AIR QUALITY IMPROVEMENT PROGRAM IN THAILAND (AQIP)

Roadmap Emission Sources and Policies Report

Sources of Air Pollution in Chiang Mai in 2022: Main Sources and Measures to Mitigate Air Pollution

Revision 00

AFD

Document Information

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1 INTRODUCTION

1.1 CONTEXT

A complete emission inventory ideally should compile all sources of air pollutants and GHGs in a region. A geographical gridded inventory allows to identify the zones with high emissions in a region and thus to better define and implement targeted measures to reduce air pollution and GHG emissions and also provides inputs for air quality models. Integrated emission inventories covering both GHGs and air pollutants are recommended by international organizations such as the Air Convention to better assess policies and measures and possible trade-offs between policies focusing solely on GHGs or on air pollutants. A regular update of the inventory provides the evolution of emissions, and if inventory methods are sufficiently developed (higher Tier methods), the inventory results thus enable a detailed assessment of the **impact of mitigation measures and public policies** in place. The national inventory allows the reporting of the country's emissions to the United Nations. In ASEAN, only GHGs must be reported to the UN. Indeed, under the Paris Agreement, countries must submit a plan to address climate change and set objectives in terms of GHG emissions reductions that are enshrined in their NDC (Nationally Determined Contribution).

In Thailand, many initiatives exist for emission inventory development (national and subnational) but they are not fully coordinated with a harmonized framework and objectives. The need for local, bottom-up emission inventories, i.e. 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 (Asian Institute of Technology-AIT, Chiang Mai University – CMU, etc.), local authorities (Chiang Mai city and province) and the Pollution Control Department (PCD) of The Ministry of Natural Resources and Environment (MoNRE). At the local scale, the Chiang Mai Municipality and Province emphasize the need for an emission inventory to identify the sources of pollution properly.

In the framework of the AQIP Thailand project, Citepa, in collaboration with AIT, built an integrated geographical gridded emission inventory (GHGs and air pollutants) for the year 2022 for Chiang Mai. The detailed methodology is described in another report "Comprehensive Inventory Methodology Report for Chiang Mai Province, Thailand (2022)" Report 2024. This integrated emission inventory can serve as a basis for policymaking and emission reduction actions. Possible emission reduction measures based on the inventory are therefore proposed in this report.

1.2 INVENTORY PREPARATION PROCESS

Citepa has established fruitful cooperation with AIT which participates in collecting information about key source categories of the inventory. Specifically, the activities carried out by the consortium, aim at the improvement of provision and collection of basic activity data and emission factors, through the exchange of information on scientific research carried out in the region and possible new sources of emissions which were not included in previous studies.

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

Numerous statistical data used for the inventory are also taken from the National Statistical Office Thailand (NSO) website (*http://www.nso.go.th/sites/2014en/statistics-from-majo-survey*), which includes both national and provincial statistics. The NSO also provides socioeconomic data (population, Gross domestic product [GDP]) that can be used as a proxy for calculating provincial emissions from national emissions when province-level data is not available.

An in-depth study was carried out to assess traffic patterns in Chiang Mai, with EGIS carrying out a traffic survey in collaboration with CMU and traffic modelling. This survey provided a better understanding of the province's technological vehicle fleet. The results of this traffic survey have been published in December 2023 in the report "Air Quality Improvement in Thailand – Output 4, Part1: Composition of the technological fleet in Chiang Mai".

Activity data used in emission calculations and their sources are briefly described in Chapter 2 but are fully described in the methodological report **"Comprehensive Inventory Methodology Report for Chiang Mai Province, Thailand (2022)."** This is the first time that a process of preparing an integrated emission inventory with a high spatial resolution has focused solely on Chiang Mai province. Emissions of GHGs and air pollutants were calculated for the year 2022, but where data was not available, activity data for 2021 was chosen. 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, were stored and archived by Citepa and were provided to PCD.

1.3 CONSIDERED AIR POLLUTANTS AND GHGS

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

Main Pollutants

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

Particulate matter

- TSP, total suspended particulate;
- PM_{10}, particulate matter not above (≤) 10 microns in aerodynamic diameter;
- $PM_{2.5}$, particulate matter not above 2.5 microns in aerodynamic diameter;
- Black Carbon (BC) and Organic Carbon (OC).

Heavy Metals (when data available)

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

Main GHGs

- Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)

2 ACTIVITY DATA COLLECTION FOR CHIANG MAI PROVINCE

To calculate emissions in a region, activity data is needed. These data must represent all the activities occurring in a given area and generating emissions. Activity data include the amount of fuel consumed (e.g. wood, oil, coal…) in power plants, industrial processes, cooking, residential heating, and transportation, electricity consumption by sector, production from various manufacturing industries, kilometers travelled per vehicle (VKT) for different vehicle types and fleet technology composition, the amount of fertilizer used in agriculture, the amount of waste generated and its composition, etc. were compiled by AIT and Citepa.

A lot of efforts have been spent to collect the data for the purpose but in many places, assumptions are still needed to complete the data. In this chapter, we summarize the data used and the hypothesis made. The detailed of activity data and sources can be found in Report **"Comprehensive Inventory Methodology Report for Chiang Mai Province, Thailand (2022)."**

2.1 FOREST AND OTHER VEGETATION FIRES

Burned areas are derived from spatial data processed in the Geographic Information System (GIS) environment to match burned areas with land-use cover categories and associated biomass categories (forest, crops, grasslands, etc.). These burned areas are derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 6 (MCD14) provided by the Fire Information for Resource Management System (FIRMS) which is available at https://firms.modaps.eosdis.nasa.gov/. Fire classification as either forest, grassland, or cropland is based on the European Space Agency Climate Change Initiative Land Cover map (ESA-CCI LC edition 2015).

Other sources of information could be used to improve emission estimates from forest and other vegetation fires. For example, more accurate estimates of the land cover category affected by fires, and thus more reliable estimates of biomass losses and associated emissions, would be possible with a more recent map of regional land cover.

In terms of spatial data for fire detection, other more sensitive instruments provide fire location information at a higher pixel resolution than MODIS products. In fact, the Visible Infrared Imaging Radiometer Suite (VIIRS - resolution of 375 meters) or the MODIS Burned Area products (MCD45A1 - resolution of 500 meters) could be used as a way of improvement.

