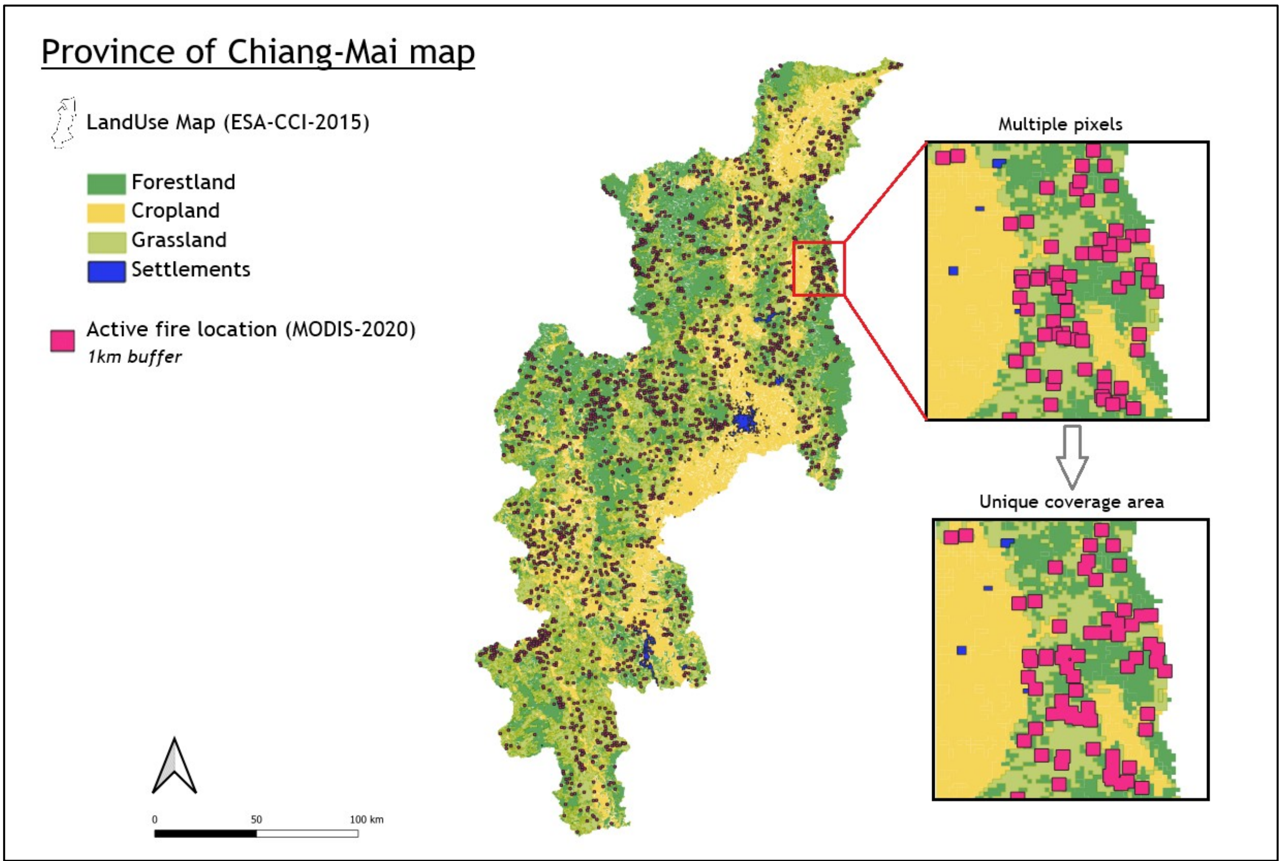


FIGURE 56: SPATIAL DISTRIBUTION AND TREATMENT OF MODIS ACTIVE FIRE LOCATION DATA IN 2020 WITH QGIS SOFTWARE

8.1.5 Biomass loads and combustion efficiency

Based on the study by Junpen et al. (2020) specific to a large region of Asia (Greater Mekong Subregion) and the study by Junpen et al. (2013) specific to deciduous forests in Thailand, biomass stocks for each land type were defined. Similarly, combustion efficiency factors were also determined. For this inventory in Chiang Mai, the grassland category gathers the values from savannah, grassland and shrubland types as mean of these three land use categories (Table 95).

TABLE 95: VALUE OF THE BIOMASS LOADS AND COMBUSTION COMPLETENESS IN EACH VEGETATION FIRE.

	Junpen et al, 2020		Junpen et al, 2013		Values selected for Chiang Mai inventory	
	Biomass loads (Dry matter)	*Combustion efficiency*	*Biomass loads (Dry matter)*	*Combustion efficiency*	*Biomass loads (Dry matter)*	*Combustion efficiency*
Forestland	4.88 (t/ha)	0.76	3.88 (t/ha)	0.80	3.88 (t/ha)	0.80
Cropland	7.50 (t/ha)	0.39			7.50 (t/ha)	0.39
Savannah	3.88 (t/ha)	0.80				
Grassland	7.60 (t/ha)	0.81			5.59 (t/ha)	0.77
Shrubland	5.30 (t/ha)	0.71				

Biomass loads in forestland appear to be very low compared to the IPCC recommendations for tropical moist deciduous and continental forest biomass stocks in Asia to be considered in wildfire inventory. It is explained by Junpen et al, (2020): *"Fires are common in most deciduous forests in the GMS (Greater Mekong Subregion). Forest fire is in the category of surface fire, which occurs on the surface and consumes only low-layer vegetation, e.g., grass, dead leaves, twigs, and undergrowth. Surface fires usually have low to moderate severity and do not cause extensive mortality in the standing vegetation. This kind of fire occurs mainly during the dry season due to the high accumulation of dead leaves on the ground from deciduous plants."*

8.1.6 Emission factors

The emission factors specific to the Greater Mekong Subregion given by Junpen et al, (2020) were used in accordance with the parameters previously employed. The values provided correspond to the magnitude orders for each atmospheric pollutant as given by the IPCC, 2006 (Volume 4 – Chapter 4), EMEP 2019 (Chapter -11B) and the ones used by Boonman et al. (2014).

TABLE 96: VALUE OF THE EMISSION FACTOR (G/KG DRY MATTER BURNT) - FROM JUMPEN ET AL, 2020 (EXCEPT CELL WITH BLUE BACKGROUND*).

