AIR QUALITY IMPROVEMENT PROGRAM IN THAILAND

SOURCES OF AIR POLLUTION IN CHIANG MAI 2022

MAIN SOURCES AND MEASURES TO MITIGATE AIR POLLUTION

GENERAL INFORMATION

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Content

1. Introduction

1.1. Context

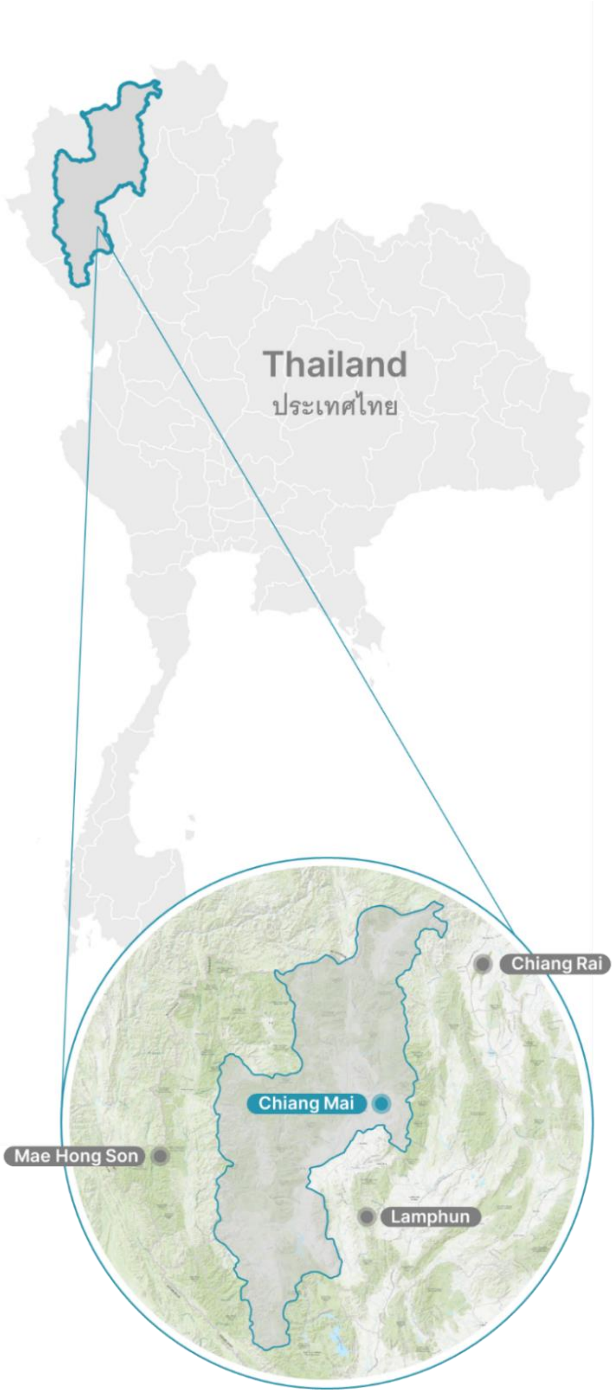
A complete emission inventory should ideally compile all sources of air pollutants and greenhouse gases (GHGs) within a territory. A geographically gridded inventory helps identify zones with high emissions, making it easier to define and implement targeted measures to reduce air pollution and GHG emissions. It also provides valuable inputs for air quality models.

Integrated emission inventories, covering both GHGs and air pollutants, are recommended by international organizations such as the Air Convention. These inventories enable a more comprehensive assessment of policies and measures, and possible trade-offs between policies focusing solely on GHGs or on-air pollutants.

Regular updates of the inventory show the evolution of emissions. When inventory methods are sufficiently advanced (e.g., higher-tier methods), the results allow for a detailed assessment of the impact of mitigation measures and public policies in place. National inventory is also crucial for reporting a country's emissions to the United Nations. In ASEAN, only GHG emissions are required to be reported to the UN. Under the Paris Agreement, countries must submit a plan to address climate change and set targets for GHG emissions reductions, which are enshrined in their Nationally Determined Contributions (NDCs).

In Thailand, several initiatives exist for developing emission inventories at both the national and subnational levels. However, further efforts could enhance coordination within a harmonized framework to establish clear and unified objectives. The need for local, bottom-up emission inventories - using source-specific data for point sources and category-specific data at the most refined spatial level for non-point and mobile sources - has been emphasized by universities,[1] local authorities (e.g., Chiang Mai City and Province), and the Pollution Control Department (PCD) of the Ministry of Natural Resources and Environment (MoNRE).

In the framework of the Air Quality Improvement program (AQIP) in Thailand, the Agence Française de Développement (AFD) has developed an integrated and geographically gridded emission inventory for Chiang Mai for the year 2022.[2] This integrated emission inventory can serve as a foundation for policymaking and emission reduction strategies. Potential emission reduction measures are also proposed in this report.



[1] (e.g., Asian Institute of Technology – AIT, Chiang Mai University - CMU)

[2] The detailed methodology is outlined in the "Comprehensive Inventory Methodology Report for Chiang Mai Province, Thailand (2022)" (Report 2024).

1.2. Inventory preparation

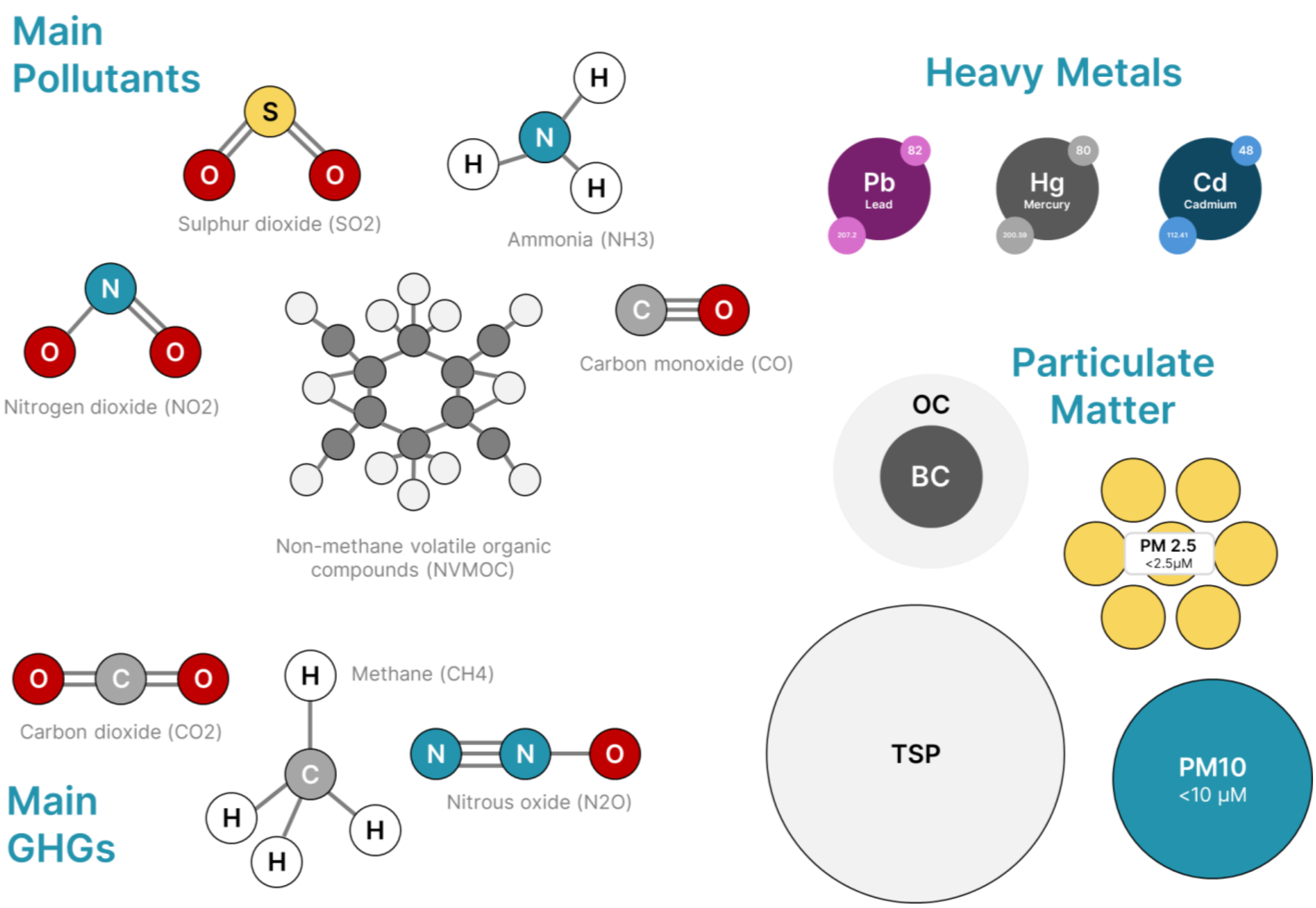
Activities undertaken as part of AQIP Thailand aimed to improve the provision and collection of activity data and emission factors, through the exchange of information on scientific research conducted in the region and the identification of new emission sources not covered in previous studies.

The primary activity data used for the preparation of the Chiang Mai emission inventory includes energy statistics from the National Energy Balance published by the Ministry of Energy (MOE), industrial production data and horsepower statistics from the Department of Industrial Works, Ministry of Industry (MIND), and agricultural production data, crop types, and land area from the Office of Agricultural Economics (OAE), Ministry of Agriculture and Cooperatives (MOAC).

Additional statistical data were sourced from the National Statistical Office of Thailand (NSO),[3] which provides both national and provincial statistics. The NSO also offers socioeconomic data, including population figures and gross domestic product (GDP), serving as proxies for calculating provincial emissions when detailed provincial-level data is not available. An in-depth study was conducted to assess traffic patterns, including a traffic survey and using traffic modeling techniques. This survey improved understanding of the province's vehicle fleet.[4]

This marks the first comprehensive emission inventory for Chiang Mai Province developed with a focus on high spatial resolution. GHG and air pollutant emissions were calculated for 2022, with activity data for 2021 used where 2022 data was unavailable. Additionally, where historical data was accessible, emissions were calculated for earlier years to analyze emission trends.

The following classes of pollutants are included in the emission inventory:



[3] http://www.nso.go.th/sites/2014en/statistics-from-majo-survey

[4] *The results of this traffic study were published in December 2023 in the report "Air Quality Improvement in Thailand – Output 4, Part 1: Composition of the Technological Fleet in Chiang Mai."*

2. Activity Data Collection for Chiang Mai

To calculate emissions for a given territory, comprehensive activity data is required. This data must account for all emission-generating activities, including fuel consumption (e.g., wood, oil, coal) across power plants, industrial processes, cooking, residential heating, and transportation; electricity usage by sector; production in manufacturing industries; vehicle kilometers traveled (VKT) by vehicle type and fleet composition; fertilizer application in agriculture; and waste generation and composition.

Despite considerable efforts in data collection, assumptions have sometimes been necessary to fill gaps. This chapter provides an overview of the data collected and the assumptions made.

2.1. Forest fires

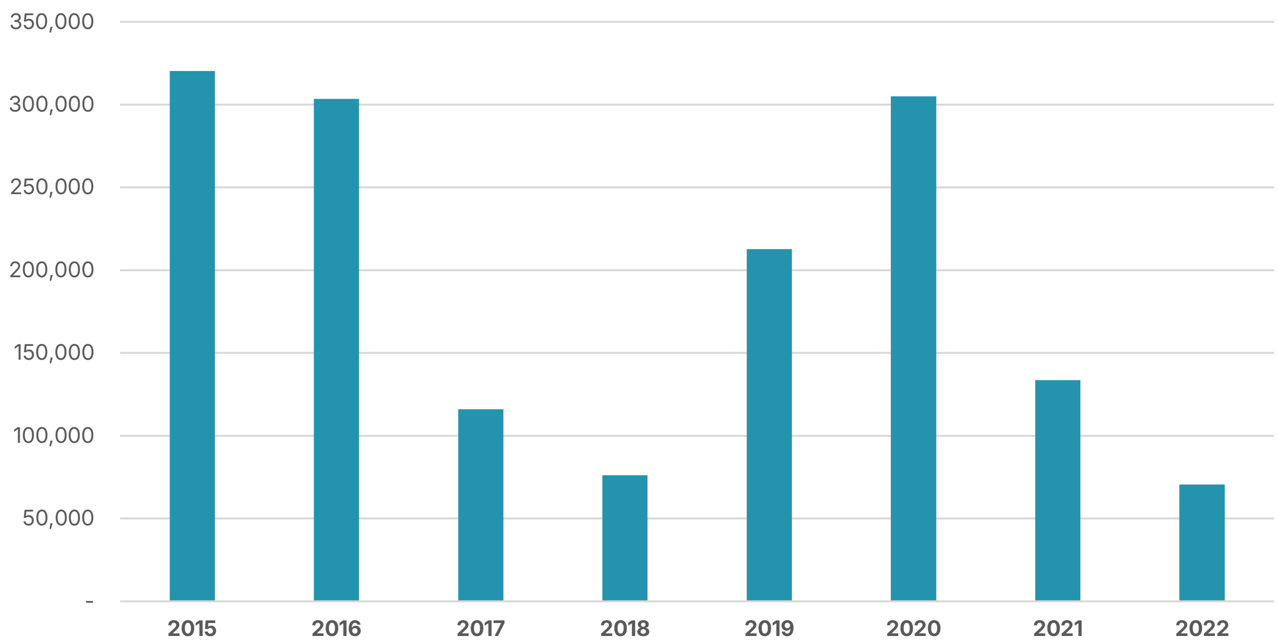
The identification of burned areas is based on spatial data processed in a Geographic Information System (GIS). The land-use categories and associated biomass types, such as forests, crops, and grasslands, are derived from this data. The primary source for this information is the Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 6 (MCD14), which is available through the Fire Information for Resource Management System (FIRMS).[5] Fire classification into forest, grassland, or cropland categories is based on the European Space Agency's Climate Change Initiative Land Cover map (2015).

Additional data sources could improve emission estimates from vegetation fires. For example, using more accurate information on the specific land cover categories affected by fires - often referred to as burn scars - would allow for more precise biomass loss and emissions estimates. A more recent, region-specific land cover map could significantly enhance these estimates.