The results from MODIS data used in the inventory are given in Figure 1. A large interannual variability is observed, which could be linked to climate conditions and to measures taken to reduce forest fire occurrence.

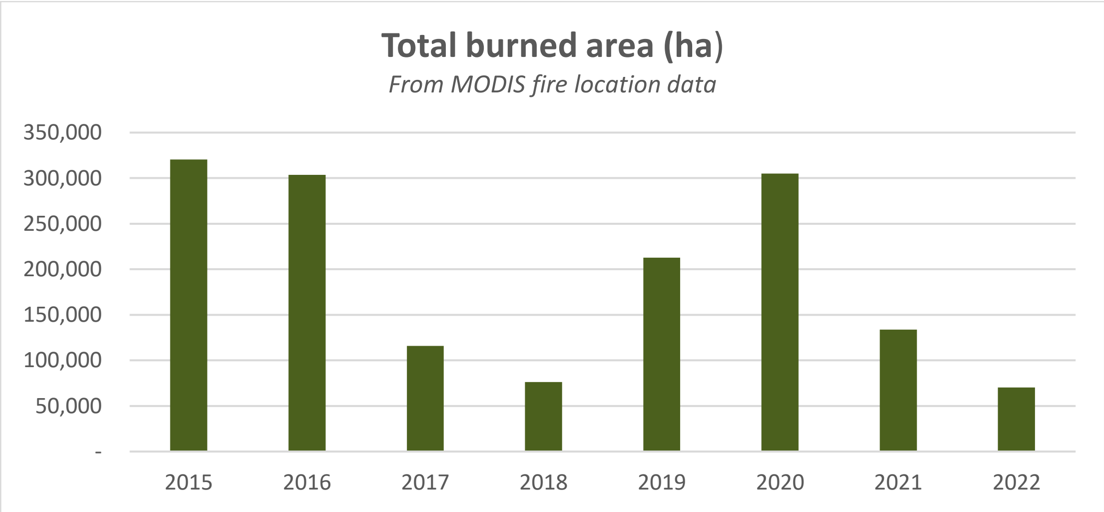

FIGURE 1: TOTAL ANNUAL BURNED AREA (HA) IN CHIANG MAI PROVINCE –FROM 2015 TO 2022 FROM MODIS DATA

2.2 AGRICULTURE

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[1] or IFASTAT[2] were used as well as data extrapolated from published literature.

2.2.1 Livestock population

Livestock population statistics of 8 different categories including 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[3] for years from 2012 - 2022. The detailed data by gender, and animal raising purpose (egg-laying chicken, meat chicken, milk cow, meat cow, etc.) were also collected whenever such data were available from the statistics.

The bodyweights for several animal categories were reviewed in different 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). In case animal body weights aren't available, IPCC default values were used.

Milk yield from dairy cows has been collected from FAOSTAT[4] statistics. Finally, the fat content of milk was assumed to be 3.59% according to 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, the statistics from the OAE[5] were used, distinguishing between major rice and off-season rice production. Statistics distinguish irrigated and non-irrigated rice. However, for Chiang Mai province, all rice production can be considered as continuously flooded (Rungcharoen et al., 2014). Other parameters used to calculate CH_4 emissions were taken from different literatures (Thambhitaks et al., 2021; Yodkhum et al., 2017; Katoh et al., 1999) and IPCC default values.

2.2.3 Animal manure and synthetic fertilizer inputs to agricultural soils

Organic nitrogen inputs to agricultural soils mainly come from animal manure. Total N inputs to agricultural soils from synthetic fertilizer have been calculated based on the estimated usage of fertilization rate per major crop type in Chiang Mai and the associated land area.

Data from several information sources was used as detailed in the Methodology Report. The OAE provides statistics on the total amount of synthetic fertilizer used per major crop category[6] 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, Diammonium phosphate (DAP), Ammonium Sulphate, etc.) assuming a homogenous distribution of fertilizers by province.

Other inputs to agricultural soils are crop residues returning to soils, compost, sewage sludge, wastewater effluent, and mineralisation 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:

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[1] FAOSTAT – *Food and Agriculture data*

[2] IFASTAT – *International Fertilizer Association*

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

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

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

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

- Cheewaphongphan et al. (2018); Khonpikul et al. (2017)
- The national emission inventory[7]
- Phairuang et al., 2017
- IPCC 2019 default values

2.2.4 Field burning of agricultural residues

The quantity of residues available for burning has been estimated using the IPCC 2019 methodology for crop residues estimation. Moreover, agricultural residue burning was estimated only for annual crops (Maize, Rice, Soybean and Cassava) accounting for 63% of Chiang Mai harvested area.

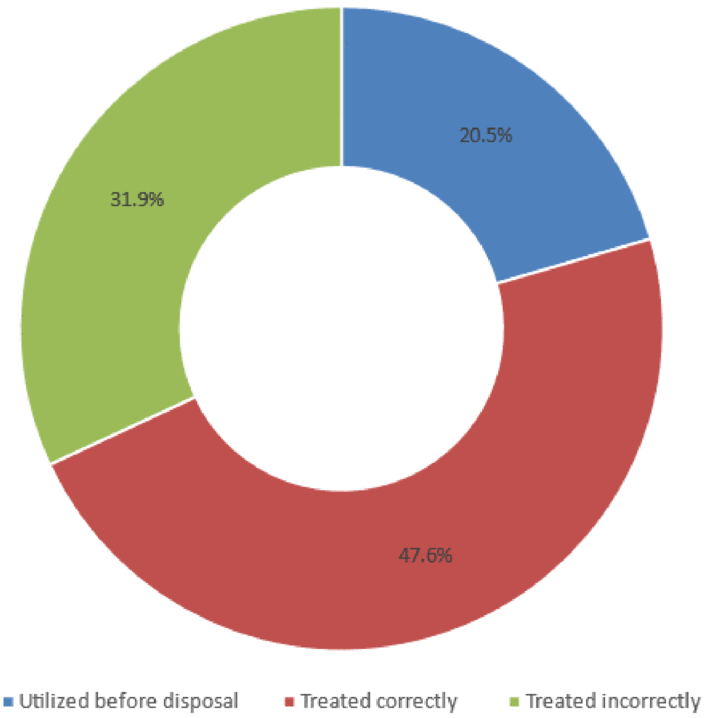
2.3 WASTE

The total amount of municipal solid waste (MSW) generated in Chiang Mai was compiled from various editions of the 'Reports on the Current Status of Municipal Solid Waste Management in Thailand,' published by the Pollution Control Department (PCD). A distinction was made between the quantities of waste produced in rural and urban areas. Assumptions regarding solid waste generation and treatment are based on Pansuk et al. (2018). In Chiang Mai Province, approximately 75% of MSW is collected, while the remaining portion is uncollected (Pansuk et al., 2018).