Land Cover	SO_2	NOx	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	BC	$PM_{2.5}$	PM_{10}	TSP	OC
Forestland	0.40	2.55	8.10 *	5.07	93	1643	0.20	1.33	0.52	9.10	10 *	10 *	4.71
Grassland	0.48	3.90	8.10 *	1.94	63	1686	0.20	0.52	0.37	7.17	10 *	10 *	2.62
Cropland	Estimated elsewhere (NFR sector 3F)												
Wetland	Not estimated												
Other land	Not estimated												
Settlement	Not estimated												

* Values extracted from IPPC, 2006 Vol.4-Chap.4; EMEP, 2019 (11B), Junpen et al, 2018 or Akbari et al, 2021

8.1.7 Ways of improvement

Assuming that emission factors and biomass loads are already based on country-specific data, the current focus for improvement lies in the estimation of the activity data: the burned area. The following options could be studied:

- Apply the methodology developed by Junpen et al, 2020 and Boonman et al, 2014 to correct potential bias (under-overestimation) from spatial data on active fire location;
- Obtain a more recent and if possible, a local land cover map for a more accurate distribution of fires according to each land use category. The following information could enhance precision: the differentiation of forest types (deciduous, evergreen, broadleaf...), the differentiation of grassland into several subcategories such as shrubland, wooded grasslands, and savannas;
- Develop verification methods to cross check estimations for burned areas with regional scientific literature and local data from local authority services that monitor fire prevention and fire control daily operations to cross check estimations.

9 GEOGRAPHICAL SPATIALISATION OF EMISSIONS

This Chapter focuses on the spatialization of atmospheric pollutant emissions in Chiang Mai province, based on the inventory work presented in the previous Chapters. The primary objective of this Chapter is to present the method used to perform this spatial disaggregation. For each sector of activity, we describe the proxies used for emission spatialization, which are the auxiliary data and methods that allow the geographically distribution of estimated emissions. These proxies include demographic, economic, land-use data, and other relevant types of data for each sector.

By providing a detailed overview of the spatialization methods and proxies used, this Chapter aims to enhance the understanding of the sources and geographic distributions of atmospheric pollutants in Chiang Mai province. This will not only help identify high emission potential areas but also facilitate developing targeted strategies to reduce air pollution, improve public health, and protect the environment.

The specific knowledge and data related to certain sectors have not always allowed for highly accurate emission estimates and precise spatial mapping. Therefore, it is essential to consider the strong dependence of emission spatialization quality on the methods and inventory data used upstream.

9.1 OBJECTIVES AND APPROACH

9.1.1 Identification of priority sectors to map

A DETAILED AND PRECISE APPROACH HAS BEEN DEVELOPED FOR THE KEY SECTORS OF THE INVENTORY THAT ARE RESPONSIBLE FOR THE PRIMARY EMISSIONS OF POLLUTANTS. THE TOTAL EMISSIONS ANALYSIS REALIZED ON EACH POLLUTANT (

Table 2) allow to identify two main key sources of pollutant in Chiang Mai province.

The Transport Sector: this is the principal source of nitrogen oxides (NOx), ammonia (NH_3), non-methane volatile organic compounds (NMVOCs), black carbon, and fine particles. The transport sector's emissions are largely influenced by vehicle type, fuel usage, and traffic patterns, necessitating accurate and comprehensive data collection to properly spatialize these emissions.

The Open-Burning Sector: this includes forest fires, agricultural residue burning, and waste burning, which are the primary sources of fine particles ($PM_{2.5}$, PM_{10}) and organic carbon. Open burning of biomass and waste significantly impacts air quality, especially during the dry season when the frequency and intensity of fires increase. Spatializing emissions from this sector requires detailed information on land use, fire occurrence, and biomass types.

By focusing on these sectors, the report aims to provide a clear and comprehensive picture of emission distributions, which is essential for targeting interventions and mitigating pollution impacts in Chiang Mai province.

9.1.2 General Approach for Emission Spatialization

For all the NFR sectors estimated in the inventory (and often for specific subsectors), a comprehensive methodology has been developed, incorporating various geographic parameters (point sources or diffuse emissions, location of sources, precision of the original data available at finer administrative scales, land use, urban or rural appearance), as well as demographic, economic, and sector-specific parameters. A summary table, with the proxies used for each sector, is provided in the "Spatialization" file annexed to this report.

The results of the spatialization of emissions, for each sector, are presented at two resolution levels. The primary output format is at **a 1km² hexagonal grid** covering the entire territory of Chiang Mai province. This allows for a systematic representation of the spatial distribution of emissions. Additionally, a secondary output format is presented at the **administrative level 3 scale**, corresponding to sub-districts, also known as ***Tambon***. Specific files, for each of these two output formats, are provided in the annexes of this report ("GridHex_Spatialisation" and "Tambon_Spatialisation").

9.1.3 General Strategy for Pollutant-Emitting Sectors

The strategy for spatializing emissions across different sectors involves several critical steps to ensure accuracy and relevance:

- **Identification of emission sources**: for each sector, emission sources are identified and categorized. This includes distinguishing between point sources (e.g., industrial facilities) and diffuse sources (e.g., transportation networks).
- **Geographic parameterization**: the spatial distribution of emissions is mapped based on geographic parameters. This involves using land use data, identifying urban and rural areas, or determining the specific locations of emission sources. The accuracy of these parameters depends on the precision of the original data, which is for sectors available at finer administrative scales (e.g. 1A2 Industry).
- **Demographic factors**: demographic data (such as population density) are integrated into the spatialization process. This factor helps refine the spatial distribution by correlating higher emissions with areas of intense human activity or economic production.
- **Sector-specific characteristics**: each sector has unique characteristics that influence emission patterns. For example, the transport sector's emissions depend on vehicle types, traffic volumes, and road networks, while the biomass burning sector's emissions are influenced by the frequency and location of fires.

9.1.4 Construction of Proxies

The proxies used in the spatialization process are constructed to translate the sector-specific data into spatially distributed emission estimates. This involves:

- **Data collection and integration**: gathering relevant data from various sources, including satellite imagery, national statistics, and local surveys. The collected data are then integrated into a coherent framework that supports spatial analysis.
- **Proxy development**: developing proxies involves creating representative indicators that correlate well with emission sources. For instance, population density can serve as a proxy for residential heating emissions, while road network density can proxy for transport emissions.
- **Validation and adjustment**: the developed proxies are validated against known emission patterns and adjusted to correct any discrepancies. This step ensures that the proxies accurately represent the spatial distribution of emissions.
- **Implementation in spatial models**: the validated proxies are implemented in spatial models that generate emission maps. These maps are then used to create the final output formats at both the hexagonal grid and sub-district levels.

By following this detailed and systematic approach, the spatialization of emissions in Chiang Mai province aims to provide a robust and accurate representation of where pollutants are emitted. However, we remind that this emission map is not a concentration map. It represents only the sources of emissions.

9.2 METHODOLOGY

9.2.1 Sectoral specialization

9.2.1.1 Overview

Every sector estimated within the pollutant inventory framework was associated with a distribution strategy. Table 97 summarizes all the proxies used to spatialize the emissions from all sectors.