In terms of spatial data for fire detection, more sensitive instruments provide fire location information at a higher pixel resolution than MODIS products. For instance, the Visible Infrared Imaging Radiometer Suite (VIIRS), which has a resolution of 375 meters, or the MODIS Burned Area products (MCD45A1), with a resolution of 500 meters, could be used to improve detection accuracy.

The results from the MODIS data used in this inventory are shown in Figure 1. A large interannual variability is observed, which may be linked to climate conditions and to efforts made to reduce forest fire occurrence.

Figure 1. Total Annual Burned Area (ha) in Chiang Mai Province, 2015-2022 (MODIS Data)



[5] https://firms.modaps.eosdis.nasa.gov/

2.2. Agriculture

Activity data and calculation parameters were gathered from official statistics provided by various Thai government departments, including the Department of Livestock Development (DLD) and the Office of Agricultural Economics (OAE). In cases where national data were unavailable, international databases such as FAOSTAT[6] and International Fertilizer Association (IFASTAT)[7] were consulted, along with data extrapolated from published literature.

2.2.1. Livestock population

Livestock population statistics for eight different categories - chicken, cow, buffalo, pig, duck, goat, sheep, and others (including quail, donkey, mule, elephant, horse, geese, and turkey) - were collected from the DLD reports on annual animal numbers[8] for the years 2012 to 2022. Detailed data by gender and animal raising purpose (e.g., egg-laying chicken, meat chicken, milk cow, meat cow) were also gathered where available.

Body weights for several animal categories were reviewed in various studies (Jaturasitha et al., 2009; Thanapongtharm et al., 2016; Preechajarn, 2018; Wattanachant, 2008; Feed and Livestock Magazine, 2022; Faarungsang, 2003; Srisakdi et al., 2019; Chaiwatanasin et al., 1998). When specific body weight data was not available, IPCC default values were used.

Milk yield data from dairy cows was collected from FAOSTATstatistics. Additionally, the fat content of milk was assumed to be 3.59%, based on the study by Wongpom et al. (2017).

2.2.2. Rice cultivation for CH_4 emission

For the annual planted and harvested areas of rice cultivation in Chiang Mai, statistics from the Thai Centre for Agricultural Information (OAE)[9] were used, distinguishing between major rice and off-season rice production. The data also differentiates between irrigated and non-irrigated rice. However, according to Rungcharoen et al. (2014), all rice production in Chiang Mai can be considered as continuously flooded.

Other parameters used to calculate methane (CH_4) emissions were sourced from various studies (Thambhitaks et al., 2021; Yodkhum et al., 2017; Katoh et al., 1999) as well as from IPCC default values.

2.2.3. Animal manure and synthetic fertilizer inputs to agricultural soils

Organic Organic nitrogen inputs to agricultural soils primarily come from animal manure. The total nitrogen (N) inputs from synthetic fertilizers have been estimated based on the fertilization rates for major crop types in Chiang Mai and associated land areas.

Data from several sources were used to estimate these inputs. The OAE provides statistics on the total amount of synthetic fertilizer used per major crop category[10] each year. However, the nitrogen content of the fertilizer mix used is not directly available. It was estimated based on import data for Thailand by fertilizer type (e.g., Urea, Diammonium Phosphate - DAP, Ammonium Sulphate), assuming a uniform distribution of fertilizers across provinces.

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

The selection of parameters for Chiang Mai was based on the following order of priority:

- Cheewaphongphan et al. (2018); Khonpikul et al. (2017)
- The national emission inventory[11]
- Phairuang et al. (2017)
- IPCC 2019 default values

2.2.4. Field burning of agricultural fires

The quantity of residues available for burning has been estimated using the IPCC 2019 methodology for crop residue estimation. Agricultural residue burning was considered only for annual crops - specifically maize, rice, soybean, and cassava - which together account for 63% of the total harvested area in Chiang Mai.

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[6] Food and Agriculture Organization Corporate Statistical Database: https://www.fao.org/faostat/fr/#data
[7] *https://www.ifastat.org/*
[8] *https://ict.dld.go.th/webnew/index.php/th/service-ict/report/355-report-thailand-livestock/animal-book*
[9] *https://oaezone.oae.go.th/view/22/Home/EN-US*
[10] Rice, Maize, Soybean, Cassava
[11] *PCD and AIT, 2020, Report on the results of the development of a data linkage system for air pollution accounting management. [report translated by google translate]*

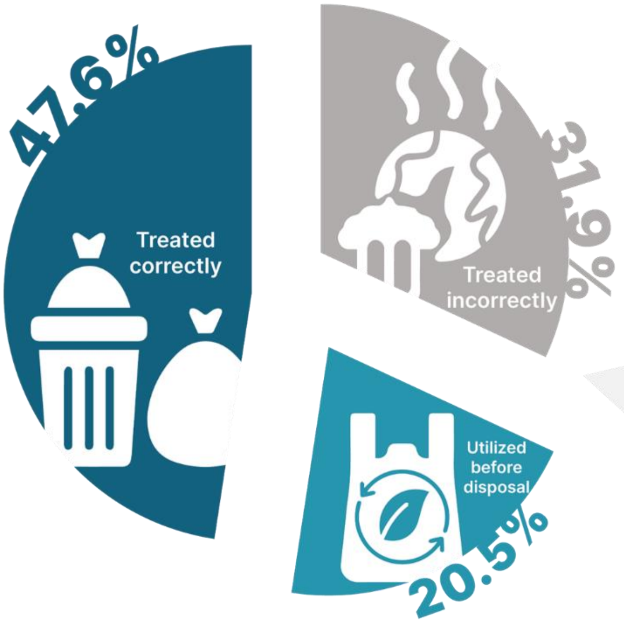
2.3. Waste

The total amount of municipal solid waste (MSW) generated in Chiang Mai was gathered from various years of the Reports on the Current Status of MSW Management in Thailand published by the Pollution Control Department (PCD). Waste generation was distinguished between rural and urban areas. Assumptions regarding solid waste generation and treatment were based on Pansuk et al. (2018). In Chiang Mai, approximately 75% of MSW is collected, while the remaining 25% is not.[12]

For the collected MSW, it is assumed[13] that 21% are recycled before disposal, 48% is treated properly, and the remaining 32% is treated improperly. It is assumed that all MSW that is treated correctly is completely disposed of in landfills. Note that there is no incineration of MSW in Chiang Mai province, except for one incinerator handling hospital waste. For the improperly treated portion of collected MSW, it is assumed that all of it is disposed of in open dumps. Additionally, it is assumed that no open burning occurs for the collected MSW.

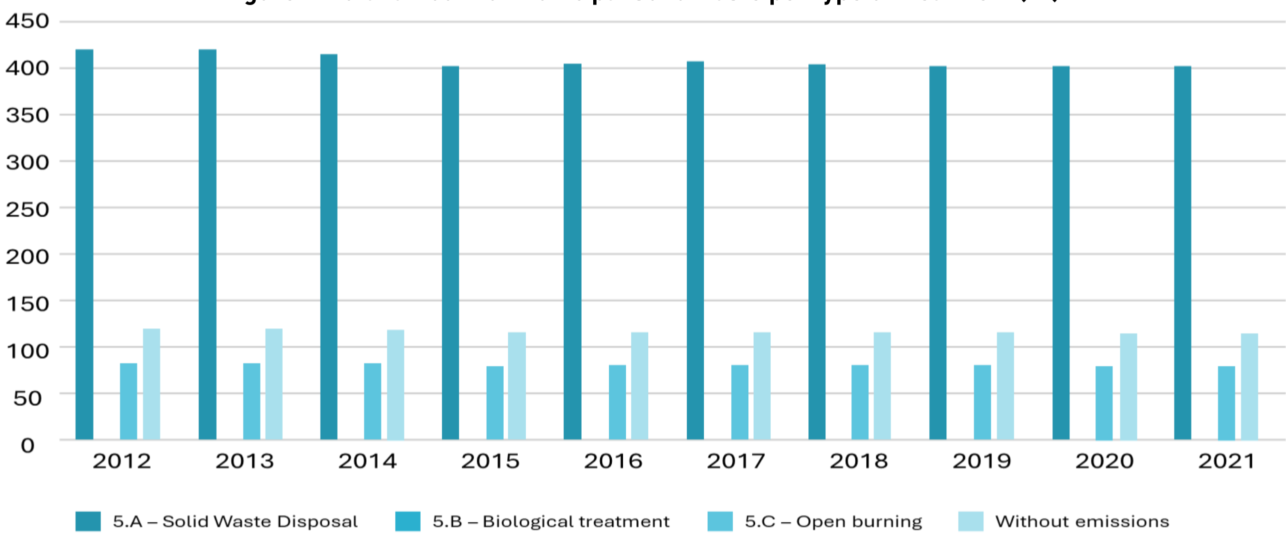
For the uncollected MSW, there are 15 methods employed by households to dispose of waste, as identified in Pansuk et al. (2018) from interviews with 4,300 households residing in areas without MSW collection and disposal services across Thailand. Among these methods, 53.7% of uncollected MSW is burned, and this percentage was used to estimate the total amount of MSW subject to burn in Chiang Mai.

Figure 3. Treatment Pathways Concerning the Collected Part of MSW Generated (A)



In 2021, the total amount of MSW burnt is estimated at about 14% of the total amount of MSW generated in Chiang Mai. This calculation is based on information from the national survey and should represent the realistic MSW amount of open burning in the province. Further surveys in Chiang Mai province on residents' waste disposal habits would enable a better assessment of the fraction of MSW open burning.

Figure 2. Total amount of municipal solid waste per type of treatment (kt)



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[12] *Pansuk et al., 2018*

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

2.4. Energy sector

The energy sector (excluding transport) includes emissions linked to energy consumption by energy industries (e.g., power stations, oil refineries, and the production of solid, liquid, and gaseous fuels), along with energy consumption by manufacturing industries, the residential/commercial sector, and agriculture. It also accounts for fugitive emissions from the production of petroleum products and from the extraction and distribution of fuels (e.g., mines, natural gas transport networks, service stations).

The primary source of data for calculating emissions from the "Energy" sector is the energy consumption information provided by the National Energy Balance, published by the Ministry of Energy of Thailand.

The data in the National Energy Balance is more aggregated than the sector-specific information listed above, and it provides energy consumption figures for industries such as manufacturing, residential, commercial, agriculture, and construction.

At the provincial level, however, less detailed data on fuel/energy consumption is available. Therefore, the National Energy Balance data is extrapolated to the provincial scale using specific proxies (e.g., population, cropland area) in most cases. It is important to note, however, that some sources, such as refineries and public power plants, do not operate in Chiang Mai.

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2.5. Road transport

The activity data related to both abrasion and combustion emissions is based on the distance traveled by the vehicle fleet. Vehicles are classified by type (e.g., heavy duty vehicles, personal cars, two-wheelers), fuel type, and technology.

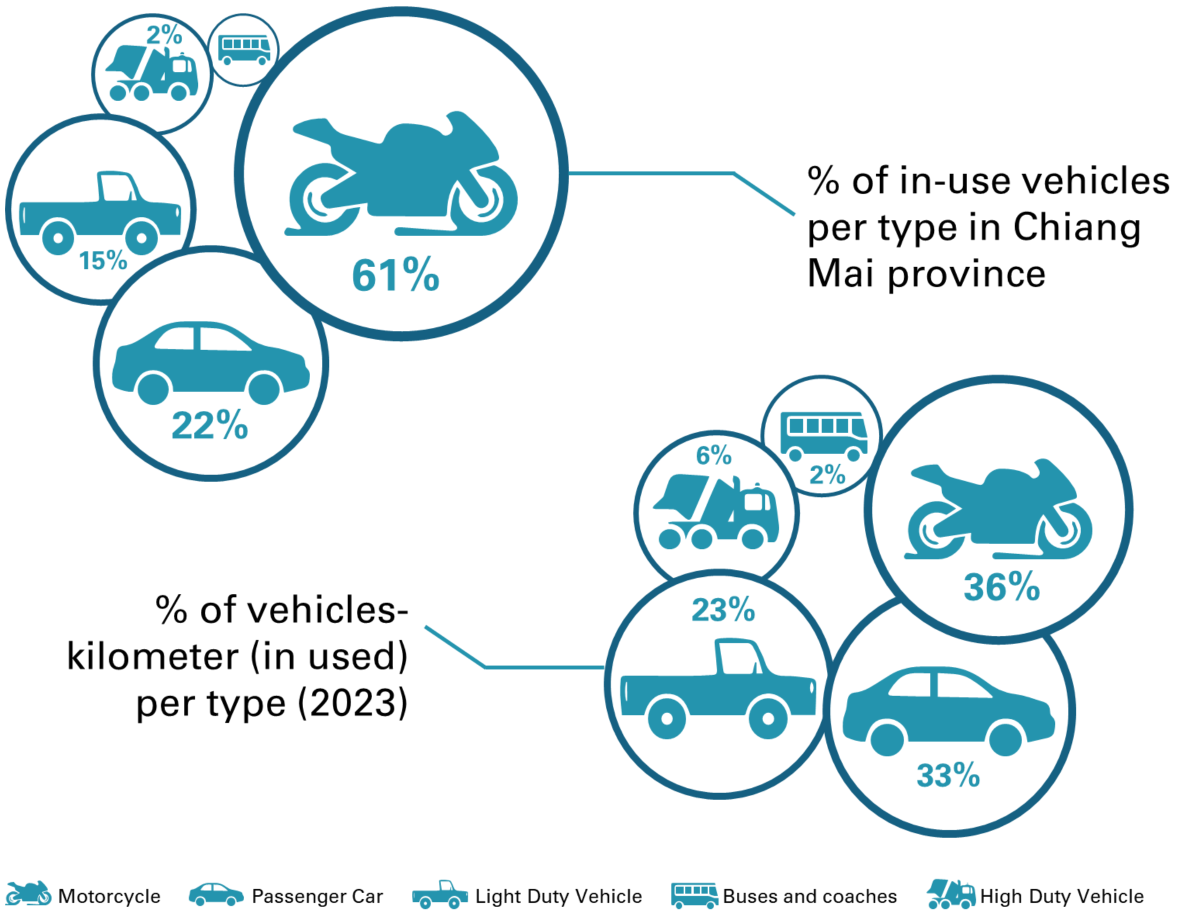
The composition of the vehicle fleet was determined from a traffic survey conducted as part of AQIP Thailand, which took place in September 2023.[14] The estimated average annual distances traveled by vehicles are derived from a traffic model produced by Egis. This model is based on road counts conducted in the Chiang Mai Metropolitan Area, which were then extrapolated to cover the entire province.