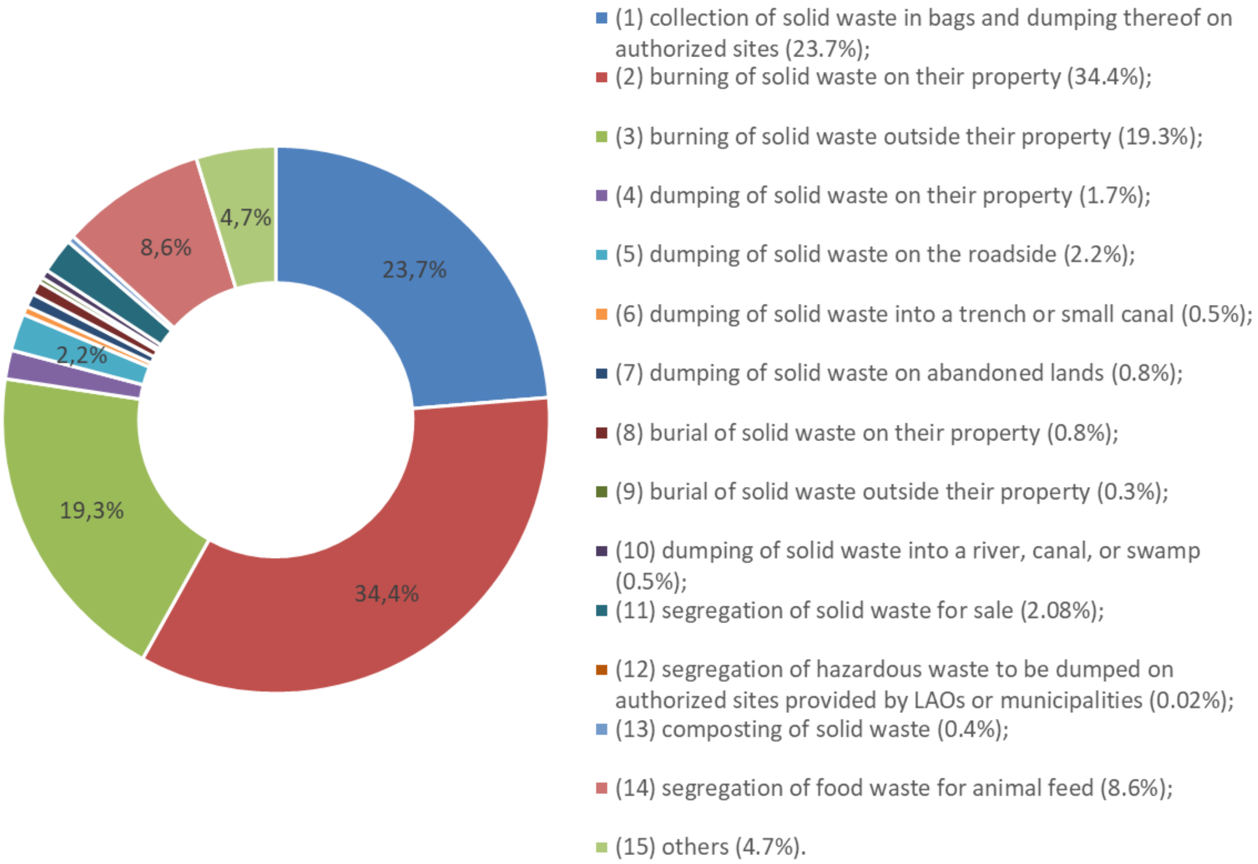
Regarding the management of collected municipal solid waste (MSW), it is assumed, in line with the Plastic Waste Management Action Plan (Phase II: 2023-2027), that 21% undergoes recycling before disposal, 48% is correctly treated, and the remaining 32% is treated incorrectly. It is further assumed that all MSW treated correctly is disposed of entirely in landfills. It should be noted that there are no MSW incinerators in Chiang Mai province, except for one dedicated to hospital waste. For the incorrectly treated portion of collected MSW, it is assumed that all of it is disposed of in open dumps. Additionally, it is presumed that no open burning occurs for the collected MSW.

With regard to uncollected municipal solid waste (MSW), households employ 15 different methods for waste disposal, as identified by Pansuk et al. (2018) (Figure 2). These methods were determined based on interviews with 4,300 households located in areas lacking MSW collection and disposal services across Thailand (Pansuk et al. 2018). Of the uncollected MSW, 53.7% is burned, a figure used to calculate the total amount of MSW subject to burning in Chiang Mai.

[7] *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]*



(A) Treatment pathways concerning the collected part of MSW generated



(B) Methods employed by the households to get rid of the wastes for the uncollected part of MSW generated

FIGURE 2: TREATMENT PATHWAYS CONCERNING THE COLLECTED (A) AND UNCOLLECTED (B) PARTS 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) looks like:

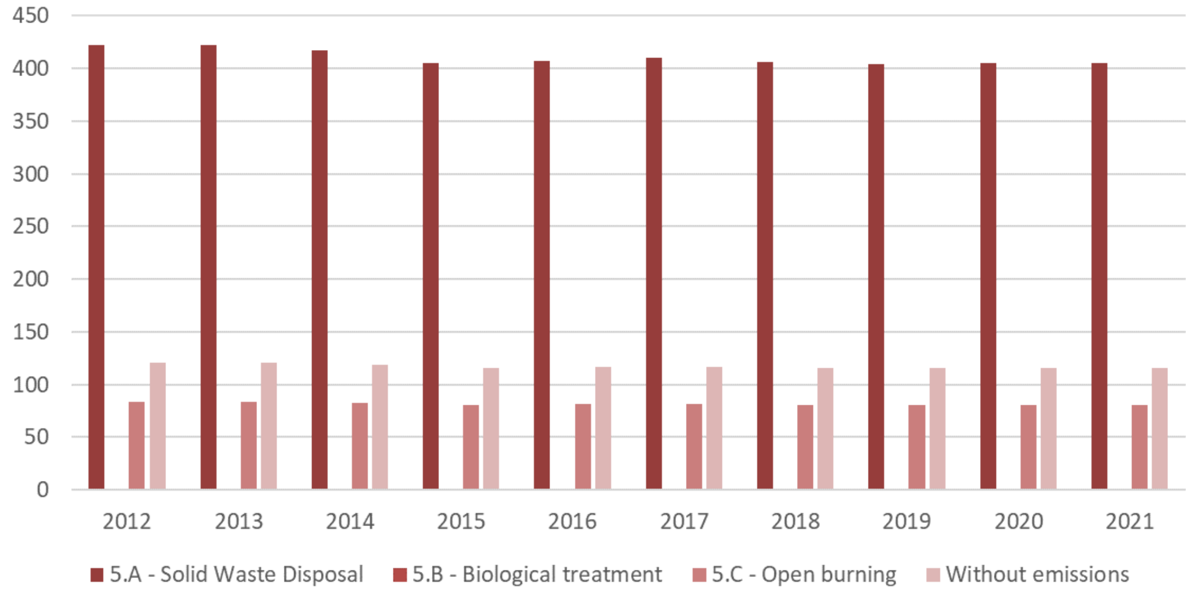


FIGURE 3: TOTAL AMOUNT OF MUNICIPAL SOLID WASTE PER TYPE OF TREATMENT (kT). 5A: DISPOSAL SITES, 5B: COMPOSTING AND METHANISATION AND 5C: OPEN-BURNING.

In 2021, the total amount of MSW burnt is estimated at about14% 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. A survey in Chiang Mai province on residents' waste disposal habits would enable a better assessment of the fraction of MSW open burning.

2.4 ENERGY SECTOR (EXCLUDING TRANSPORT)

The energy sector (excluding transport) includes emissions linked to the energy consumption by the energy industries (energy producers: power stations, oil refineries, and the production of solid, liquid, and gaseous fuels in particular), the manufacturing industries, as well as energy consumption by the residential/commercial sector and agriculture. There are also 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);
- Domestic cooking, heating, and lighting;
- Commercial cooking, heating, and lighting;
- Public Service;
- Construction, Fishing and Agriculture Machineries;
- Diesel generators;
- 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** (Ministry of Energy of Thailand). The data available in the National Energy Balance are more aggregated than the listed above, which give the energy consumption for Industry, Residential, Commercial, agriculture, construction, etc. At provincial scale, less data is available regarding fuel/energy consumption. Thus, the National Energy Balance is used and extrapolated at provincial scale using specific proxies (population, cropland area…) in most of the cases. Nevertheless, some sources, such as refineries and public power plants, do not operate in Chiang Mai.

2.5 ROAD TRANSPORT

The activity data associated with both abrasion and combustion emissions is related to the distance travelled by the vehicles fleet. Vehicles are classified per type (High Duty Vehicles (HDV), personal cars, two wheelers…), per type of fuels used and per technology.

The composition of the vehicles fleet was determined based on a traffic survey managed by EGIS in cooperation with the Chiang Mai University (Figure 4 and Figure 5) conducted in September 2023 (EGIS, 2023). More details about the vehicle fleet are presented in a dedicated report "Air Quality Improvement in Thailand – Output 4, Part1: Composition of the technological fleet in Chiang Mai" published in December 2023.

The estimated average annual distances travelled by vehicles are based on the results of the traffic model produced by EGIS. The model is based on road counts carried out in the Chiang Mai Metropolitan area, which were then extrapolated to the entire province.

As shown on Figure 4 (left), motorcycles are the main vehicles on the roads in Chiang Mai. They account for 61% of the vehicle fleet. Passenger cars account for 22%, light duty vehicles (LDV) for 15% and heavy commercial vehicles (plus buses and coaches) for 2% of the fleet. The situation is different if we examine the number of kilometers traveled per vehicle, as motorcycles generally travel fewer kilometers than other vehicle types. Indeed, in the figure on the right, the number of kilometers traveled by motorcycles and passenger cars is fairly similar (around one third), while LDV account for 23% of kilometers traveled in the province, with HDVs and buses/coaches accounting for the final 8%.

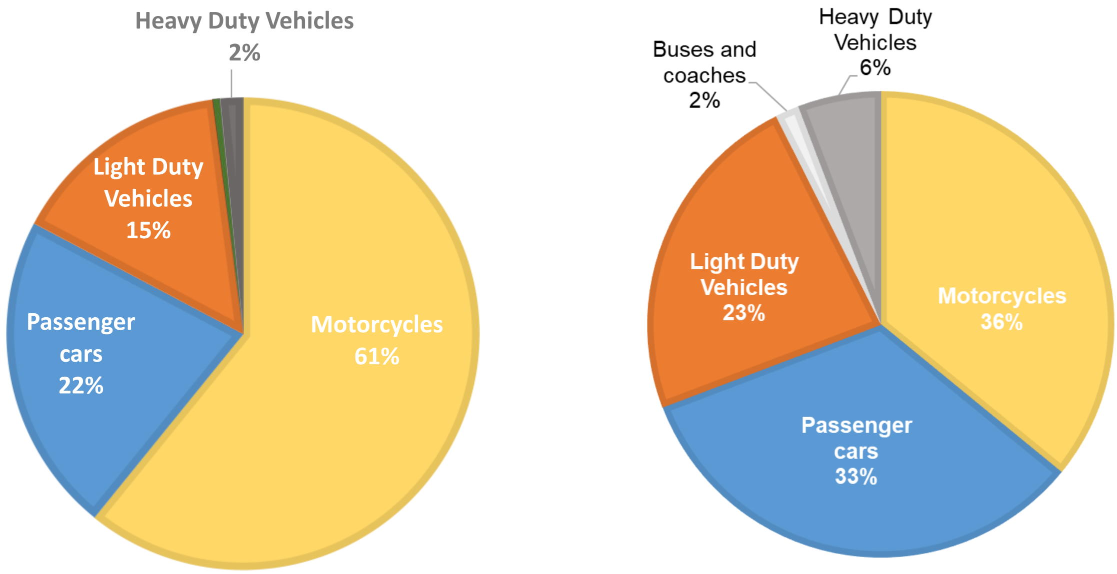


FIGURE 4: FLEET COMPOSITION.
LEFT: PERCENTAGE OF IN-USE VEHICLES PER TYPE IN CHIANG MAI PROVINCE.
RIGHT: PERCENTAGE OF VEHICLES-KILOMETER (IN USED) PER TYPE (2023)

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) as shown in Figure 5.