TABLE 97: LIST OF PROXY USED FOR EACH NFR SECTOR

Sector Description	NFR code	Proxy name
Industry	1A2	Factories in urban areas
Aviation	1A3a	Chiang Mai Airport area
Road Transport - Passenger cars	1A3bi	Passenger cars
Road Transport - Light duty vehicles	1A3bii	Light Duty Vehicles
Road Transport - Heavy duty vehicles and buses	1A3biii	Trucks
Road Transport - Mopeds & motorcycles	1A3biv	Motorcycles
Road Transport - Gasoline evaporation	1A3bv	Petrol evaporation
Road Transport - Tire and brake wear	1A3bvi	Tire and brake
Road Transport - Road abrasion	1A3bvii	Road abrasion
Railways	1A3c	Railway
Commercial_Institutionnal	1A4ai	Urban areas with population
Residential	1A4bi	Urban areas with population
Off-road vehicles and other machinery	1A4cii	Agricultural areas
National fishing	1A4ciii	National fishing
Distribution of oil products	1B2av	Petrol station
Quarrying and mining	2A5a	Quarry and Mining
Construction and demolition	2A5b	Urban areas with population
Domestic solvent use	2D3a	Population density
Paint and Coating Applications	2D3d	Population density
Other Solvent Use - Adhesives	2D3di	Population density
Enteric fermentation	3A	Agricultural areas
Manure management	3B1a	Manure production and application areas
Rice	3C	Rice fields
Animal manure applied to soil	3Da2	Manure production and application areas
Synthetic fertilisation and crop residues left on field	3Da4	Synthetic and organic fertilisation
Agricultural residue burning	3F	Residue Open Burning
CO_2 emissions from Urea application	3H	Synthetic and organic fertilisation
Managed landfilling	5A1	Landfill zones (x3)
Unmanaged landfilling	5A2	Rural areas with population
Uncategorized landfilling	5A3	Rural areas with population
Composting	5B	Rural areas with population
Incineration	5C1bii	Hospital Incinerator
Cremation	5C1bv	Temples
Open burning of waste	5C2	Rural areas with population
Wastewater	5D	Waste Water
Other waste	5E	Not Occurring
Forest and other vegetation fire	11B	Forest and other vegetation fire

9.2.2 Description of the strategy for each sector

9.2.2.1 1A2 – Industry

The emissions from the Industrial sector were estimated based on information from each factory registered and permitted to operate as of the end of 2022 *(more details can be found in the emissions inventory methodological report)*. Factories addresses information is not detailed enough to identify the Tambon location of each site. Consequently, the distribution of emissions is organized in two steps: first, disaggregation was done at the district level (administrative boundaries level 2) based on the declared "Horse-Power" for each factory; in the second step, these emissions distributed proportionally to the horsepower factories per districts were then distributed within each district among urban areas using the proxy “Urban areas”.

The proxy used for this sector is called “Factory”, it combines the urban proxy grouped by district with the power and the location of each factory across the province.

9.2.2.2 1A3a – Aviation

The emissions from the Aviation sector are distributed proportionally to the Chiang Mai airport's surface area. In order to take into account the emissions from takeout and landing that go beyond the limit of the airport area, two zones are identified in order to distribute 80% to the exact location of the airport and the remaining 20% in a radius of approximately 1 km around the airport (Figure 57).

FIGURE 57: GIS BASED CONSTRUCTION PROCESS FOR THE PROXY AIRPORT IN CHIANG MAI.

9.2.2.3 1A3b – Road transportation

The emissions, from the Road transportation sector, were spatialized based on vehicle counts and modelling conducted in the Chiang Mai province by EGIS (2023) (Air Quality Improvement in Thailand – Output 4, Part1: Composition of the technological fleet in Chiang Mai”, December 2023). The model provides information on the volume of four vehicle categories (motorbikes, passenger cars, light-duty vehicles, and Heavy vehicles) throughout almost all the roads in the province. The emissions of each sub-sector are distributed proportionally according to the contribution of each vehicle category to the total emissions of each sub-sector.

9.2.2.4 1A3c – Railways

The emissions from the Railways sector were distributed proportionally to the length of railways provided by the Open Street Map (OSM) dataset. The presence of multiple railway tracks at a station level is detected by the cartographic product, consequently allowing for a greater allocation of emissions in the station area compared to an isolated railway track.

9.2.2.5 1A4a – Commercial institutional

The emissions from the Commercial & institutional sector were distributed proportionally to the population density only in urban areas, lacking information on the specific emissions for specific buildings (e.g. commercial, hospitals, etc.). The proxy used called “Urban areas with population weight” was based on geographical zones (urban areas) and population density.

9.2.2.6 1A4b – Residential

The emissions from the Residential sector were distributed proportionally to the population density only in urban areas. The proxy used called “Urban areas with population weight” was based on geographical zones (urban areas) and population density. The methodology used for this proxy was further developed in section 9.2.3.

9.2.2.7 1A4c – Off-road vehicles and other machinery

The emissions from the Off-road vehicles and other machinery sector were distributed across the agricultural areas throughout the province. The agricultural areas proxy corresponds to cropland and grassland land cover categories provided by the ESA CCI Land Cover map (edition 2015). The proxy also includes a national spatial dataset on fields locations from the GISTDA portal. The fusion of cropland and grassland areas with precise fields location allows the construction of the agricultural areas map. This map was then intersected with the settlements areas map to remove buildings identified in agricultural areas. The final agricultural areas map is the result of these steps. Lastly, for the off-road vehicles and other machinery sector, information on farmhouse locations was used to allocate greater weight to agricultural areas within a 10-kilometer radius around farmhouses.

9.2.2.8 1B2a – Distribution of oil products

The emissions from the Distribution of oil products sector were allocated to petrol and fuel stations identified with Open Street Map spatial dataset. The emissions were distributed equitably among all identified fuel and petrol stations, using the proxy labelled “Petrol station”.

9.2.2.9 2A5a – Quarrying and mining

The emissions from the Quarrying and mining sector were allocated to quarries locations in Chiang Mai province extracted from Open Street Map spatial dataset. The emissions were distributed equitably among all identified quarries, using the proxy labelled “Quarry”, lacking information on the production per quarry.

9.2.2.10 2A5b – Construction and demolition

The emissions from the Construction and demolition sector were distributed proportionally to the population density only in urban areas. The proxy used called “Urban areas with population weight” is based on geographical zones (urban areas) and population density. The methodology used for this proxy was further developed in section 9.2.3.

9.2.2.11 2D3a – Domestic solvent use

The emissions from Domestic solvent use sector were spatialized proportionally to the population density using the proxy “Population density”.

9.2.2.12 2D3d – Paint and Coating Applications

The emissions from Paint and Coating Applications sector were spatialized proportionally to the population density using the proxy “Population density”.

9.2.2.13 2D3di – Other solvent use and adhesives

The emissions from Other solvent use and adhesives sector were spatialized proportionally to the population density using the proxy “Population density”.