As shown in the figure below, motorcycles make up most vehicles on the roads in Chiang Mai, accounting for 61% of the vehicle fleet. Passenger cars represent 22%, light-duty vehicles (LDVs) 15%, and heavy commercial vehicles (HDV) 2%, including buses and coaches.

However, the distribution changes when considering the number of kilometers traveled by each vehicle type. Motorcycles generally travel fewer kilometers than other vehicle types. Here, motorcycles and passenger cars each account for approximately one-third of the total kilometers traveled, while LDVs account for 23%. HDVs and buses/coaches together account for the remaining 8%.

The fuels used per type of vehicles are mainly gasoline for motorcycles (93%). The diesel is mainly used by LDV (78%), HDV (84%), buses and coaches (100%). Personal cars use both types of fuel in almost equal quantities (52% gasoline, and 45% diesel).

Chiang Mai light duty vehicles fleet is mostly composed of Euro 4 (71%), and to a lesser extent, Euro 3 vehicles (19%), and the remaining Euro and pre-Euro conventional (10%). Most personal cars are Euro 4 (84%). The remaining personal cars vehicles fleet is composed of Euro 3 (13%) and lower (remaining 3%). HDVs are mainly represented by Euro III vehicles.[15] Still, 17% of HDV are associated with conventional engines which are strong particles emitters.



[14] *More details on the vehicle fleet composition are available in the report titled "Air Quality Improvement in Thailand – Output 4, Part 1: Composition of the Technological Fleet in Chiang Mai," published in December 2023.*

[15] *An additional survey would be necessary for HDV and buses*

Figure 4. Share (%) of Fuel Used Per Type of In-Use Vehicles

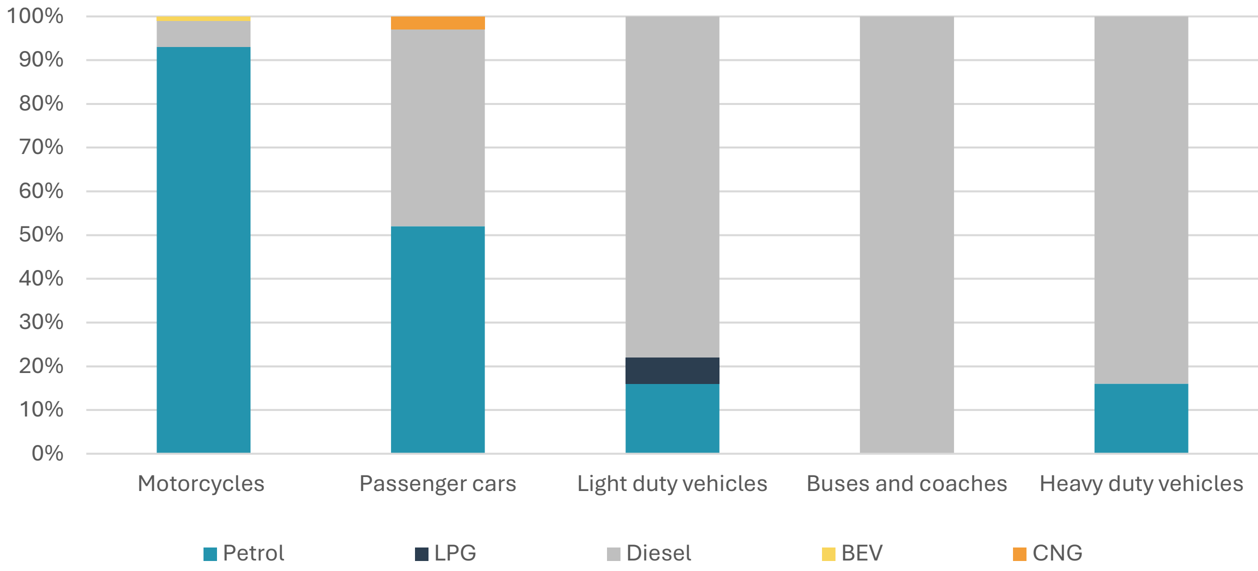
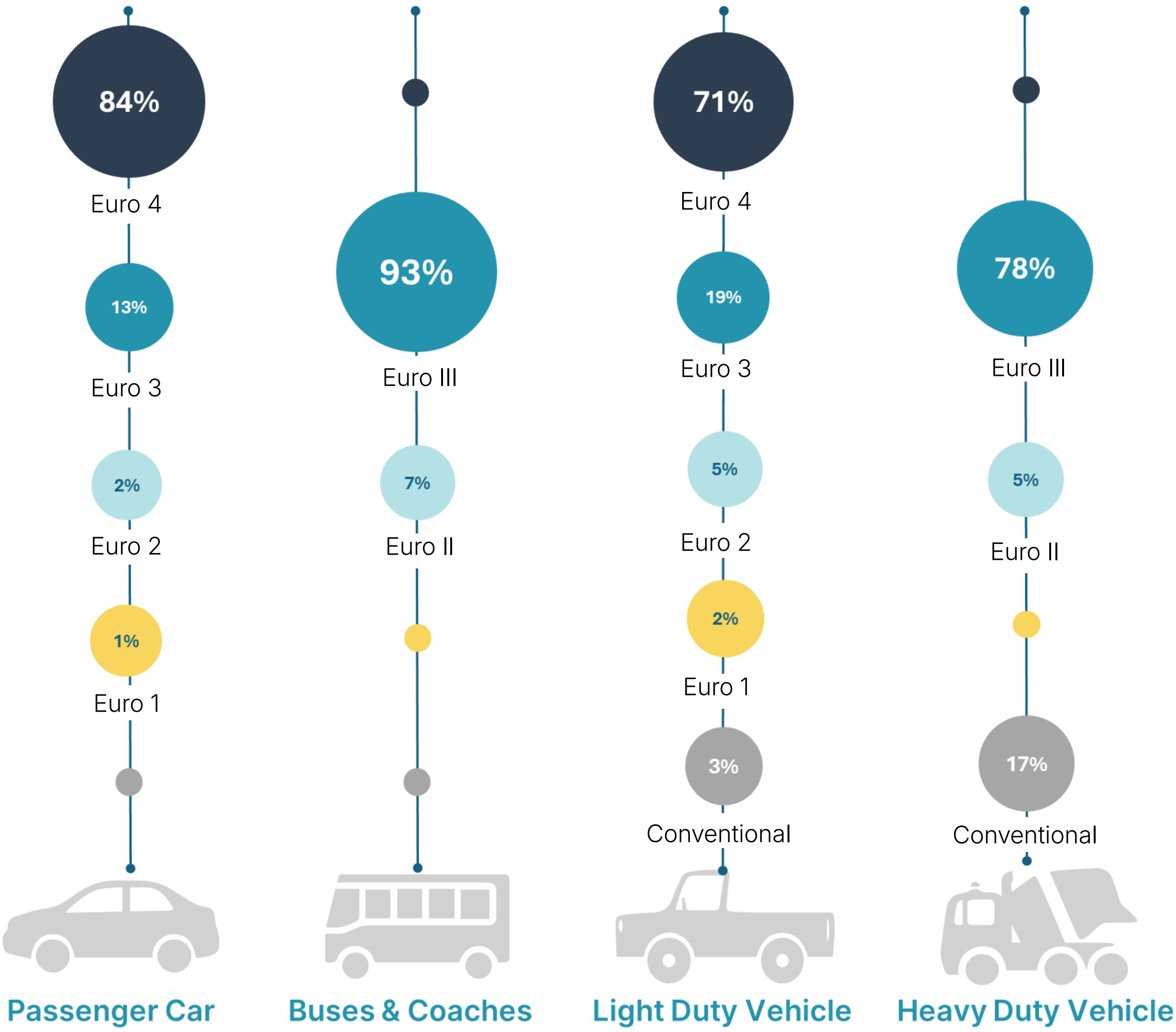


Figure 5. Fleet composition per Euro norms in Chiang Mai Province




INTERSECTION
COCKPIT
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3. Main Emission Sources Per Substance

3.1. Acidification, eutrophication, and photochemical pollution

3.1.1. Sulphur dioxide (SO_2)

In Chiang Mai, SO_2 emissions are primarily generated by the combustion of sulfur-containing fossil fuels. The main sources of SO_2 emissions are the manufacturing industries and the residential/ commercial sectors, with smaller contributions from transport, forest fires, agricultural residue burning (ARB), and waste management, particularly open waste burning (Figure 6).

As the primary sources of sulfur oxides (SOx) are anthropogenic, the highest emissions are typically recorded in urban areas and along the main roads. It is important to note that fuel combustion in small installations (e.g., ceramic craft villages), may not be categorized under the industrial sector. Instead, these emissions could be classified under residential emissions or, in some cases, may be omitted from the total emissions inventory altogether.

This misclassification could lead to an underestimation of SOx emissions from the industrial sector and an overestimation of emissions from the residential sector. Therefore, field surveys are necessary to more accurately quantify emissions from craft villages and better capture emissions from the industrial sector.

Figure 6. Main SO_2 emitting sectors in Chiang Mai province in % and in tonnes/year

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 7 illustrates the spatial distribution (grid size = 1km2) 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.

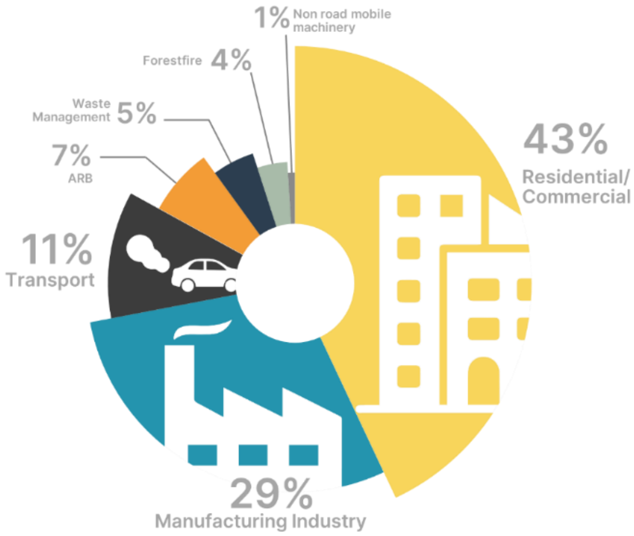
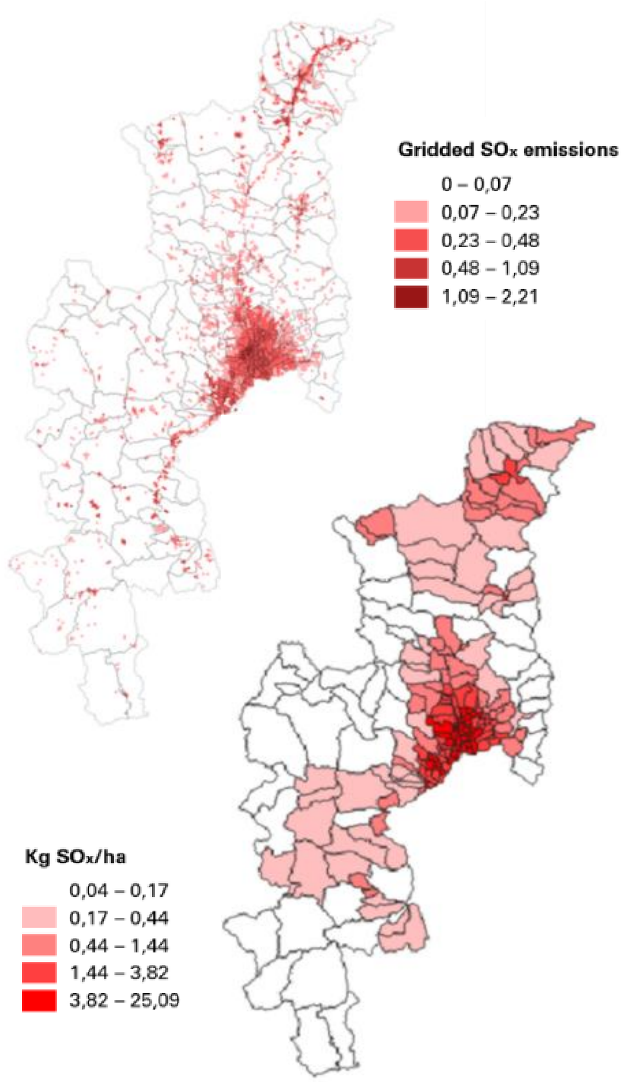


Figure 7. Spatial distribution of total Sulphur oxides (SOx) emissions in Chiang Mai



3.1.2. Nitrogen oxide (NOx)

NOx emissions are primarily produced during the combustion of fossil fuels or biomass in road transport, off-road vehicles, machinery, and the residential/ commercial sector, with smaller contributions from industry. In 2022, the transport sector accounted for the majority of NOx emissions (Figure 8). Additionally, NOx is emitted in agriculture through biological processes such as nitrification and denitrification in soils, following the application of mineral or organic nitrogen fertilizers. Small quantities of NOx are also released in livestock areas, at building/storage stations, and from the nitrogen contained in animal manure.

Certain industrial processes, such as nitric acid production and fertilizer manufacturing, also emit NOx. However, these emissions could not be quantified in this report due to the lack of specific activity data on industrial production for these products. Nevertheless, the industrial sector is considered a minor source of NOx emissions in Chiang Mai province.

It is also important to note that fuel combustion in small installations, such as those in ceramic craft villages, may not be categorized under the industrial sector. Instead, these emissions might be classified under residential emissions or, in some cases, may be excluded from the total emissions inventory altogether. This could result in an underestimation of NOx emissions from the industrial sector and an overestimation of emissions from the residential sector. To address this, field surveys are necessary to more accurately estimate emissions from craft villages and the industrial sector. Figure 9 presents the spatial distribution (grid size = 1 km2) of total NOx emissions in Chiang Mai Province. Emissions are maximal in the city center and along the roads as road transport is the main source of NOx in the Province.