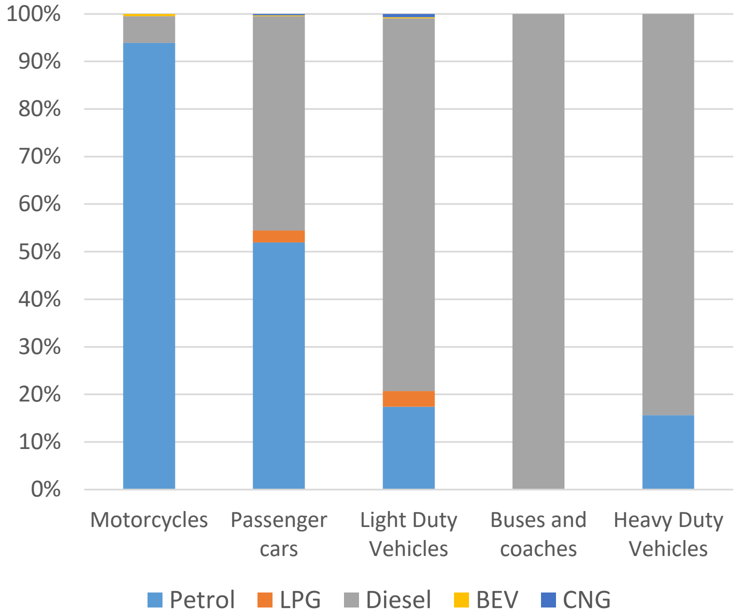
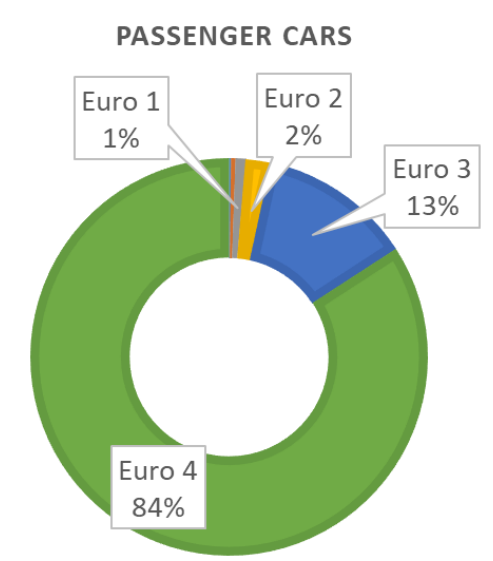
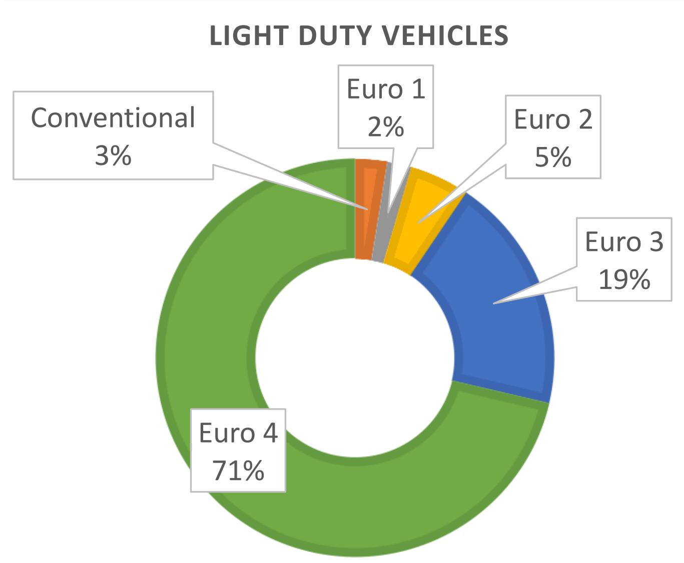


FIGURE 5: PERCENTAGE OF FUEL USED PER TYPE OF IN-USE VEHICLES.
(LPG: LIQUEFIED PETROLEUM GAS; BEV: BATTERY ELECTRIC VEHICLES, CNG: COMPRESSED NATURAL GAS)

As shown in Figure 6, 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 of personal cars are Euro 4 (84%). The remaining personal cars vehicles fleet is composed of Euro 3 (13%) and lower (remaining 3%). HDV are mainly represented by Euro III vehicles (but an additional survey would be necessary for HDV and buses). Still 17% of HDV are associated with conventional engines which are strong particles emitters.