9.2.2.14 3A – Enteric fermentation

The emissions from the Enteric Fermentation sector were distributed across agricultural areas throughout the province using the "Agricultural Areas" proxy. The agricultural areas proxy corresponds to cropland and grassland land cover categories provided by the ESA CCI Land Cover map (edition 2015). The proxy also includes a national spatial dataset on fields locations from the GISTDA portal. The fusion of cropland and grassland areas with precise fields location allows the construction of the agricultural areas map. This map was then intersected with the settlements areas map to remove buildings identified in agricultural areas. The final agricultural areas map is the result of these steps. Lastly, for the Enteric fermentation sector, information on farmhouse locations was used to allocate greater weight to agricultural areas within a 10-kilometer radius around farmhouses. Based on the agricultural waste management system data used to estimate the emissions from this sector, it was assumed that about half of the ruminant herd is raised indoors, consequently, 50% of the emissions from enteric fermentation are distributed in agricultural areas closed to farmhouse locations.

9.2.2.15 3B1a – Manure management

The emissions from the Manure management sector were distributed across agricultural areas throughout the province using the " Manure production and application " proxy. It is the same proxy as the one used for Enteric fermentation sector with different weight given to areas closed to the farmhouses. 75% of the sector's emissions come from poultry and pigs, which are mostly raised indoors (according to AWMS - inputs from spreadsheet 3B manure management). The remaining 25% come from ruminant animals (cattle, sheep, and other animals) raised half indoors and half outdoors. Consequently, it was assumed that 50% of ruminant emissions are distributed along with emissions from poultry and pigs on the agricultural areas closed to farmhouses. Zone 1 is defined as the agricultural areas close to farm buildings identified from OSM buildings. Zone 2 encompasses the rest of the agricultural areas that are more than 10 kilometers from a farmhouse.

9.2.2.16 3C – Rice

The emissions from Rice sector were spatialized equally on rice field location provided by the GISTDA national dataset.

9.2.2.17 3Da2 – Animal manure applied to soil

The emissions from the Animal Manure Applied to Soil sector were allocated to agricultural areas using a similar proxy as the one used for the Manure Management sector, labelled 'Manure Production and Application.' This proxy involved agricultural areas and the ratio between indoor and outdoor settings for each animal species, based on average waste system information (specific data detailed in spreadsheet 3D in the agriculture sector)

9.2.2.18 3Da4 – Other 3D emissions (synthetic fertilisation and crop residues left on field)

The emissions from synthetic fertilisation and crop residues left on the field were allocated to agricultural areas and specific crop field locations using the proxy “Fertilisation”. This proxy was based on fertilizer input data specific to each crop, gathered into three crop categories: rice, maize, and other crops. The emissions from rice and maize were distributed exactly to their respective field locations, while the emissions from other crops were distributed across the remaining agricultural areas.

9.2.2.19 3F – Agricultural residue burning

The emissions from the Agricultural residue burning sector were estimated from the burning of the residues of the rice and maize crops. Therefore, the spatial distribution of these two crops was used as a proxy for this category as it is shown in Figure 58 (data extracted from the GIS_AGRO_4 website provided by GISTDA).

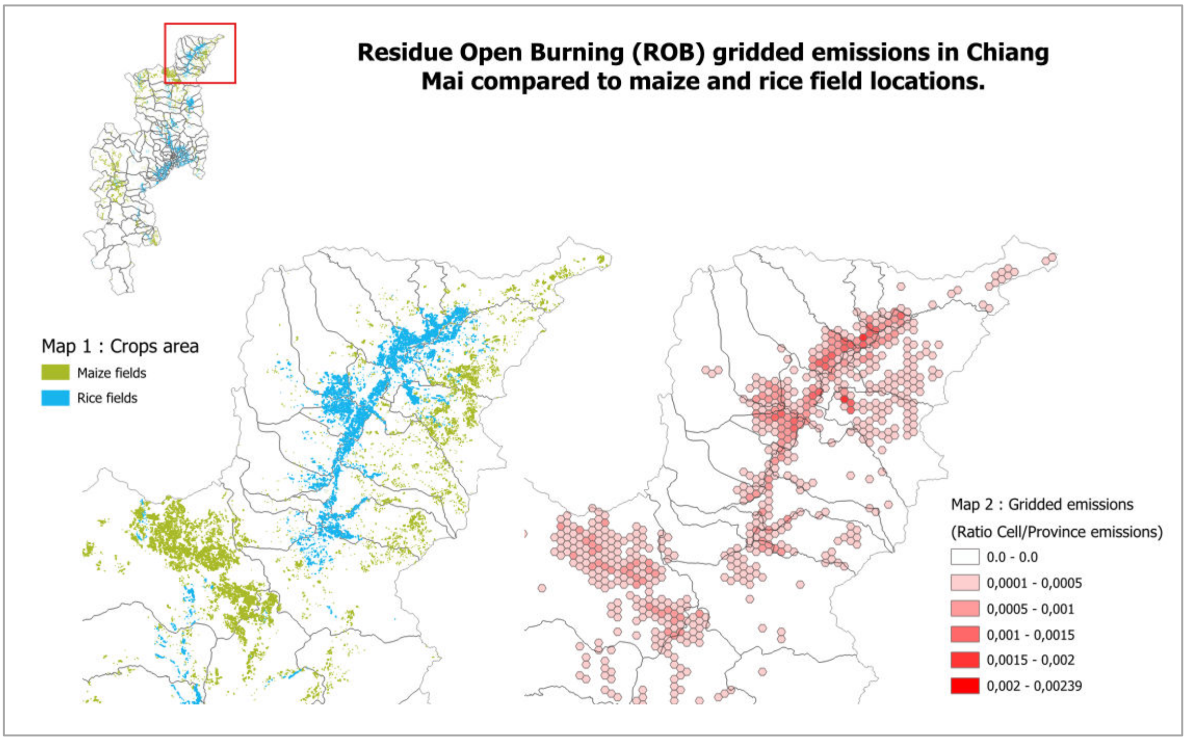


FIGURE 58: RESIDUE OPEN BURNING (ROB) GRIDDED EMISSIONS IN THE NORTH OF CHIANG MAI COMPARED TO MAIZE AND RICE FIELD LOCATION.

9.2.2.20 3H – CO_2 emissions from urea application

The CO_2 emissions from urea application on crops were allocated to specific crop fields location and agricultural areas using the same proxy as the one used to spatialized synthetic fertilisation sector using the proxy labelled "Fertilisation".

9.2.2.21 5AA – Managed landfilling

The emissions from the Managed landfilling sector in Chiang Mai province were allocated to the three landfills using the "Landfill zones" proxy. This proxy is based on the location of each landfill identified with Google Map (Figure 59) and the annual treatment capacity of each landfill, with Ban Tan landfill handling about 80% of the province's waste.