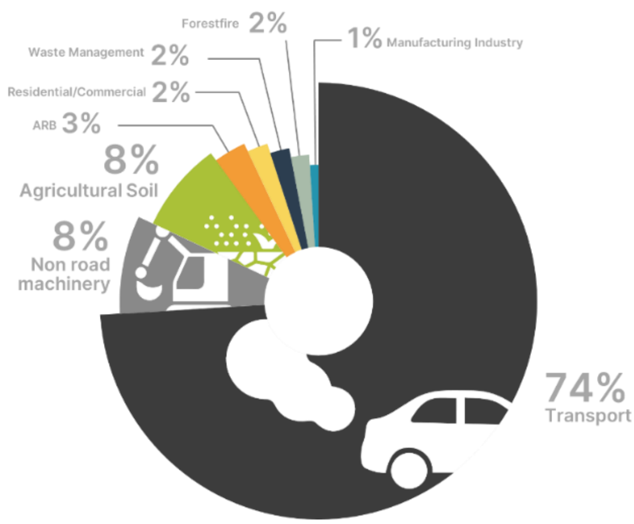
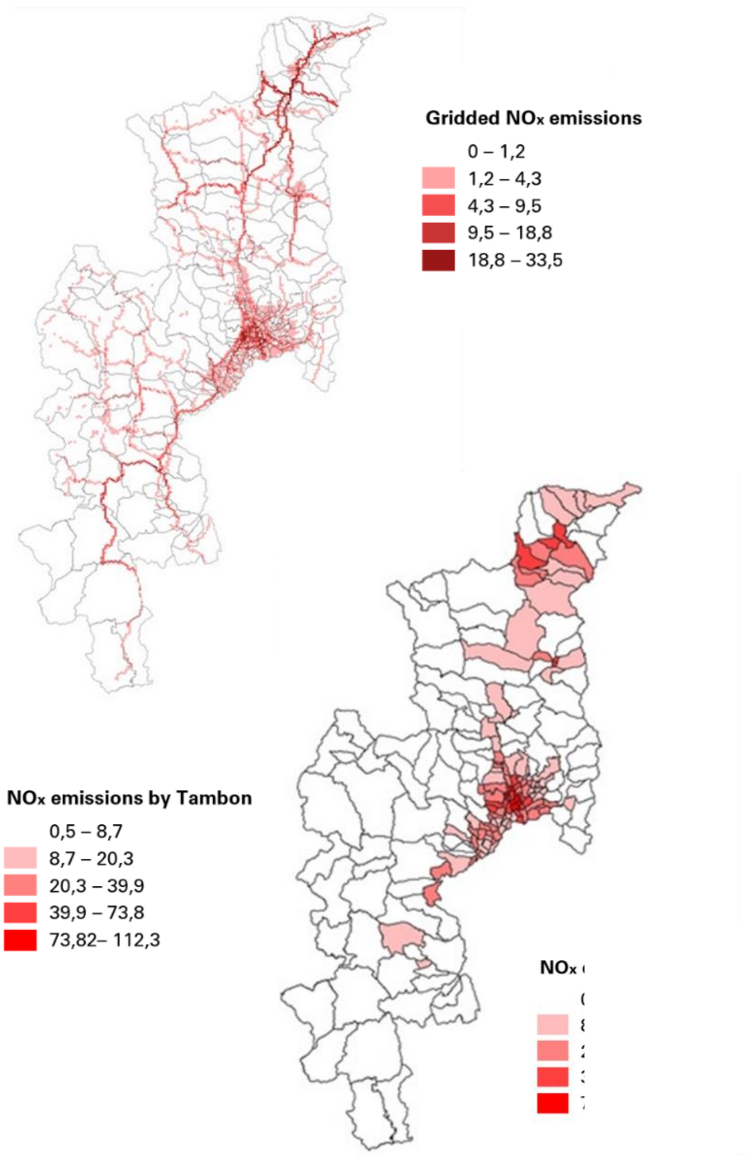


Figure 8. Main NOx emitting sectors in Chiang Mai province in % and in tonnes/year

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

Figure 9. Spatial distribution of TOTAL Nitrogen oxides (NOx) emissions in Chiang Mai



3.1.3. Non-methane volatile organic compounds (NMVOCs)

NMVOCs are emitted during combustion, evaporation, chemical or biological reactions. The main contributing sectors presented below and are illustrated in Figure 10:

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

Figure 11 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.

Figure 10. Main NMVOCs emitting sectors in Chiang Mai province in % and in tonnes/year

Sector (t/year)	2022
Manufacturing Industry	188
Transport	6,177
Non-road mobile machinery	270
Residential and 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**

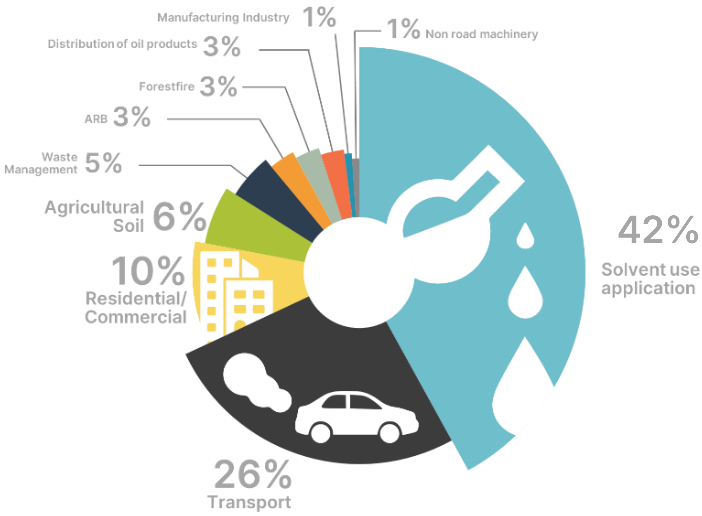
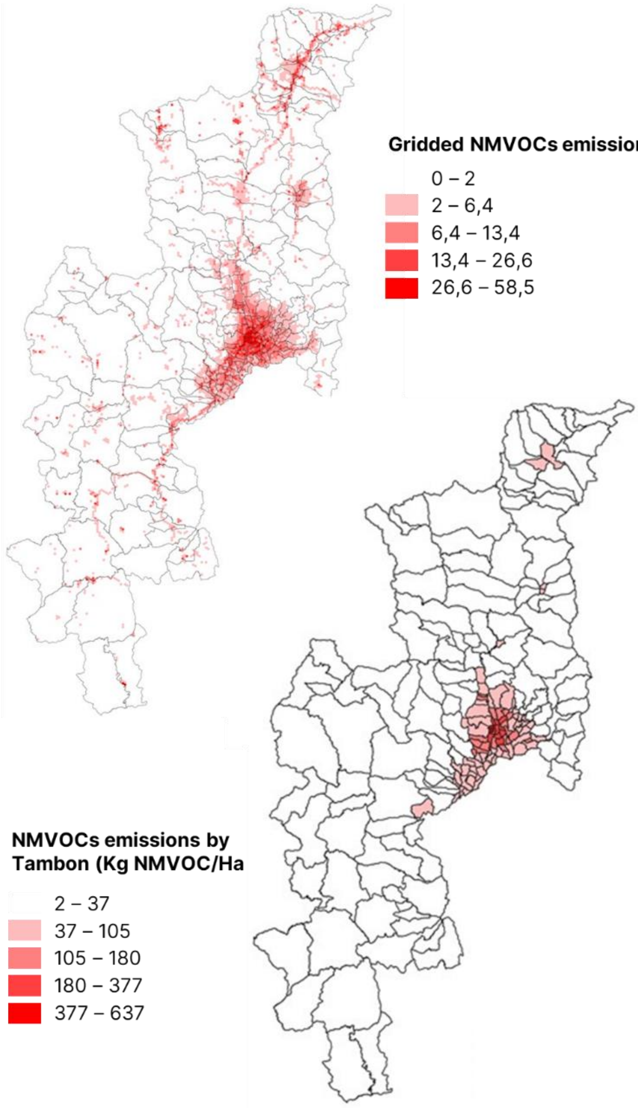


Figure 11. Spatial distribution of total non-methane volatile organic compounds (NMVOCS) Emissions in Chiang Mai



3.1.4. Carbon monoxide (CO)

The major contributing sectors in 2022 are:

- Energy: 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 cooking (wood in particular). Energy sector is reponsible for 71% of CO emissions (Figure 12).
- Not controlled combustion from forest fires (14%), agricultural residue burning (10%) and waste open-burning (5%).

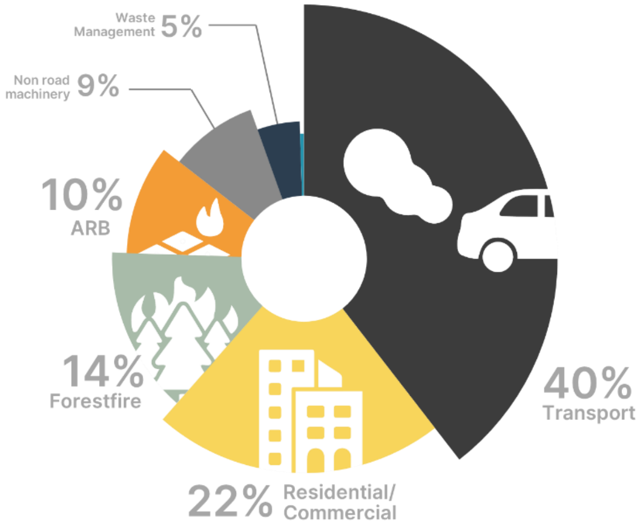


Figure 12. Main CO emitting sectors in Chiang Mai province in % and in tonnes/year

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

3.1.5. Ammonia (NH_3)

The main emitting sector is agriculture, due both to the management of animal manure and agricultural soils (fertilizer application, etc.), which respectively account for around 47% and 46% of the sector's emissions in 2022. Agricultural residue burning accounts for 3% of emissions in 2022, while the residential/commercial sector and waste management account for the remaining emissions.

Figure 13 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.

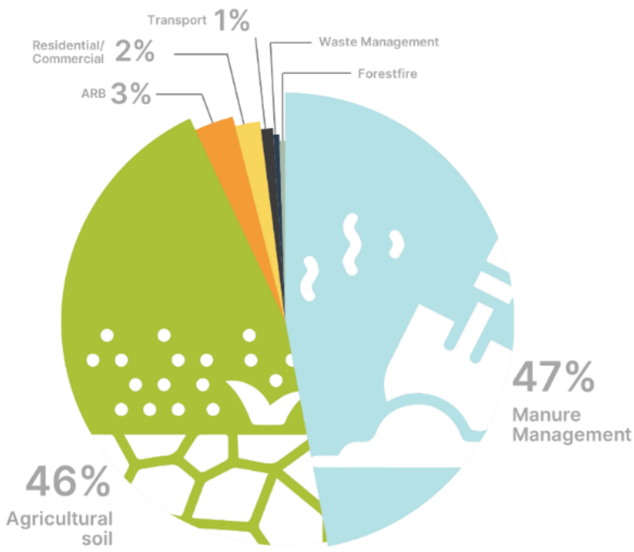
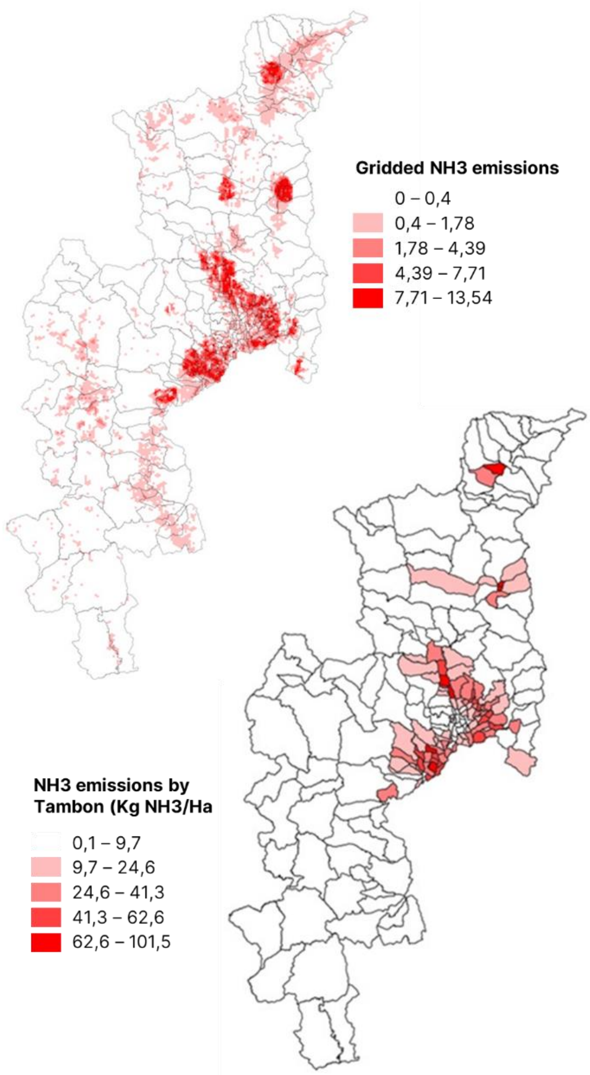


Figure 13. Main NH3 emitting sectors in Chiang Mai province in % and in tonnes/year

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

Figure 14. Spatial distribution of total ammonia (NH3) emissions in Chiang Mai



3.2. Particulate matter (PM)

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 15) and 85% of $PM_{2.5}$ (Figure 17). 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 15 and Figure 17). 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 16 and Figure 18).