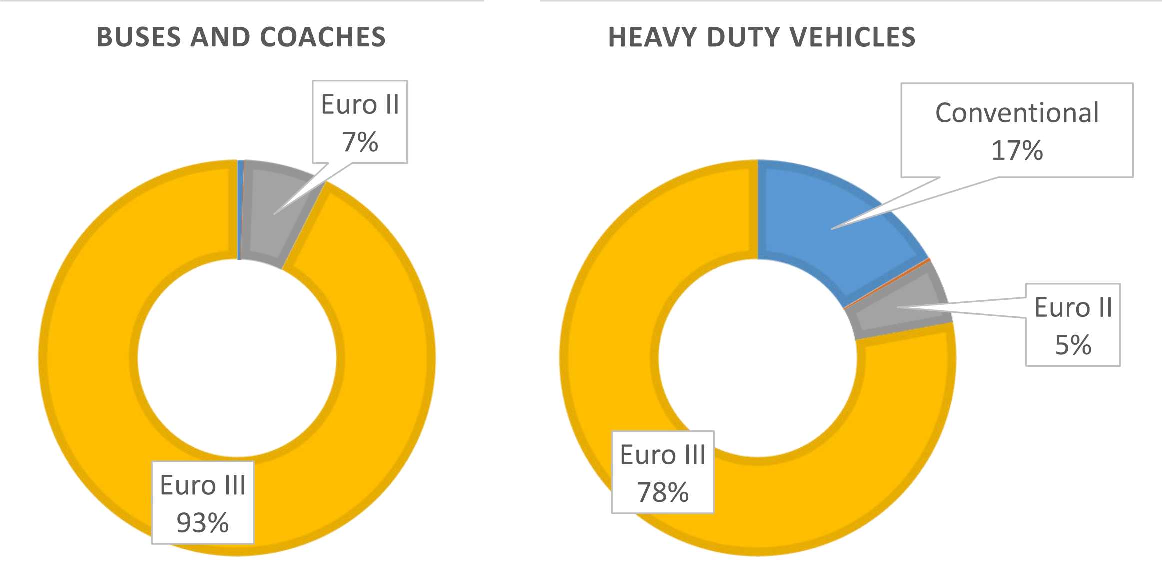


FIGURE 6: FLEET COMPOSITION PER EURO NORMS IN CHIANG MAI PROVINCE

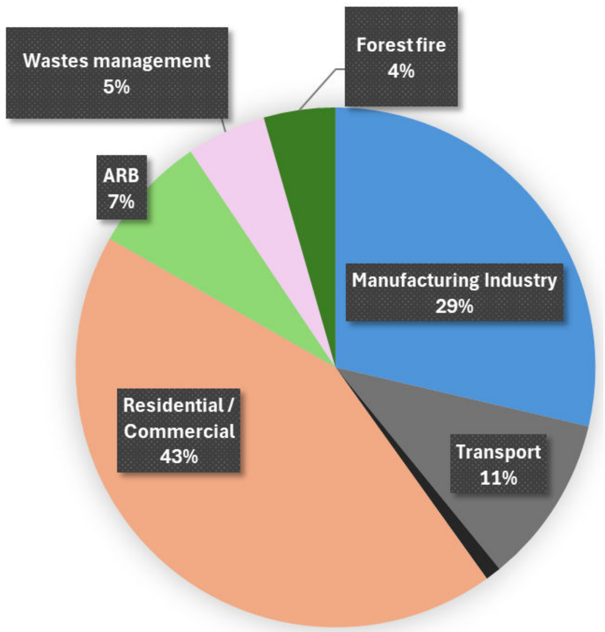
3 MAIN EMISSION SOURCES PER SUBSTANCE

3.1 ACIDIFICATION, EUTROPHICATION AND PHOTOCHEMICAL POLLUTION

3.1.1 Sulphur dioxide (SO_2)

In Chiang Mai, the SO_2 emissions are mainly produced by the combustion of sulfur-containing fossil fuels: Manufacturing industry and residential/commercial were the main sources of SO_2 emissions and to a lesser extent were for transport, forest fires, Agricultural Residue Burning (ARB) and waste management, mainly waste open-burning (Figure 7).

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.



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: MAIN SO_2 EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN TONS/YEAR

Figure 8 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.