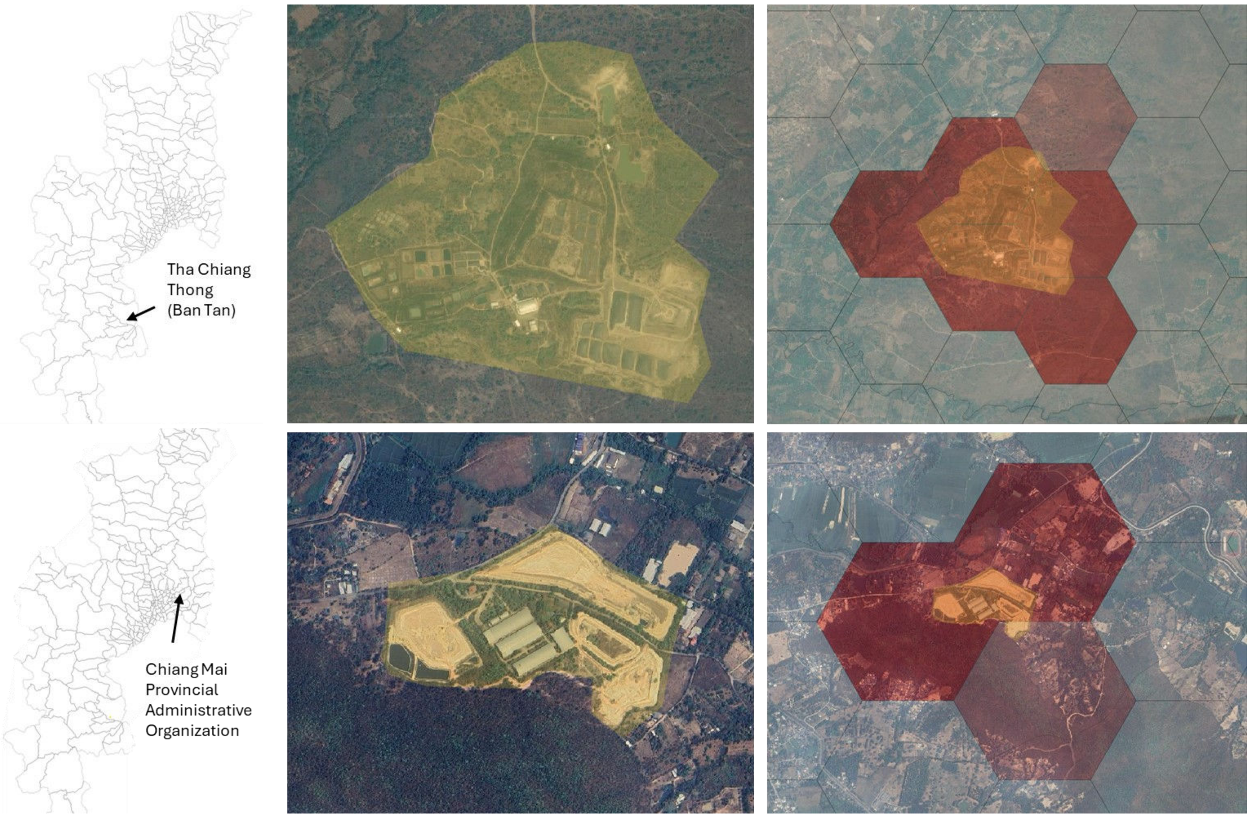


FIGURE 59: GIS BASED CONSTRUCTION PROCESS FOR THE PROXY "LANDFILL ZONES", EXAMPLE FOR TWO LANDFILLS IN CHIANG MAI

9.2.2.22 5A2 – Unmanaged and 5A3 – Uncategorized landfilling

The emissions from the Unmanaged landfilling sector were distributed across the rural areas of the province in proportion to population density using the "Rural Areas and Population Density" proxy.

9.2.2.23 5B – Composting

The emissions from the Composting sector were distributed across the rural areas of the province in proportion to population density using the "Rural Areas and Population" proxy further described in section 9.2.3.

9.2.2.24 5C1bii – Incineration of waste

The emissions from the Incineration of the waste sector were distributed to a single point source, the Chiang Mai hospital's recent incinerator developed in cooperation with Kinsei company, using the proxy called "Hospital".

9.2.2.25 5C1bv – Cremation

The emissions from the Cremation of human bodies sector were distributed to temple location map extracted from OpenStreetMap data, using the proxy "Temples".

9.2.2.26 5C12 – Open burning of waste

The emissions from the Open burning of the waste sector were allocated to rural areas proportionally to the population density using the proxy "Rural areas and population" further described in section 9.2.3.

9.2.2.27 5D – Wastewater

The emission estimates for the Wastewater sector were based on two emission factors corresponding to rural and urban systems, proportional to the population. Consequently, the proxy used for this sector involved the geographical zone (urban and rural areas), the population density, and the contribution weight of rural and urban areas to the total emissions of the sector, using the proxy called "Wastewater".

9.2.2.28 11B – Forest and other vegetation fires

The emissions from Forest fires sector were derived from spatial data with location information of each fire, in line with the data used to calculate emissions. From these geographical data, burned areas were estimated and were used as the proxy to spatialise the emissions from forest and other vegetation fires. The proxy used was called "Forest fire".

9.2.3 Geographic and demographic parameters used as proxies

The spatialization of numerous sectors relies on proxies derived from geographic and demographic data. This data serves as the foundation for constructing proxies like Urban Areas, Agricultural Areas, Population, or Urban Areas with Population Density, underscoring its significance in the specialization methodology.

Population distribution was based on population data from the National Statistical Office of Thailand (Statistical Yearbook Thailand 2023), with the most recent data available for 2018 provided at the Tambon resolution. The population distribution was based on three main area types, assuming that the majority of the population living in settlement areas with the remaining population residing in **rural areas** and, third, considering that **natural areas** are uninhabited.

9.2.3.1 Land type map

A map of Chiang Mai province was created with natural and settlement features. The remaining territory outside of natural (with no population) and settlement areas (urban areas) was designated as rural areas.

- **Settlements areas**

Settlement areas were identified from building features derived from OpenStreetMap data. The building map has been enhanced by adding building features to existing urban areas that are not identified by the GIS OSM building product but are visible on Google Earth. A buffer was applied to each building feature to provide continuous coverage of the settlement areas.

- **Natural areas**

Based on ESA-CCI-Land Cover 2015 map, land cover categories corresponding to dense forests and wooded areas were isolated to create natural areas assumed to be uninhabited. The selected land cover categories for this map are summarized in Table 98.