3.2.1. Particles PM_{10}

Figure 15. Main PM_{10} emitting sectors in Chiang Mai province in % and in tonnes/year

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

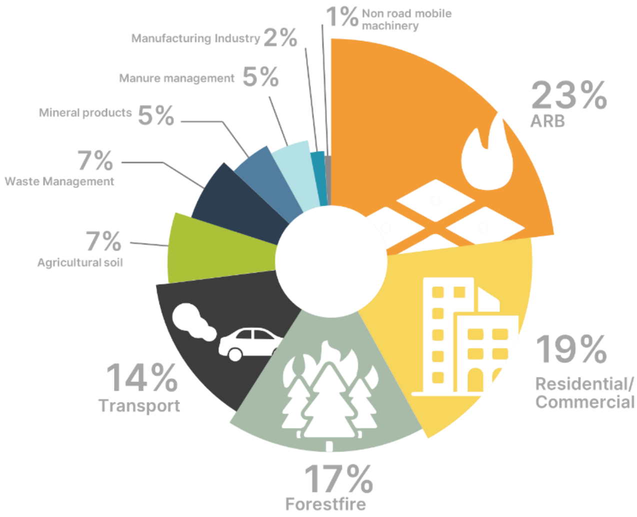
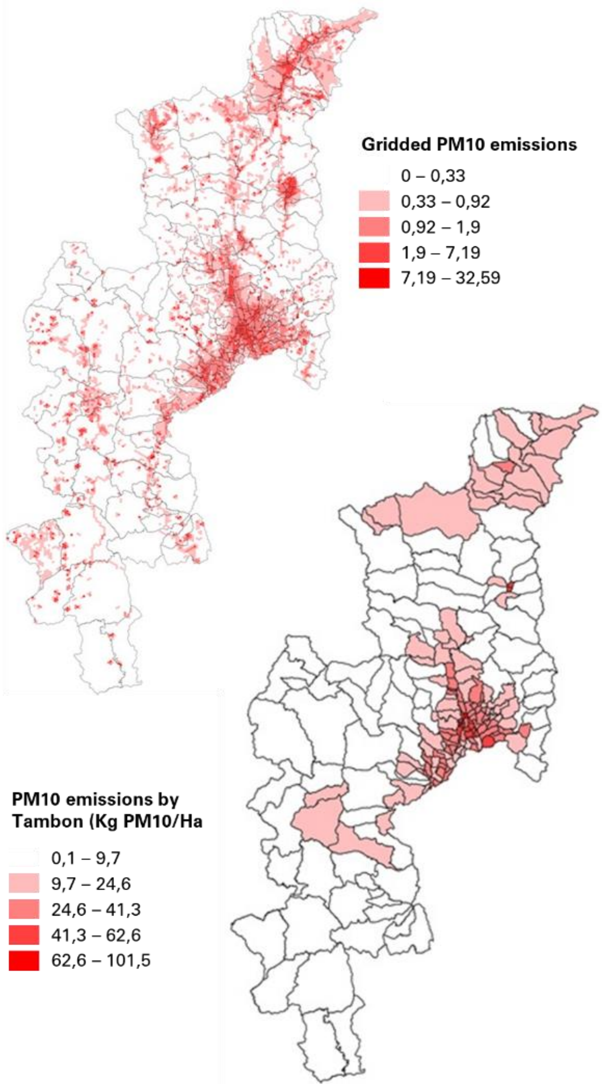


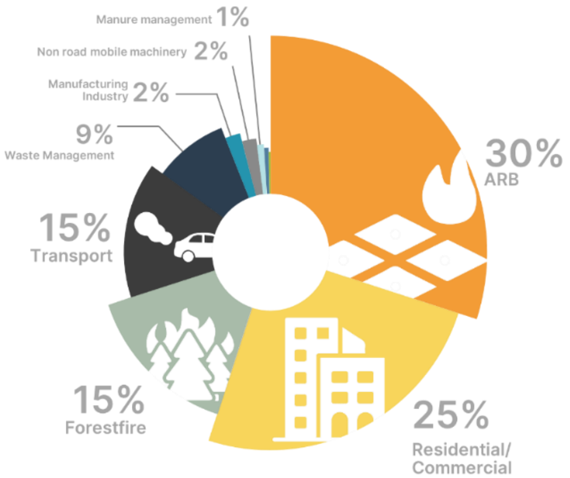
Figure 16. Spatial distribution of total particles (PM_{10}) emissions in Chiang Mai province



3.2.2. Particles $PM_{2.5}$

Figure 17. Emissions of $PM_{2.5}$ by main sectors in Chiang Mai province in % and tonnes/year

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



3.2.3. Black carbon (BC)

The main source of BC in Chiang Mai province 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 18).

Figure 18. Emissions of BC by main sectors in Chiang Mai province in % and tonnes/year

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

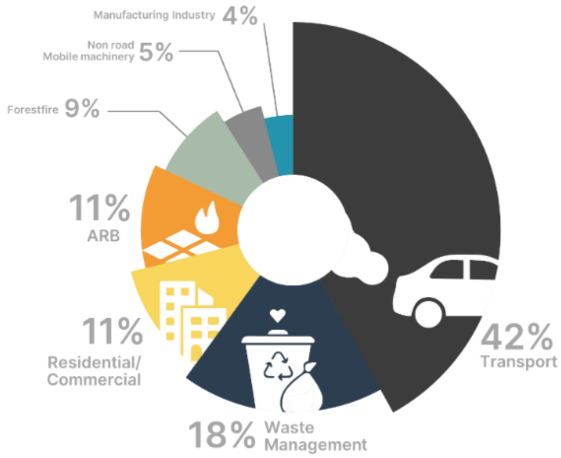
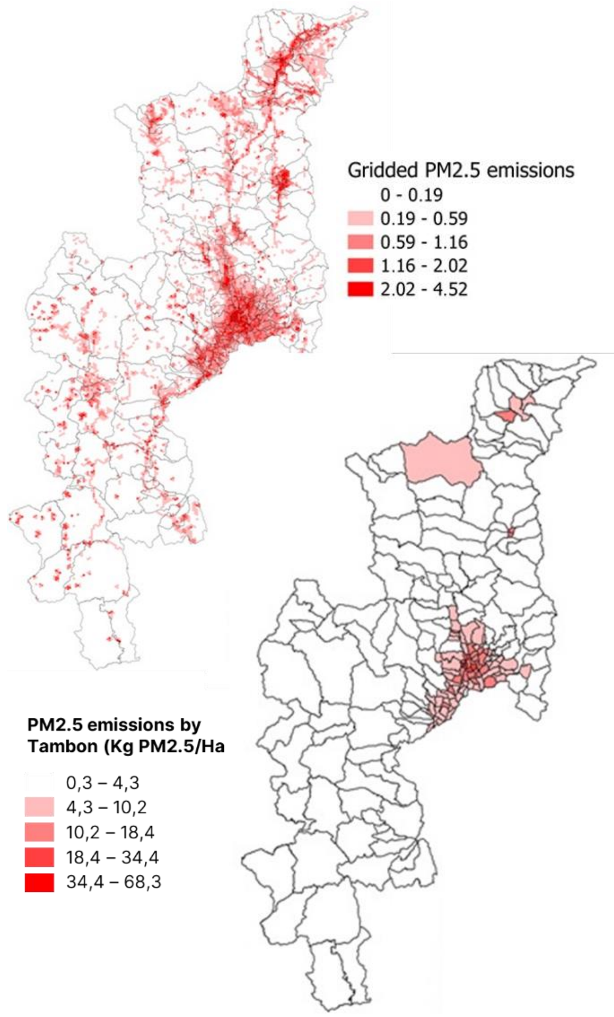


Figure 19. Spatial distribution of total particles (PM2.5) emissions in Chiang Mai



3.3. GHGs

3.3.1. Carbon dioxide (CO_2)

The main source of CO_2 is transport, with accounting for 68% of total CO_2 emissions from Chiang Mai province in 2022. The other high emitters of CO_2 are residential/Commercial sector (15%), Agricultural Residue Burning (5%), forest fire (4%), non-road mobile machinery (3%) and manufacturing industry (3%) as illustrated in Figure 20.

Figure 20. Emissions of CO2 by main sectors in Chiang Mai province in % and tonnes/year

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**

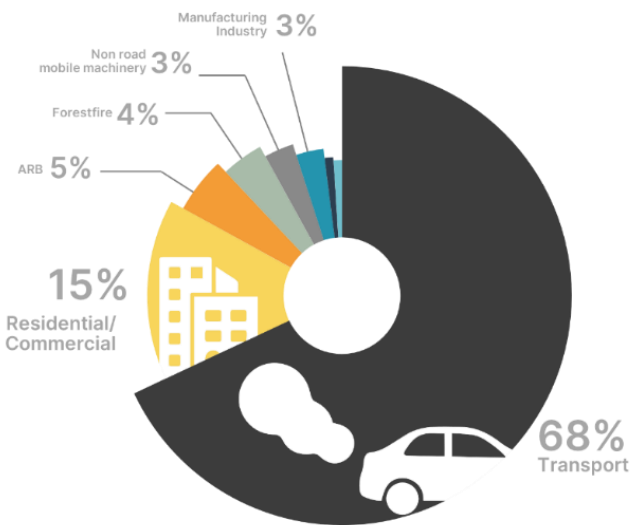
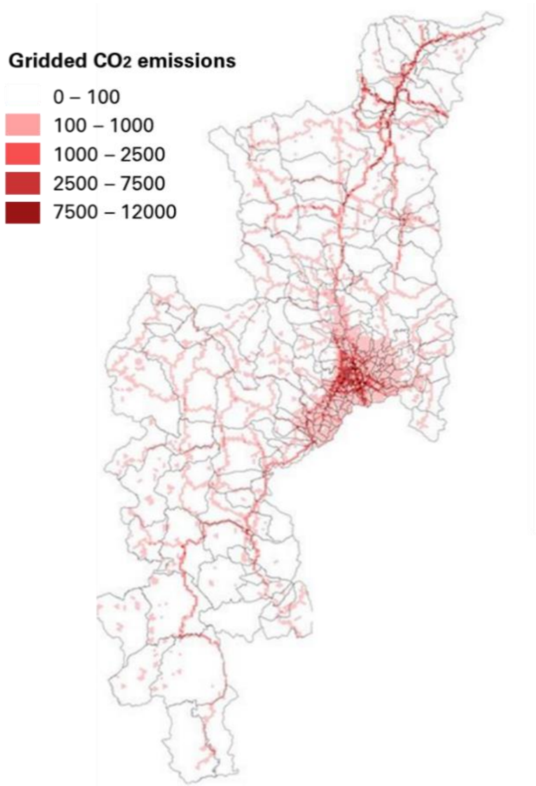
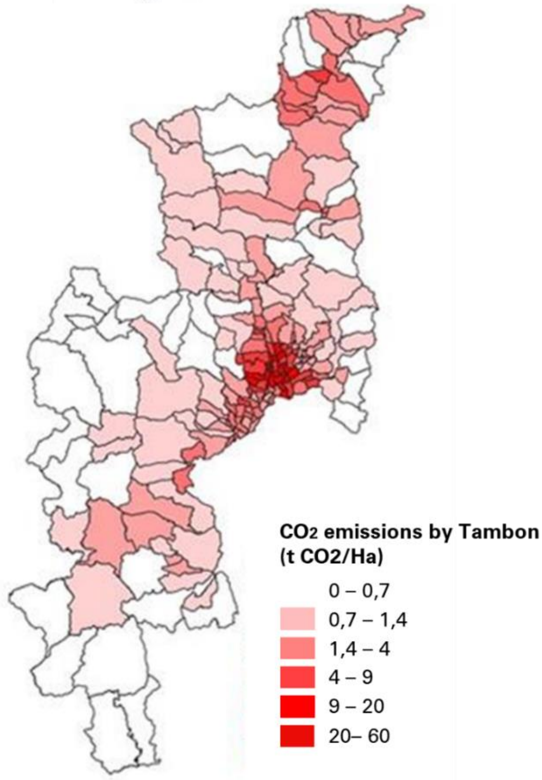


Figure 21. Spatial distribution of total Carbon Dioxide (CO2) emissions in Chiang Mai





3.3.2. Methane (CH_4)

The main source of methane is agriculture (71%): rice cultivation/paddy (38%), enteric fermentation (26%) and manure management (7%). Waste management (23%), in particular emissions from landfill and wastewater treatment facilities, is also a major source of CH_4. Forest fires (2%), the residential and commercial sector (2%) and transport (1%) are minor sources of CH_4 Figure 22. Methane emissions are mainly due to agriculture and waste management and are therefore distributed throughout rural and urban areas Figure 23.

Figure 22. Emissions of CH4 by main sectors in Chiang Mai province in % and tonnes/year

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 cultivation/paddy	21,317
Waste management	13,137
Forest fire	547
Total	**55,356**

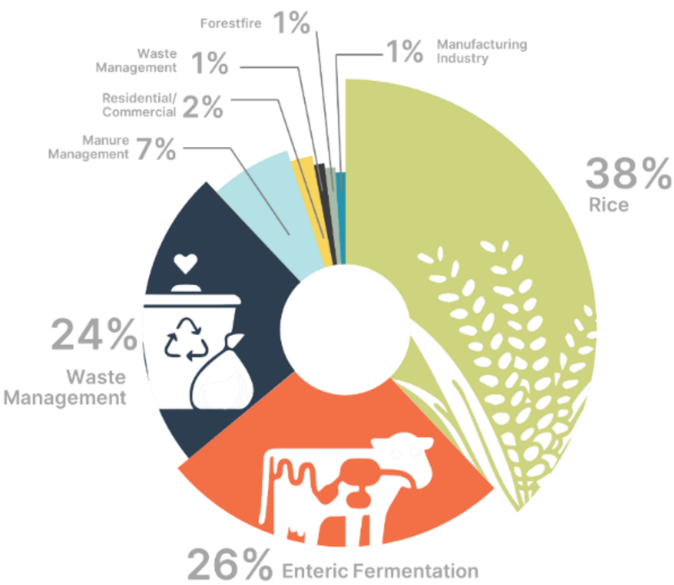
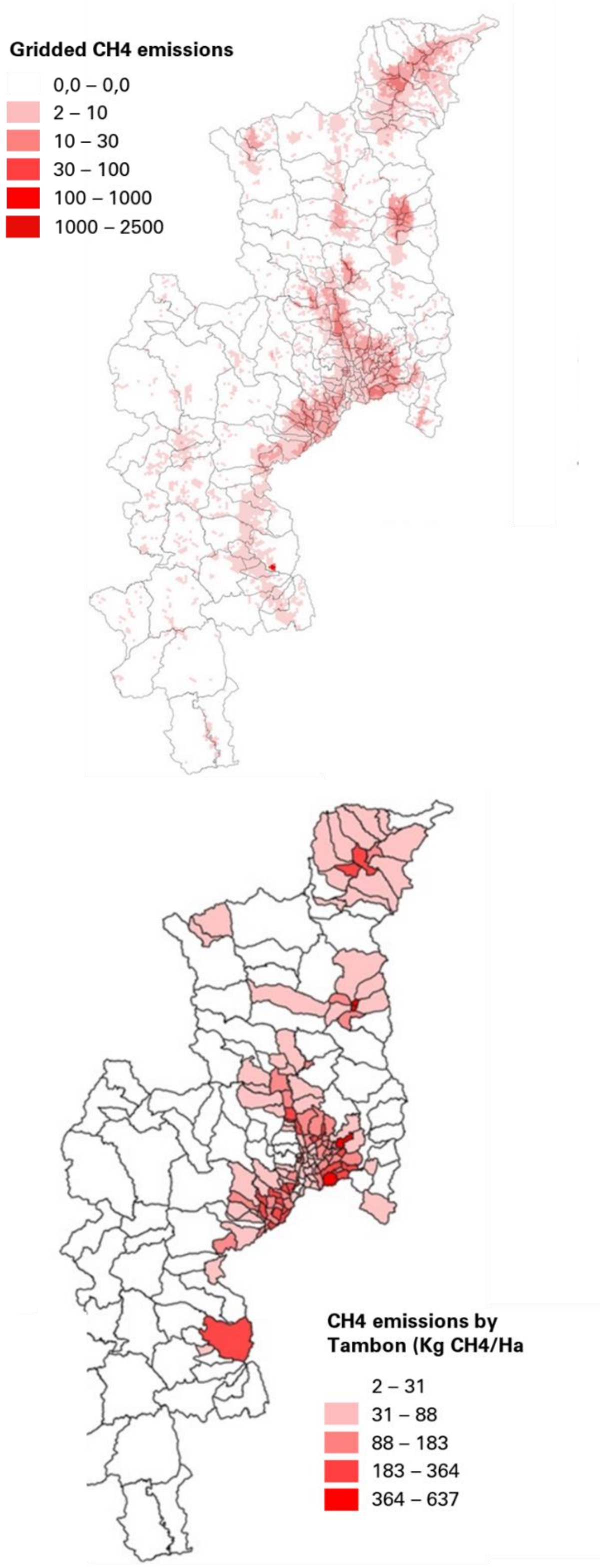