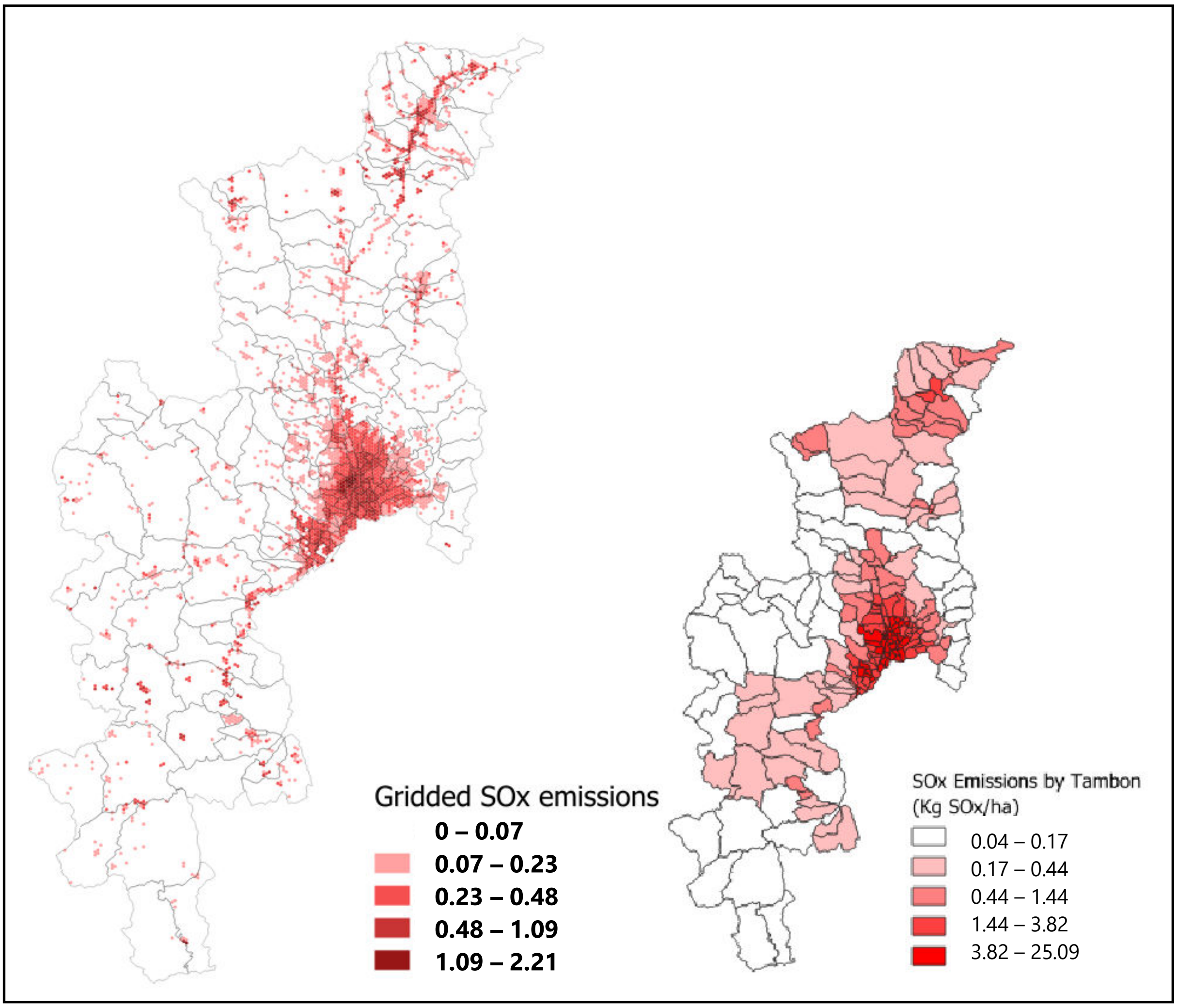


FIGURE 8: SPATIAL DISTRIBUTION OF TOTAL SULPHUR OXIDES (SOX) EMISSIONS IN CHIANG MAI

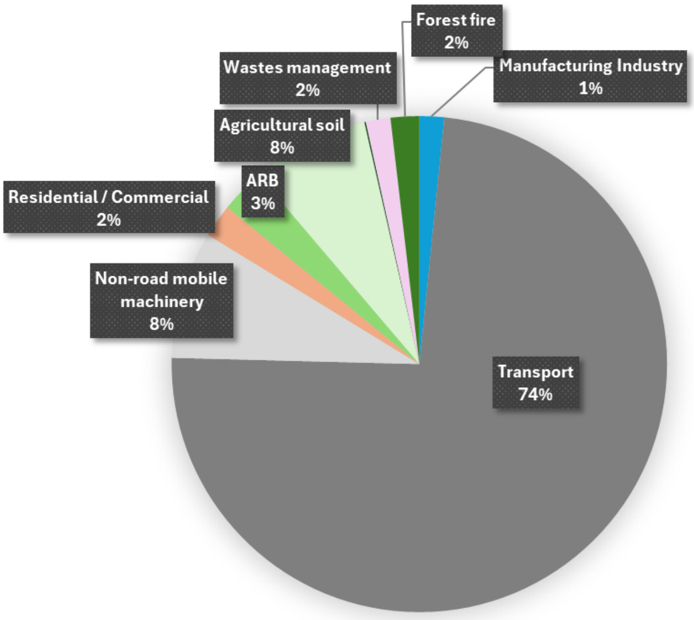
3.1.2 Nitrogen oxide (NOx)

NOx are emitted during the combustion of fossil fuels or biomass in road transport, off-road vehicles and other machinery, 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 9). 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 manufacturing, etc.) which could not be determined in this report due to the lack of activity data on industrial production for these products. Nevertheless, industry sector is considered to be minor in Chiang Mai province in terms of NOx emission.

Moreover, 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.

Figure 10 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.



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: MAIN NOx EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN TONS/YEAR

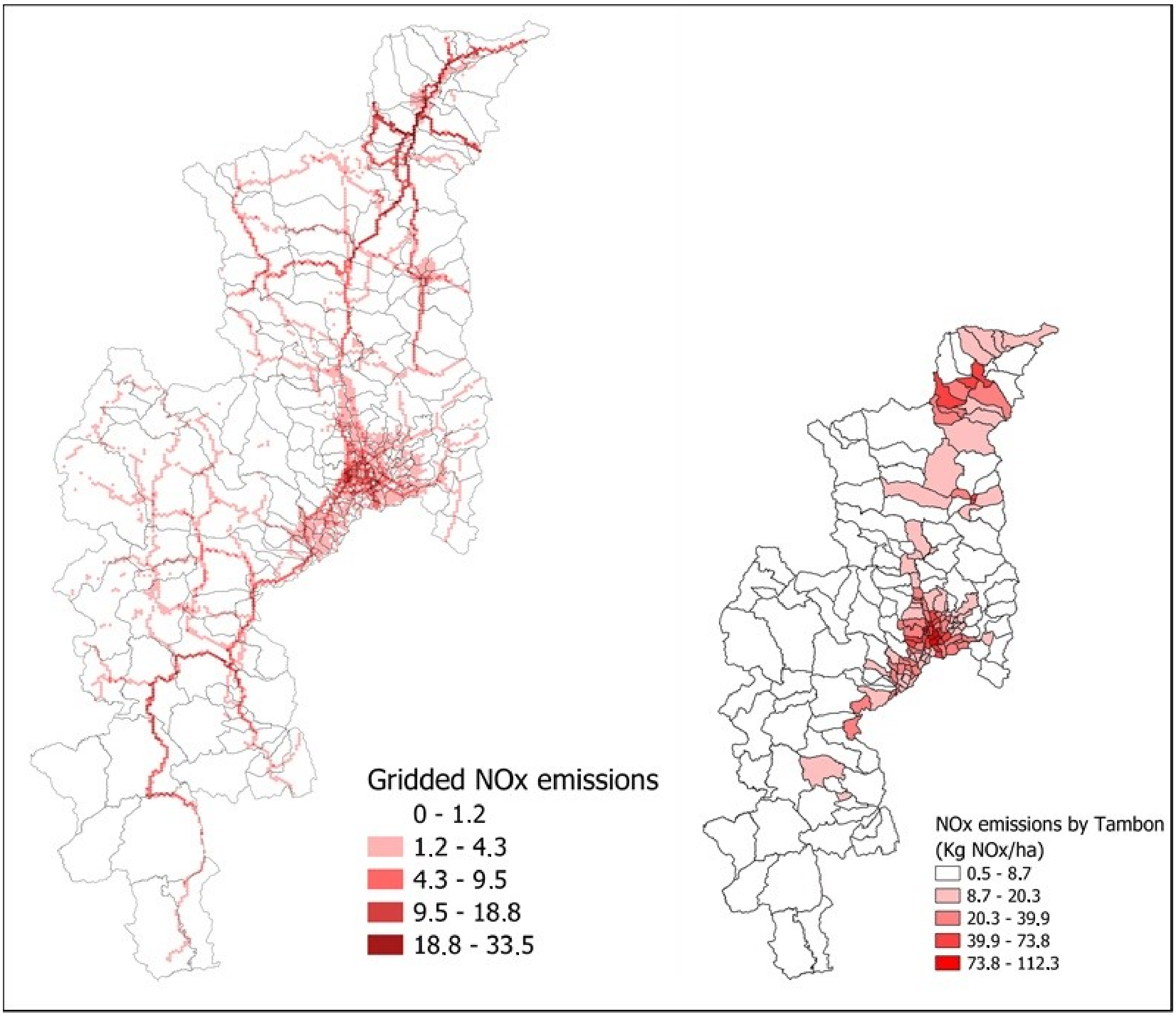
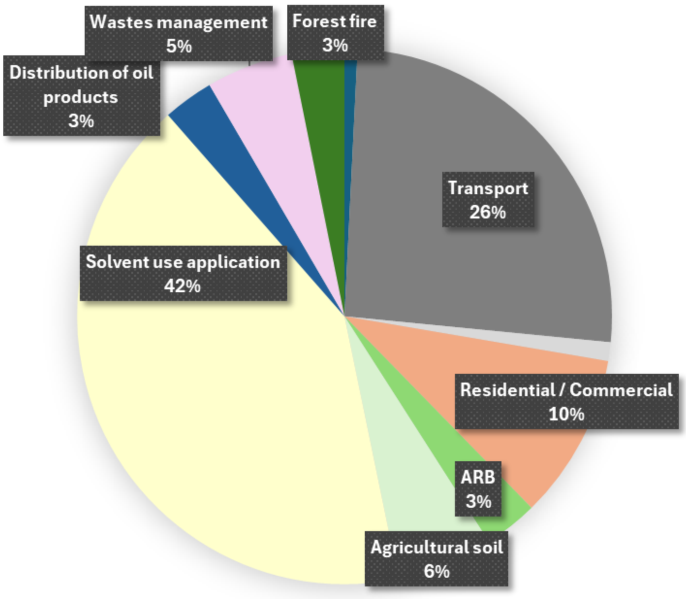