TABLE 98: LAND COVER CATEGORIES FROM ESA-CCI-LC-2015 SELECTED TO CREATE NATURAL AREAS

DN attribute Land cover Code	Land Cover label
50	Tree cover, broadleaved, evergreen, closed to open (>15%)
60	Tree cover, broadleaved, deciduous, closed to open (>15%)
61	Tree cover, broadleaved, deciduous, closed (>40%)
70	Tree cover, needle leaved, evergreen, closed to open (>15%)
210	Water bodies

9.2.3.2 Population distribution

Based on the land type map, a default parameter was set to distribute 80% of the Tambon population to settlement areas, the remaining 20% are distributed to rural areas. When a Tambon is 100% covered by settlements features, 100% of the population is distributed to urban areas. The same applies to Tambons without identified settlement areas, where 100% of the Tambon population is distributed to rural areas. Natural areas remain without population distribution. The Figure 60 illustrates the gridded population proxy used to spatialize sectors of the inventory.

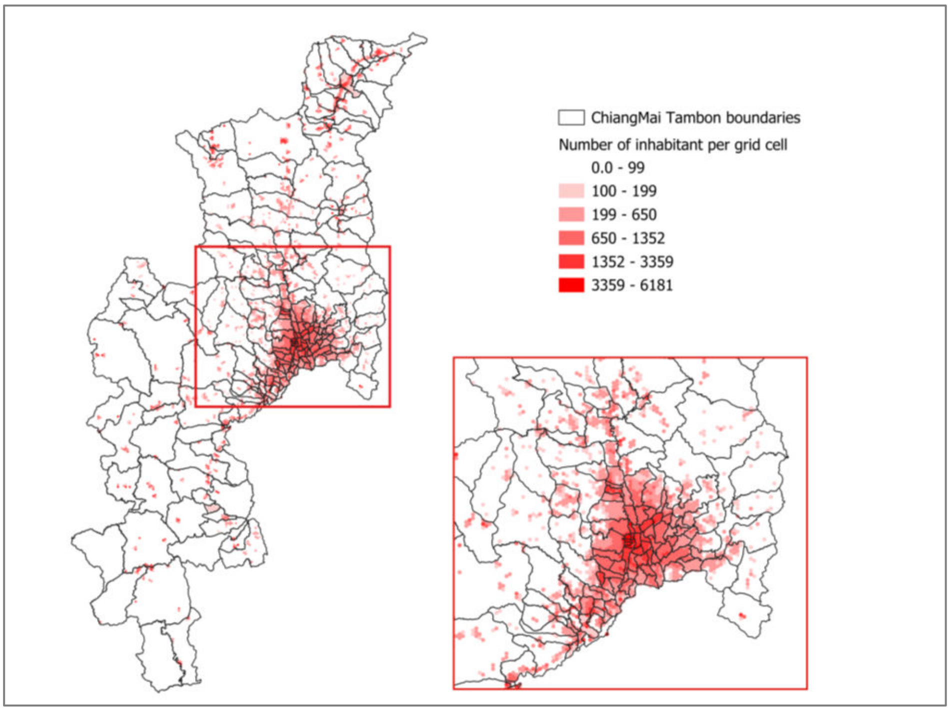


FIGURE 60: MAP OF THE GRIDDED POPULATION - ZOOM ON CHIANG MAI URBAN AREAS

9.2.3.3 Geographical zones: urban, rural and natural classification of the territory

Based on the population distribution and the number of inhabitants in each grid cell, an urban designation was assigned to any grid cell containing more than 100 inhabitants. This threshold represents 0.00567% of the total provincial population.

Segmenting the territory based on the number of inhabitants allows for more precise distribution of emissions from certain sectors compared to using settlement areas. Settlement areas are only used to distribute the Tambon population across the territory, and they do not provide information on population density. Natural areas described in 8.2.1 section of this report still qualified as natural area with no population and rural area is the difference between urban and natural areas (all grid cells that have between 1 to 100 inhabitants). The Figure 61 presents the geographical zones based on the population distribution of the province.

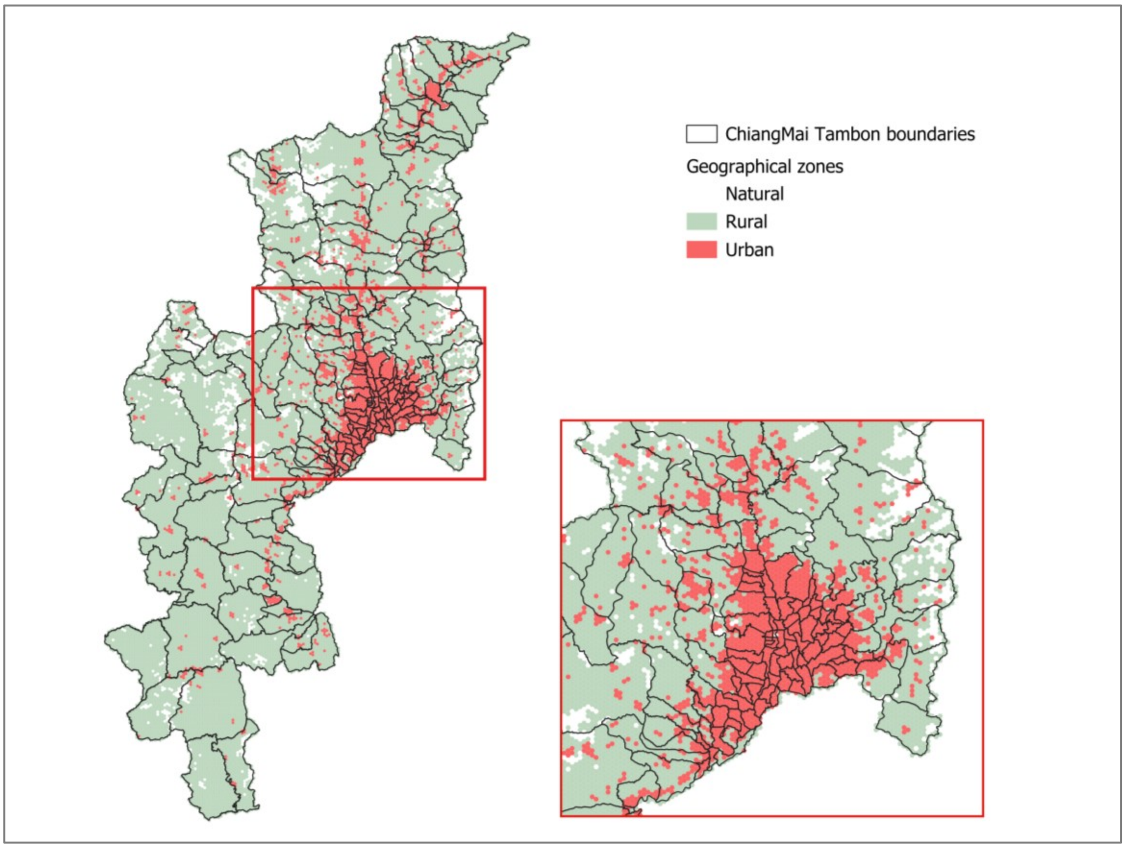


FIGURE 61: GEOGRAPHICAL ZONES IN CHIANG MAI PROVINCE (NATURAL, URAN & RURAL)

10 CONCLUSIONS

As part of the AQIP program, an integrated gridded emissions inventory has been developed for the province of Chiang Mai. This integrated emissions inventory is the first one developed in the province and even in Thailand with such characteristics. A set of air pollutants and GHGs are covered in a consistent method. The Gridded emissions inventory details the location and magnitude of emissions across Chiang Mai province for the year 2022.