Figure 23. Spatial distribution of total Methane (CH4) emissions in Chiang Mai



3.4. Most emitting sources of air pollutants in Chiang Mai

As shown in Figure 25, biomass uncontrolled combustion and open burning (mainly agricultural residue burning and forest fires) are large sources of $PM_{2.5}$ emissions in Chiang Mai province. Energy, especially road transport and residential sectors are also strong contributors to particles.

Moreover, it is also important to examine inorganic gaseous pollutants (NOx, SO_2 and NH_3), which are the major precursors of secondary particulate matter. Indeed, NH_3 is produced mainly by agriculture, SO_2 by manufacturing industries and residential sector, and NOx by transport.

While open burning, especially forest fires, is a significant source of particulate matter, it typically occurs only during the dry season (February-April) in Chiang Mai. Throughout the rest of the year, and particularly during periods with less biomass burning, transportation becomes the main source of particulate matter.

These findings are supported by the study conducted by Chansuebsri et al. (2024), which analyzed the chemical composition of $PM_{2.5}$ in Chiang Mai. The authors examined fine particulate matter at an urban site near an intersection during both smoky and smoke-free periods. Their study indicates that biomass combustion contributed 51% of fine particles during smoky periods, while traffic emissions accounted for 76% of $PM_{2.5}$ during smoke-free periods. Regarding GHGs (Figure 24), Energy is the main source of CO_2, especially transport, and to a lesser extent, residential and commercial sector. Agriculture is the main source of CH_4, especially rice cultivation and enteric fermentation. Waste, especially landfilling and wastewater, is also a significant source of CH_4.

3.4.1. Air pollutants

The residential sector is dominant for emissions like PM10 and BC, while road transport is the main contributor to NOx. Agricultural activities, including manure management and agricultural soils, significantly contribute to NH3, whereas the manufacturing industry leads in SOx emissions. Further details can be seen in Figure 25.

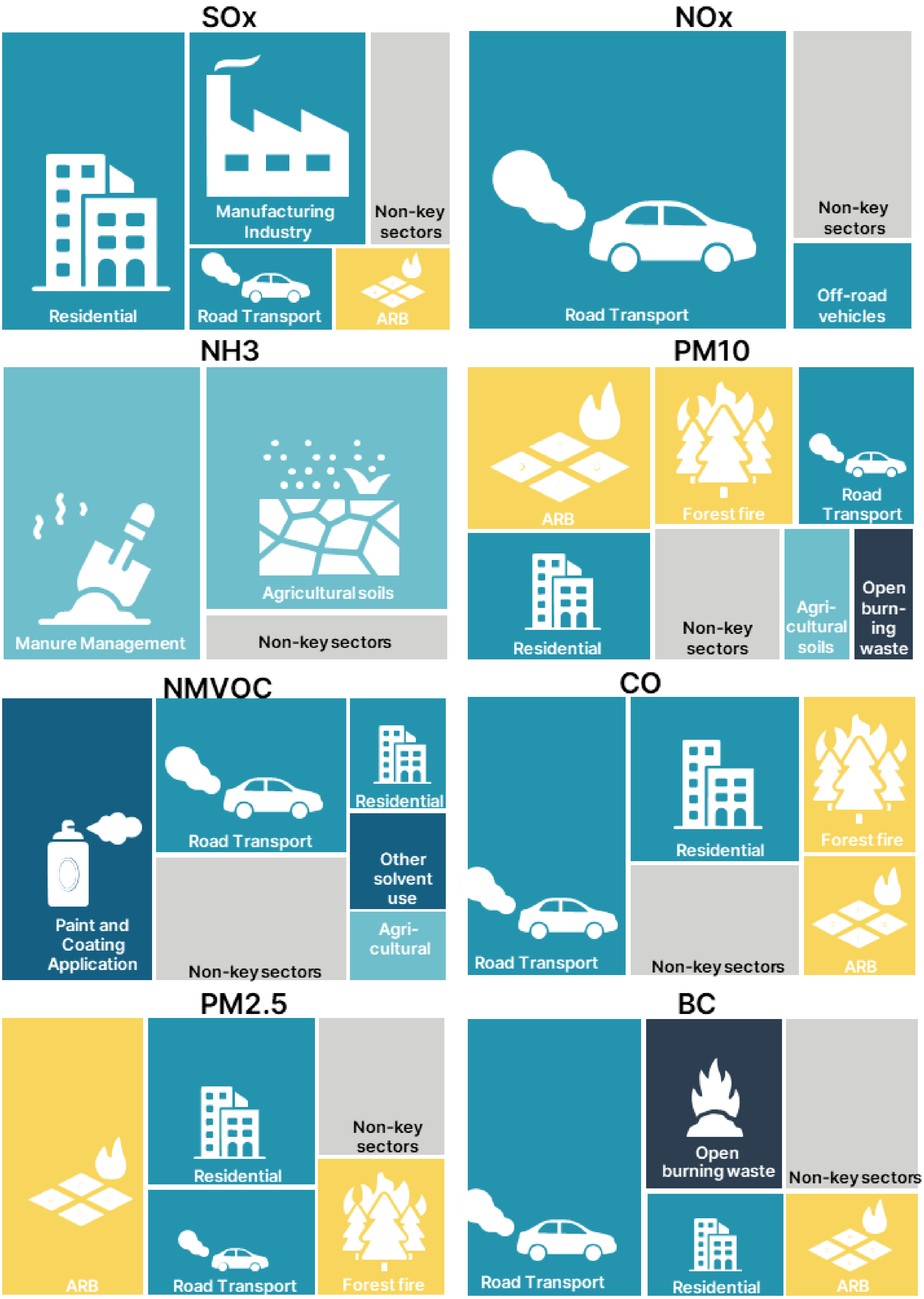
3.4.2. GHGs

Road transport emerges as a dominant source, followed by residential and commercial activities, rice cultivation, and waste management. Agricultural soils and manure management also play significant roles in contributing to emissions, depending on the pollutant. Further details can be seen in Figure 24.

In addressing the air quality concerns in Chiang Mai, it's crucial to highlight that $PM_{2.5}$ concentration represents the main issue, overshadowing other pollutants. Focusing on $PM_{2.5}$ emissions will provide a clearer picture of the environmental challenges facing by the province. Therefore, the next chapter targets $PM_{2.5}$ and its precursors and policies and actions to effectively tackling the region's air quality problems.

Figure 24. Keys sources of GHG in Chiang Mai province

Figure 25. Keys sources of air pollutants in Chiang Mai province



THE DIFFERENCE IN METHODOLOGY BETWEEN EMISSIONS INVENTORIES AND SOURCE APPORTIONMENT:

The methodology used by Chansuebsri et al. (2024) called source apportionment, using the positive matrix factorization (PMF) receptor model and the potential source contribution function (PSCF), identifies the sources responsible for particulate concentrations in the air at a given location. It therefore takes into account primary and secondary particles, as well as transboundary effects. Emissions inventories quantify the amount of air pollutants produced by all sources in a given area and only primary emissions.

4. Measures to Reduce Biomass Burning Emissions

Open burning of biomass is a large source of PM_{10}, $PM_{2.5}$, Organic Carbon (OC) and BC. As mentioned above, this open burning source of emissions is significant, but especially forest fires, is limited to a few months in a year.

On an annual average, biomass combustion is the main source of primary fine particles (PM2.5) emissions. Indeed, a collective 53% of $PM_{2.5}$ emissions come from open burning, which among of these is 30% from crop residues burning (ARB), 17% from forest burning and 9% from open burning of waste.

Mitigation measures are being taken by the Thai Government and the districts of Chiang Mai Province to limit the impact of forest fires. The number of hotspots fell sharply between 2020 and 2022, but it is unclear whether this trend is due to weather conditions, forest fire mitigation measures or both.

Figure 26. Sources of PM2.5 with a focus on open-burning

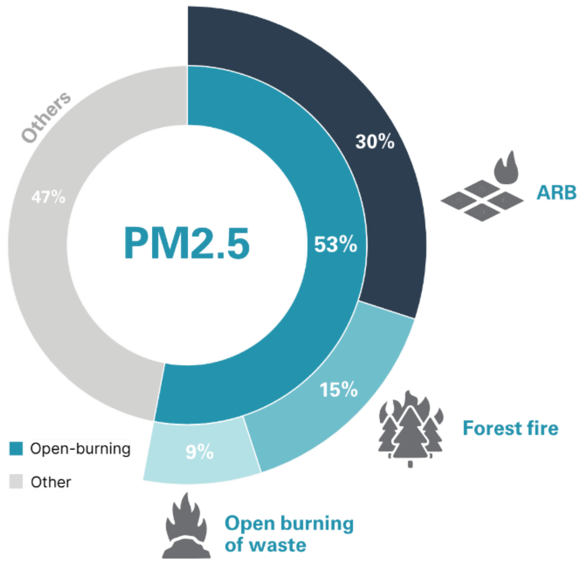
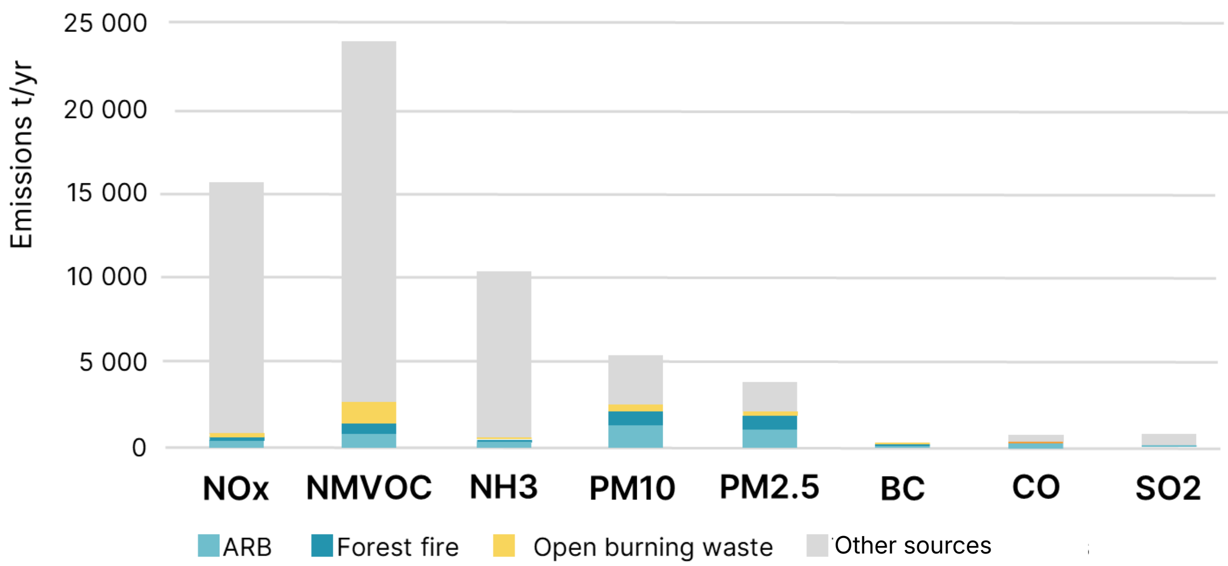


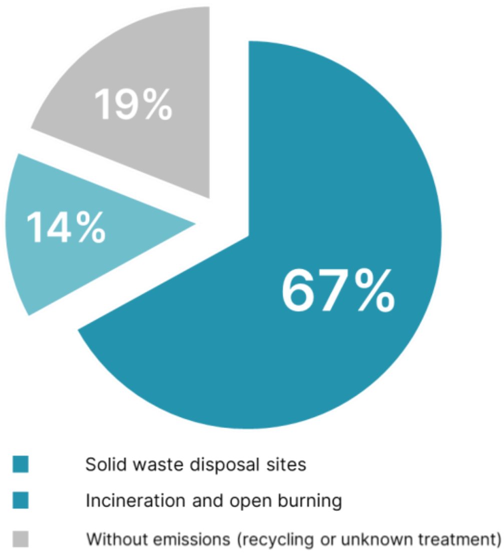
Figure 2720. Emissions of air pollutants from open-burning: forest-fire, agricultural residue burning and



In Chiang Mai province, open burning of waste is responsible for 8% of total $PM_{2.5}$ emissions for base year 2022. This result is based on calculations using several assumptions, with most of the data being national. Proxies, such as population data, were also applied to estimate the results for Chiang Mai. As shown in Figure 28, 14% of total waste generated in 2022 was either burned outdoors or incinerated (including hospital waste), contributing significantly to PM emissions from waste management.

It would be valuable to take this analysis further by estimating the amount of waste specifically burned within Chiang Mai province. A survey could be conducted to obtain more accurate estimates of the quantity of waste being burned. If the quantity is substantial, measures should be taken to reduce this practice, as it is a significant source of PM emissions and can be easily avoided.

Figure 21. Distribution by type of solid waste treatment in Chiang Mai

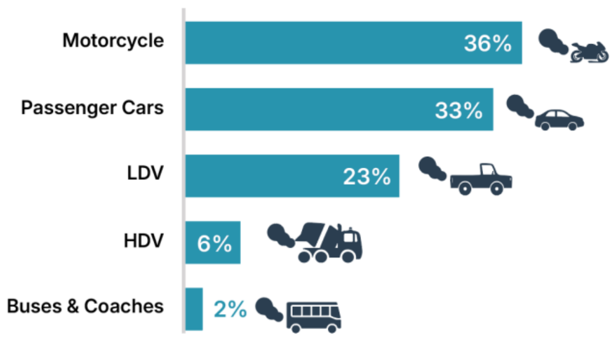


4.1. Measures to reduce road transportation emissions

Several measures can be taken to reduce the impact of road transport on air pollutant emissions. Most of them are summarized in Table 1. In this section, we will concentrate mainly on the results of the traffic survey and on what can be deduced from the composition of the vehicle fleet.

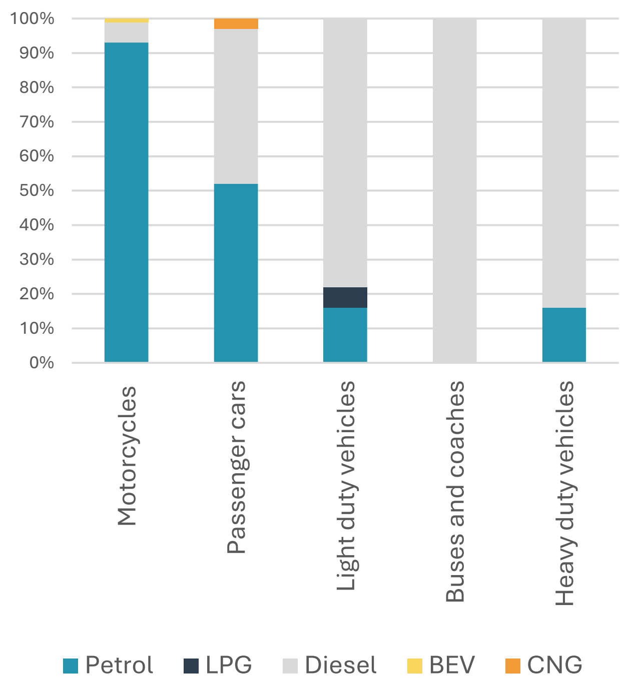
The number of kilometers travelled in the province is due to motorcycles (36%), passenger cars (33%), LDV (23%), HDV (6%), and buses and coaches (2%).

Figure 29. Percentage of Vehicles-Kilometer (In Used) Per Type (2023)



Passenger cars use both types of fuel (gasoline and diesel) in almost equal quantities. Other fuels by vehicle type show a "classic" pattern: gasoline for motorcycles and mainly diesel for HDVs, buses and coaches.

Figure 30. Share of fuel used per type of in-use vehicles



The composition of the vehicle fleet is fairly recent (at the time of the survey, the standard in force was Euro 4 for passenger cars and Euro III for trucks): 84 % of passenger cars are Euro 4, 71 % of LDV are Euro 4 and 93% of Buses and Coaches and 78% of HDV are EURO III.

Figure 31. Fleet composition per Euro norms in Chiang Mai province

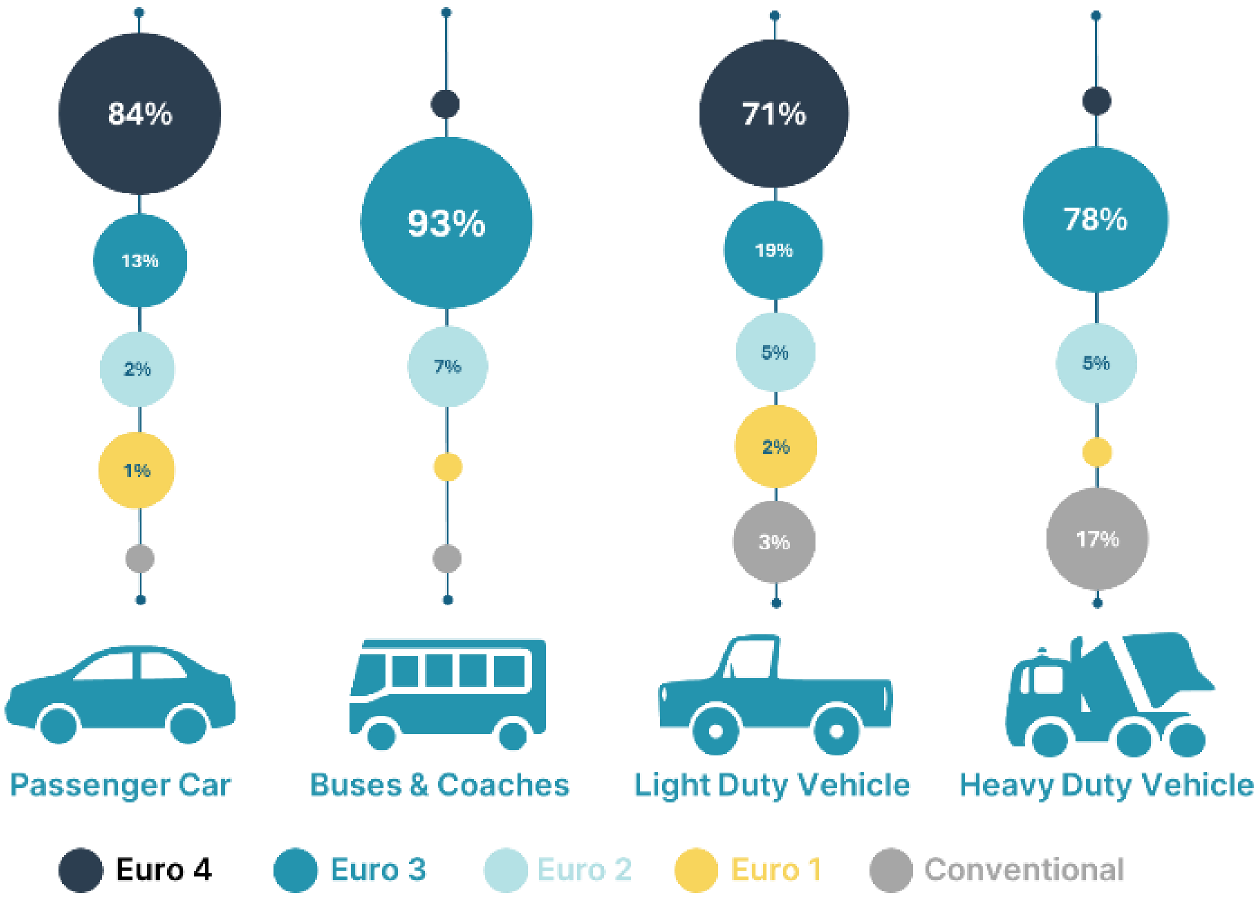


Figure 32 shows the high proportion of PM and NOx emitted by LDV (38% of $PM_{2.5}$ and 21% of NOx) and heavy vehicles (HDV, buses and coaches) (30% of $PM_{2.5}$ and 57% of NOx), even though these vehicles represent a minority in terms of kilometers traveled in the province (LDV: 23%, buses and coaches: 2% and HDV 6%).

This result underlines the importance of scrapping the oldest heavy vehicles (Euro II and before) which are very high emitters of fine particles.

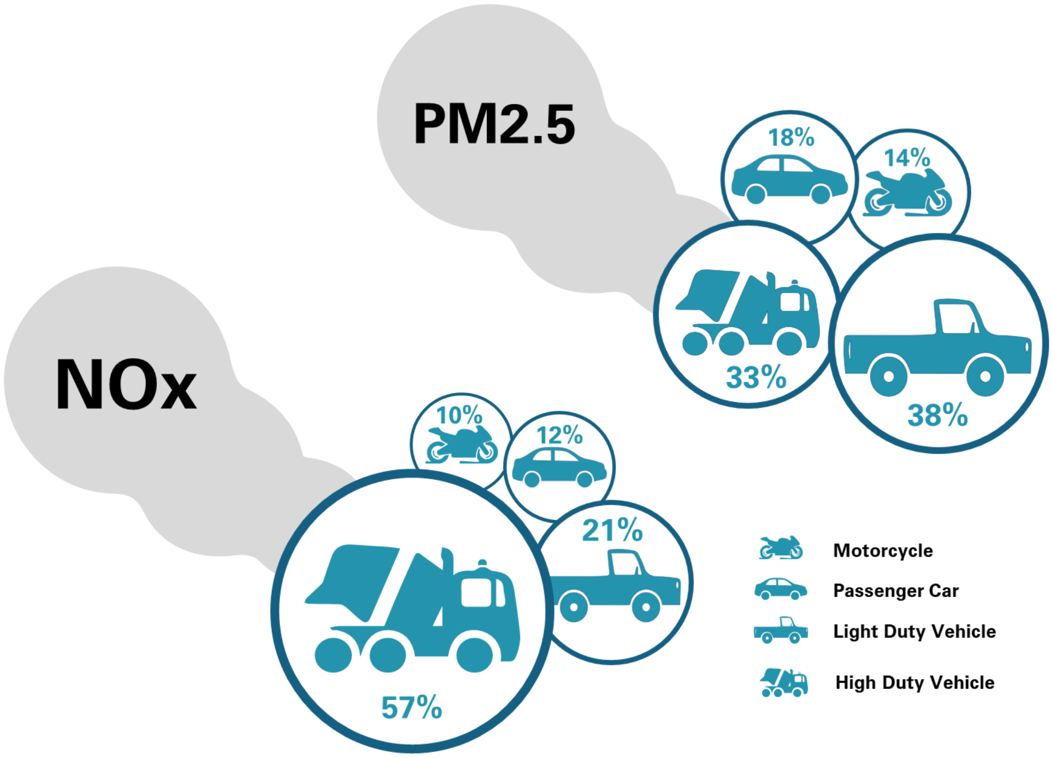
In addition, the latest decree on Euro 5 vehicles and fuel quality imposes the Euro 5 emission standard on newly manufactured light vehicles, and a fuel sulfur content of less than 10 ppm. These regulations will help reduce air pollution from road transport, as particulate filters are mandatory with Euro 5/V and are highly effective in drastically reducing particles emissions. Incentives could also be offered to speed up fleet renewal, particularly for older vehicles.

Furthermore, the country plans to implement Euro 6/VI standards for LDV, passenger cars and HDV within the next two years. It is crucial that the government follows through on this plan, as these measures are essential to reducing emissions and improving air quality across the country.

Figure 33 shows the spatial distribution of NOx emissions by vehicle type: motorcycles, passenger cars, light duty vehicles and heavy vehicles.

As this figure shows, emissions from motorcycles and passenger cars are highest in the city center, while emissions from light and heavy-duty vehicles are highest on major roads outside the city. Switching to electric power for two-wheelers would help reduce particulate and NOx emissions in city centers.

Figure 32. Emission of PM2.5 and NOx from road transport in Chiang Mai province



The following measures could be taken:

Fleet renewal incentives for PC/LDVs (e.g. scrappage bonus, Euro 5 vehicles fitted with particulate filters)

Incentives to get rid of pre-Euro trucks (17% of trucks are pre-Euro, replaced by Euro III or IV)

Improvement and development of public transport services to encourage a modal shift towards less polluting modes of transport

Follow the plan to issue a decree to introduce the Euro 6/VI standards for light and heavy vehicles

Incentives to switch to electric mobility for mopeds, motorcycles, light vehicles and passenger cars

Promotion of NMT modes (cycling, walking) such as investments on infrastructures, urban planning and pedestrian-oriented development, education, awareness campaigns