To build this integrated air pollutant and GHG inventory, the most appropriate methodologies were used. The calculation of road transport emissions was based on a traffic survey and subsequent modelling carried out by EGIS that provide a better description of the composition of the vehicle fleet in circulation, and of traffic per vehicle type (passenger cars, light duty vehicles, heavy-duty vehicles and two-wheel vehicles). Road transport modelling by EGIS allow an assessment of the kilometers driven per vehicles and per main roads (EGIS, 2023).

For other sectors, including agriculture, waste, IPPU and energy, cooperation between AIT and Citepa has enabled to collect the most appropriate data for the province. Nevertheless, in some cases when adequate data were not available, simplifications were necessary. A detailed description of the methodology developed and work plans for improving the inventory step by step are provided in this report. Methodological recommendations and ways of improvement are provided in this methodological report.

This program has allowed for a clear definition of the composition of the in-use vehicle fleet, enabling detailed assessments. However, more data is needed on other sectors, such as industrial processes and combustion at the provincial level. Information on the amount of waste generated by residents and their treatment, as well as a comprehensive energy balance at the provincial level, would be valuable additions.

The key emission sources of the different pollutants and GHG were identified. For particulate matters (the main air quality problem in the province) and their precursors (SO_2, NOx, NH_3) the main sources are open burning of biomass, road transport, residential/commercial sector but also open-burning of waste and agriculture.

This report emphasizes the importance of data accuracy and consistency. By utilizing reliable data sources and following standardized procedures, the emission calculations results can be trusted for policymaking, regulatory compliance, and environmental planning.

However, the calculation of emissions is a constant work in progress. Regular improvements of the methodology are necessary to track progress, identify trends, and respond to changes in technology, economic activities, and environmental policies.

In conclusion, this methodological report serves as a guide to regularly updating and improving the emissions inventory for Chiang Mai. Regular updates and methodological enhancements, particularly in key sectors, will ensure that the approach remains robust and relevant in the face of evolving challenges and opportunities.

11 TABLES LIST

12 FIGURES LIST

13 REFERENCES

Akbari, M. Z., Thepnuan, D., Wiriya, W., Janta, R., Punsompong, P., Hemwan, P., ... & Chantara, S. (2021). Emission factors of metals bound with PM2. 5 and ashes from biomass burning simulated in an open-system combustion chamber for estimation of open burning emissions. Atmospheric Pollution Research, 12(3), 13-24.

ATRANS study, An Analysis of Vehicle Kilometers of Travel of Major Cities in Thailand. 2009.

Boonman T., Garivait S., Bonnet S. and Junpen A. (2014). An Inventory of Air Pollutant Emissions from Biomass Open Burning in Thailand Using MODIS Burned Area Product (MCD45A1)

Bremmer H.J. and van Engelen J.G.M. (2007). Paint Products Fact Sheet: To assess the risks for the consumer, RIVM.

Bremmer H.J., Prud'homme de Lodder L.C.H., van Engelen J.G.M. (2006). Cosmetics Fact Sheet: To assess the risks for the consumer, RIVM.

Chaiwatanasin W., Chantsavang S. and Thanintarathratharn B. (1998). Production of crossbred sheep in Thailand. Agriculture and Natural Resources, 32, 2, 158-162.

Chansuebsri, S., Kolar, P., Kraisitnitikul, P., Kantarawilawan, N., Yabueng, N., Wiriya, W., ... & Chantara, S. (2024). Chemical composition and origins of PM2.5 in Chiang Mai (Thailand) by integrated source apportionment and potential source areas. Atmospheric Environment, 327, 120517.

Cheewaphongphan P., Junpen A., Kamnoet O., and Garivait S. (2018). Study on the Potential of Rice Straws as a Supplementary Fuel in Very Small Power Plants in Thailand, Energies, vol. 11, n° 2, Art. n° 2, doi: 10.3390/en11020270.

EGIS (2023). Air Quality Improvement in Thailand – Output 4, Part1: Composition of the technological fleet in Chiang Mai", December 2023.

Elsoragaby, S., Yahya, A., Mahadi, M. R., Nawi, N. M., & Mairghany, M. (2019). Analysis of energy use and greenhouse gas emissions (GHG) of transplanting and broadcast seeding wetland rice cultivation. *Energy*, *189*, 116160. https://doi.org/10.1016/j.energy.2019.116160

EMEP/EEA, Air Pollutant Emission Inventory Guidebook - 1.A.2 Combustion in manufacturing industries and construction, 2023.

EPA (1986), A Guideline for Surface Coating Calculations.

Faarungsang S. (2003). Thai swamp Buffalo general information. Asia-Pacific Economic Cooperation. Agricultural Technical Cooperation Working Group. *The Relationship Between Indigenous Animals and Humans in APEC Region*.

Frost and Sullivan (2017). Independent Market Research on the Paint and Coating Industry in Selected Southeast Asian Countries.

Giglio, L., van der Werf, G. R., Randerson, J. T., Collatz, G. J., & Kasibhatla, P. (2006). Global estimation of burned area using MODIS active fire observations. *Atmospheric Chemistry and Physics*, *6*(4), 957–974. https://doi.org/10.5194/acp-6-957-2006

Huy L. N., and Kim Oanh N. T. (2020). Emission control for volatile organic compounds from gasoline stations and implication on ozone-forming potential. Atmospheric Pollution Research, 11(6), 87–98. *https://doi.org/10.1016/j.apr.2020.03.002*.

Huy L. N., Winijkul E. and Kim Oanh N. T. (2021a). Assessment of emissions from residential combustion in Southeast Asia and implications for climate forcing potential. Science of the Total Environment, 785, 147311.

Huy L. N., Kim Oanh N.T., Phuc N. H. and Nhung C. P. (2021b). Survey-based inventory for atmospheric emissions from residential combustion in Vietnam. Environ Sci Pollut Res Int, 28(9):10678-10695, doi: 10.1007/s11356-020-11067-6.