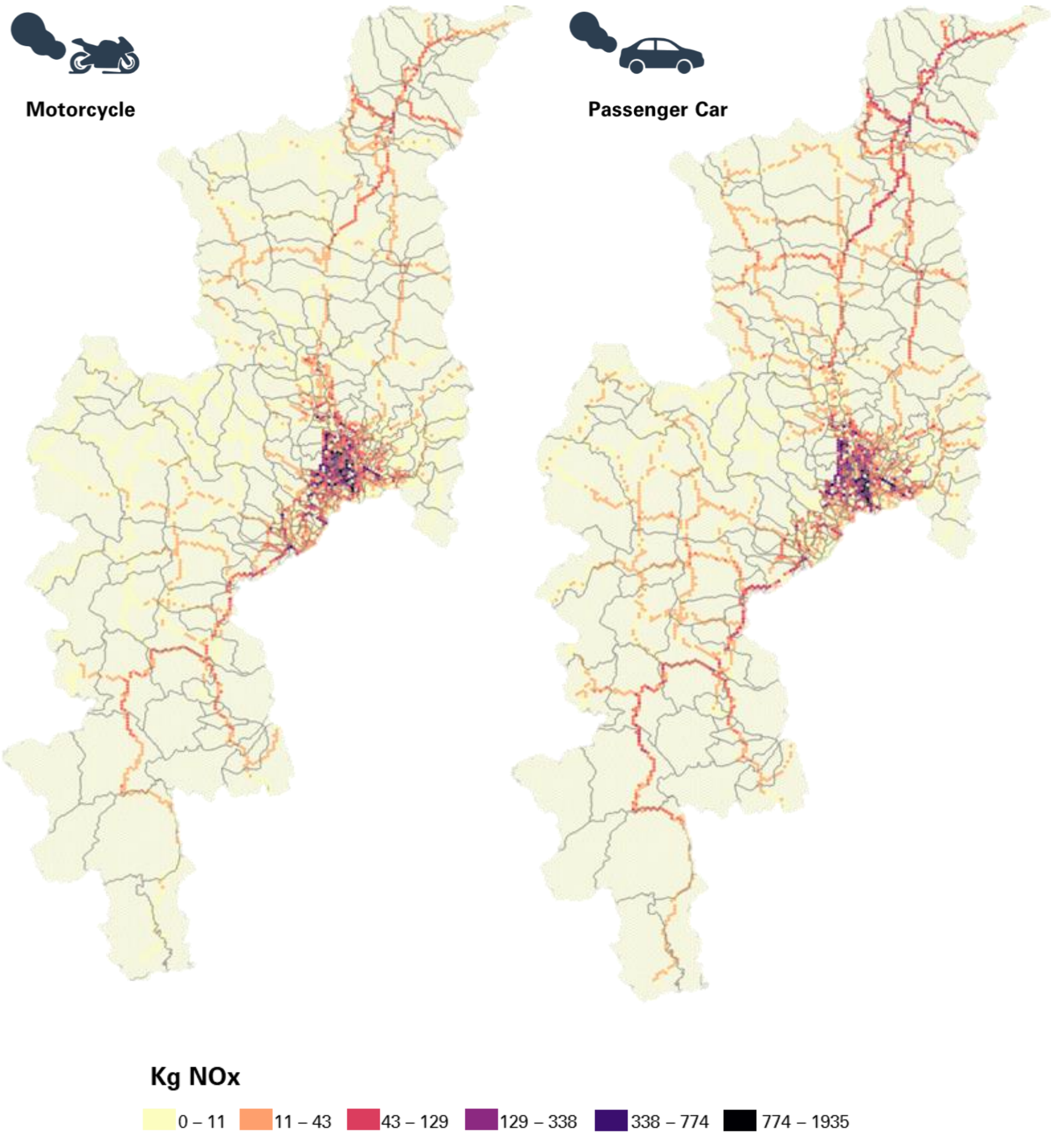
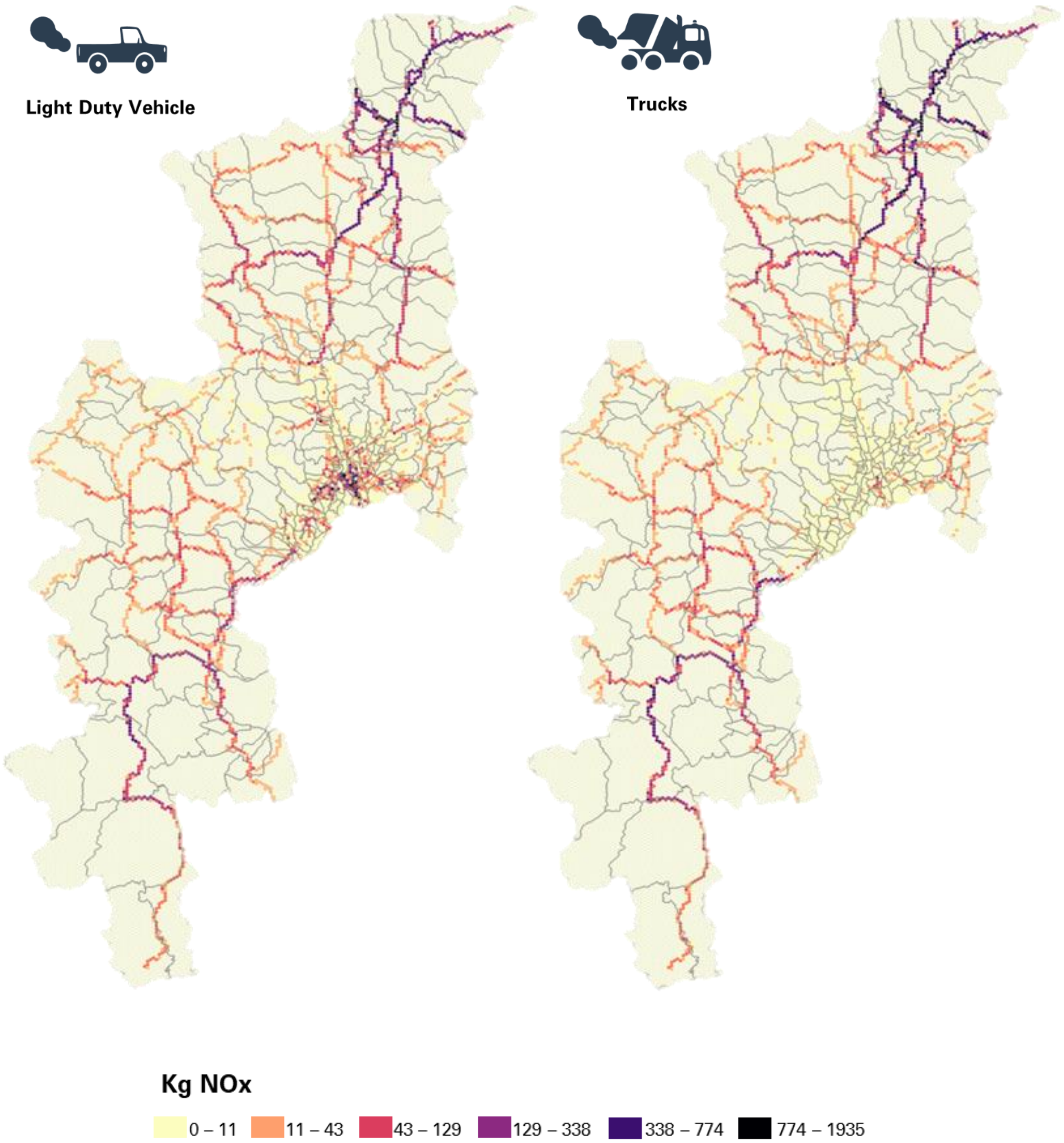


Figure 33. Spatialised emissions of NO_x in Chiang Mai province (kg of NOx), in 2022


Light Duty Vehicle
Trucks
Kg NOx
0 – 11
11 – 43
43 – 129
129 – 338
338 – 774
774 – 1935

4.2. Measures to reduce air pollution from all sectors

As shown in the inventory, particulate precursors (NH_3, SO_2 and NOx) are emitted by many different sectors. Therefore, it is important to reduce emissions from all sectors to improve air quality. Proposals for emission reduction measures in Chiang Mai province are shown in the table below.

Although not shown in the table below, it is also essential to work on improving and regularly updating the inventory by improving the accuracy of activity data and developing specific emission factors for Thailand.

A better reporting system for industry would also be useful for improving the emissions inventory and monitoring emissions trends. Improved emissions would allow the correct identification of the main sources and the tracking of emissions from each sector over time.

Updated on a regular basis, Chiang Mai province's emissions inventory can be used by the authorities as a tool for planning actions to reduce pollutant and GHG emissions, as well as for evaluating actions taken and policies implemented.

Table 1. Measures to reduce air pollution in Chiang Mai Province

Sector	Action	Timeline	Impact
Small and medium industrial facilities	Improvement of the database on industrial emissions and improvement of the emission calculation for this sector.	S	No direct impact
	Capacity building of the operators' industrial plants on de-pollution systems, emissions monitoring and reporting.	S, M	Medium
	Regular control of small and medium industrial installations by local authorities.	S, M	Medium
	Strengthen the emission limit values and ensure their compliance.	M	High
	Survey of craft villages to better evaluate fuel types and associated emissions.	S	Medium
Residential and commercial sector	Financial Incentives for the replacement of old residential equipment with modern and less emitting ones. - Fuel shift from biomass/charcoal to LPG, NG or biogas in rural areas. - Shift f to electric stove when possible. - For street food shift from charcoal to LPG or NG.	S	Medium
	Improved fuel quality and increase inspections.	M	High
	Awareness campaign on indoor air pollution from residential combustion, its health impact and ways to improve domestic heating/cooking efficiency, kitchen and home ventilation.	S, M	High on citizen exposure
	Develop a wood and charcoal good practices guidance for professionals and the public.	M	Medium
	Measures to reduce fuel poverty: affordable clean energy.	S, M	Medium
Transport	Gradual transition of public transport (buses, minibuses) and community service vehicles to less polluting vehicles (CNG, electric, Euro IV standards).	S, M	High

Sector	Action	Timeline	Impact
	Incentive to renew the vehicle fleet: - Financial support for scrapping older diesel vehicles. - Incentives to buy Euro 5 or Electric vehicles.	S, M	High
	Implementation of Low Emission Zone in the City Centre.	S, M	High
	Promotion of soft mobility: pedestrian areas and bicycle lanes – Organisation of events like "pedestrian Sundays" to raise public awareness.	S, M	High
	Traffic management.	S, M	Medium
	Street washing to reduce resuspension of particles in dry conditions.	S	Medium
	Promotion of public transportation and sustainable urban mob ility plan.	S, M	High
	Regular inspections of the vehicles.	S, M	Medium
Agriculture	Reducing NH_3 emissions from poultry housing by improving manure management.	S, M	High
	Development of a natural crust during storage (dairy cattle and other cattle).	M, L	High
	Implementation of low emission fertilizer spreading techniques.	S	High
	Implementation of Alternate Wetting and Drying (AWD) to reduce CH4 emissions from rice cultivation, and use biochar as a soil amendment, crop rotation, etc., to reduce synthetic fertilizers.	S, M	Medium
Agricultural Residue Burning	Mapping and Monitoring to define the problem (Satellite, on-ground monitoring).	S	Medium
	Education of farmers on soil quality, crop yields and economic benefit of non-burning methods.	S, M	High
	Growing regulation in concert with farmer education and extension services, including potential incentives for adoption, equipment loan guarantees.	S, M	High
	Investigate the alternatives to ARB and their feasibility in Chiang Mai province and enforce them: ex-situ uses of crop and forest residues, animal feed and bedding, bioenergy, etc.	S, M	High
Forest Fire	Improvement of the forest fire management	S	High
Waste management	Assessment of the amount of waste burn in Chiang Mai province. A survey could be set up to obtain better estimates of the quantity of waste burned.	S, M	No direct impact
	Measures should be taken to reduce open burning of waste and improve waste collection.	M	Medium

Timeline: S: Short (Within 2 Years); M: Medium (2-5 Years), L: Long Term (> 5 Years)

5. Conclusions

As part of the AQIP project, an integrated gridded emission inventory has been developed for the province of Chiang Mai. This integrated emission inventory is the first one developed in the province. A set of air pollutants and GHGs are covered in a consistent method. The Gridded emission inventory details the location and magnitude of emissions across Chiang Mai province for the year 2022.

To build this integrated air pollutants and GHGs inventory, the most appropriate methodologies were used based on EMEP/EEA, IPCC, and scientific papers/reports. Calculation of road transport emissions is based on a traffic survey and 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 allows to assess the kilometers driven per vehicles and per main roads.

For other sectors, agriculture, waste, industrial processes and product use (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 or assumptions were necessary. A detailed description of the methodology developed, and work plans for improving the inventory step by step are provided in a methodological guide: "Comprehensive Inventory Methodology Report for Chiang Mai Province, Thailand (2022)". It is crucial to maintain and regularly update this emission inventory on a periodic basis as it is a key instrument to defines policies and measures in the different sectors and measure the progress made from year to year in terms of emission reductions.

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 biomass burning, road transport, agriculture, and the residential/commercial sectors.

A set of mitigation measures can be directly inferred from the emission inventory. While steps have already been taken to reduce forest burning in Chiang Mai Province, additional measures could be implemented to decrease the open burning of municipal waste and agricultural residues. Chansuebsri et al. (2024) highlighted that open burning is the main source of fine particles in ambient air during the smoke period, whereas road transport predominates for the rest of the year. Therefore, it is crucial to focus mitigation efforts on road transportation as well.

This report proposes several measures to reduce the impact of transport emissions, such as reducing the number of old heavy vehicles (buses, coaches, and trucks), which would significantly lower fine particulate emissions and NOx. Incentives to accelerate the renewal of passenger car and light-duty vehicle fleets would be effective, particularly following the release of the decree on Euro 5 vehicle and fuel standards in January 2024. Euro 5 vehicles are equipped with particle filters that substantially reduce emissions. Additionally, promoting walking, cycling, and public transportation can reduce not only air pollution but also GHG emission, noise pollution and urban heat islands. Modal shift is also one of the most efficient ways, with electric mobility, to reduce CO_2 emissions. This is especially relevant as road transport is the main source of CO_2 emissions in the province.

In conclusion, this integrated gridded emission inventory is a valuable tool for developing policies and actions to reduce air pollution in a consistent way. The more detailed the inventory, the more targeted and effective the resulting policies and actions will be.

In the case of Chiang Mai, this project 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 development of specific emission factors for different source sectors in Chiang Mai is necessary for improving emission results in the province.

Regular updating and improvement of this emissions inventory would allow to assess the evolution of emissions and thus the impact of policies and actions implemented. It could also provide an opportunity to implement more ambitious actions to further reduce GHGs and air pollutants.

6. References

- **AIT (2020).** The study of sources of PM2.5 and precursors of secondary PM2.5 in Bangkok Metropolitan Region.
- **Chansuebsri, S., Kolar, P., Kraisitnitikul, P., Kantarawilawan, N., Yabueng, N., Wiriya, W., Thepnuan D. and 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, 12051. *https://doi.org/10.1016/j.atmosenv.2024.120517*.
- **Cheewaphongphan et al. (2018).** Study on the Potential of Rice Straws as a Supplementary Fuel in Very Small Power Plants in Thailand. Energies 2018, Emission of Air Pollutants from Rice Residue Open Burning in Thailand
- **Citepa (2024).** Comprehensive Inventory Methodology Report for Chiang Mai Province, Thailand (2022).
- **Egis and Citepa (2023).** Air Quality Improvement in Thailand – Output 4, Part 1: Composition of the Technological Fleet in Chiang Mai
- **Khonpikul et al. (2017).** Resource use and improvement strategy analysis of the livestock and feed production supply chain in Thailand
- **Pansuk J., Junpen A. and Garivait S. (2018).** Assessment of Air Pollution from Household Solid Waste Open Burning in Thailand. Sustainability, 10, 2553; doi:10.3390/su10072553.
- **PCD. (2004).** Developing Integrated Emission Strategies for Existing Land Transport (DIESEL). Bangkok: Author.
- **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.
- **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.