Jaturasitha S, Srikanchai T, Kreuzer M, Wicke M (2008) Differences in carcass and meat characteristics between chicken indigenous to northern Thailand (black-boned and Thai native) and imported extensive breeds (Bresse and Rhode Island Red). Poultry Science 87, 160–169.doi:10.3382/ps.2006-00398

Jiawkok, S., Ittisupornrat, S., Charudacha, C., Nakajima, J. (2012). The potential for decentralized reclamation and reuse of household greywater in peri-urban areas of Bangkok, *Water and Environment Journal*, **27**.

Junpen, A., Garivait, S., Bonnet, S., & Pongpullponsak, A. (2013). Fire spread prediction for deciduous forest fires in Northern Thailand. *Science Asia*, *39*, 535-545.

Junpen A., Pansuk J., Kamnoet O., Cheewaphongphan, P., & Sarivait S. (2018). Emission of air pollutants from rice residue open burning in Thailand. Atmosphere. (11), 449; *https://doi.org/10.3390/atmos9110449*.

Junpen, A., Roemmontri, J., Boonman, A., Cheewaphongphan, P., Thao, P. T. B., & Garivait, S. (2020). Spatial and temporal distribution of biomass open burning emissions in the Greater Mekong subregion. *Climate*, *8*(8), 90.

Katoh K., Chairoj P., Yagi K., Tsuruta H., Minami K., et Cholitkul W. (1999). Methane Emission from Paddy Fields in Northern Thailand », n° 7.

Khonpikul S., Jakrawatana N., Gheewala S. H., Mungkalasiri J., and Janrungautai J. (2017). Material Flow Analysis of Maize Supply Chain in Thailand. Journal of Sustainable Energy & Environment 8, 87-89.

Kim Oanh et al. (2020) The study of source of $PM_{2.5}$ and precursors of secondary $PM_{2.5}$ in Bangkok Metropolitan Region.

Kolli Z. (2012). Dynamique de renouvellement du parc automobile: Projection et impact environnemental. Sociologie. UNIVERSITE DE PARIS I, PANTHEON-SORBONNE.

Lijewski et al, 2017. Fuel consumption and exhaust emissions in the process of mechanized timber extraction and transport. DOI 10.1007/s10342-016-1015-2. Table 2

Limanond, T., Pongthanaisawan, J., Watthanakland, D., & Sangphong, O. (2009). An Analysis of vehicle kilometers of travel of major cities in Thailand (Final Report). Bangkok: Asian Transportation Research Society.

Mordor Intelligence (2021). Thailand Adhesive Market.

Munoz et al, 2022. Carbon footprint, economic benefits and sustainable fishing: Lessons for the future from the Western Mediterranean. https://doi.org/10.1016/j.scitotenv.2022.160783

Nikolaisen M., Hillier J., Smith P., and Nayak D. (2023). Modelling CH_4 emission from rice ecosystem: A comparison between existing empirical models, Frontiers in Agronomy, vol. 4, https://www.frontiersin.org/articles/10.3389/fagro.2022.1058649

Pansuk J., Junpen A. and Garivait S.: *Assessment of Air Pollution from Household Solid Waste Open Burning in Thailan. Sustainability (2018), 10, 2553; doi:10.3390/su10072553.*

PCD. (2004). Developing Integrated Emission Strategies for Existing Land Transport (DIESEL). Bangkok. Pollution Control Department, Ministry of Science Technology and Environment, World Bank.

Phairuang W., Hata M., and Furuuchi M. (2017). Influence of agricultural activities, forest fires and agro-industries on air quality in Thailand, Journal of Environmental Sciences, vol. 52, p. 85-97, févr. 2017, doi: 10.1016/j.jes.2016.02.007.

Prasittikhet J. and Hinthao U. (2003). Effect of Fertigation on Nutrient Uptake, Growth, Yield and Quality of Longan | Thai Agricultural Research Journal », vol. 21, no 1, Consulté le: 17 janvier 2024.: *https://li01.tci-thaijo.org/index.php/thaiagriculturalresearch/article/view/213935.*

Preechajarn S. (2018). Thailand oilseeds and products annual. Washington DC. USDA Foreign Agriculture Service.

Rungcharoen J., Hungspreug S., Pleumpanya S. and Insalud N. (2014). Improvement of Local Rice Productivity in the Thai Highland Areas. Research Article: 18-23.

Sambat S., Theloke J., Friedrich R., Allemand N. (2005). Bibliographic study concerning the speciation of NMVOC, within the project INTERREG III (Annex 2 – Point 2.1), IER and Citepa.

Shrestha, R.M., Kim Oanh, N.T., Shrestha, R. P., Rupakheti, M., Rajbhandari, S., Permadi, D.A., Kanabkaew, T., and Iyngararasan, M. (2013). Atmospheric Brown Clouds (ABC) Emission Inventory Manual, United Nations Environment Programme, Nairobi, Kenya.

Soni, Peeyush (2016). Agricultural mechanization in Thailand: Current status and future outlook. AMA, Agricultural Mechanization in Asia, Africa and Latin America. 47. 58-66.

Thambhitaks K. and Kitchaicharoen J. (2021). Valuation of External Costs of Wet-Season Lowland Rice Production Systems in Northern Thailand, CMUJNS, vol. 20, n° 3, june 2021, doi: 10.12982/CMUJNS.2021.057.

Thanapongtharm W., Linard C., Chinson P, Kasemsuwan S., Visser M., Gaughan A.E., Epprech M., Robinson T.P. and Gilbert M. (2016). Spatial analysis and characteristics of pig farming in Thailand. BMC Veterinary Research, 12:2018, *https://docslib.org/doc/7760590/spatial-analysis-and-characteristics-of-pig-farming-in-thailand*.

Tyukavina, A., Potapov, P., Hansen, M.C., Pickens, A., Stehman, S., Turubanova, S., Parker, D., Zalles, A., Lima, A., Kommareddy, I., Song, X-P, Wang, L and Harris, N. (2022) Global trends of forest loss due to fire, 2001-2019. Frontiers in Remote Sensing. *https://doi.org/10.3389/frsen.2022.825190*

Vilaiphorn, A.E. (2010). Assessment of air quality and climate co-benefit for urban Public Transport: A case study of Bangkok Metropolitan Region. (Master Thesis No. EV-10-01, Asian Institute of Technology, 2010). Bangkok: Asian Institute of Technology.

Wattanachant S. (2008). Factors affecting the quality characteristics of Thai indigenous chicken meat. Agricultural and Food Sciences.

Wongpom, et. Al. (2017). Milk yield, fat yield and fat percentage associations in a Thai multibreed dairy population, Agriculture and Natural Resources, vol. 51, n° 3, p. 218-222, june 2017, doi: 10.1016/j.anres.2016.12.008.

Yodkhum S., Gheewala S. H., and Sampattagul S. (2017). Life cycle GHG evaluation of organic rice production in northern Thailand. Journal of Environmental Management, vol. 196, p. 217-223, july 2017, doi: 10.1016/j.jenvman.2017.03.004.