FIGURE 10: SPATIAL DISTRIBUTION OF TOTAL NITROGEN OXIDES (NOX) EMISSIONS IN CHIANG MAI

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 11:

- Industrial processes: in connection with the use of solvents (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).



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: EMISSIONS OF NMVOCs BY MAIN SECTORS IN CHIANG MAI PROVINCE IN % SHARE AND AMOUNT IN T/YEAR

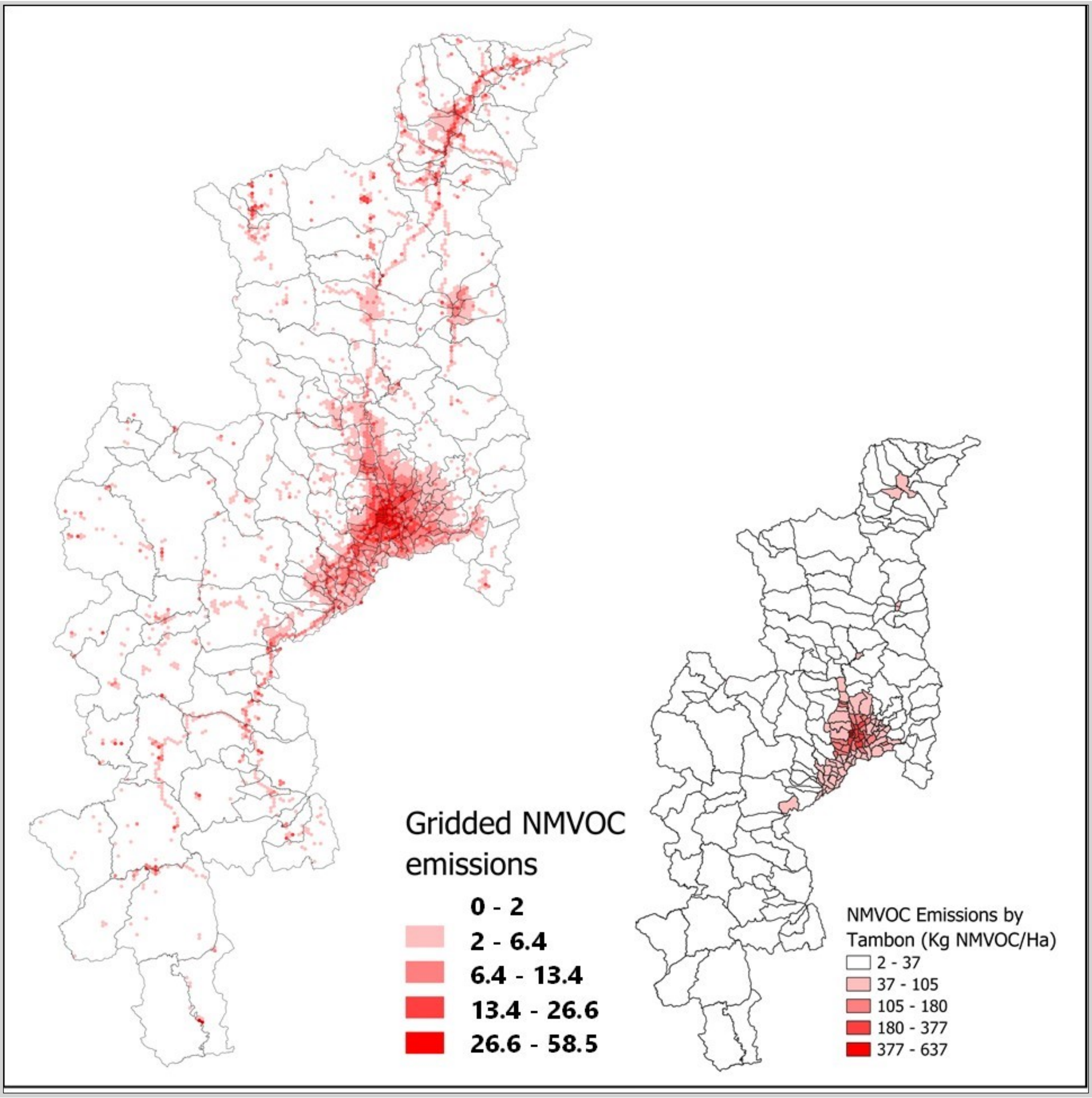


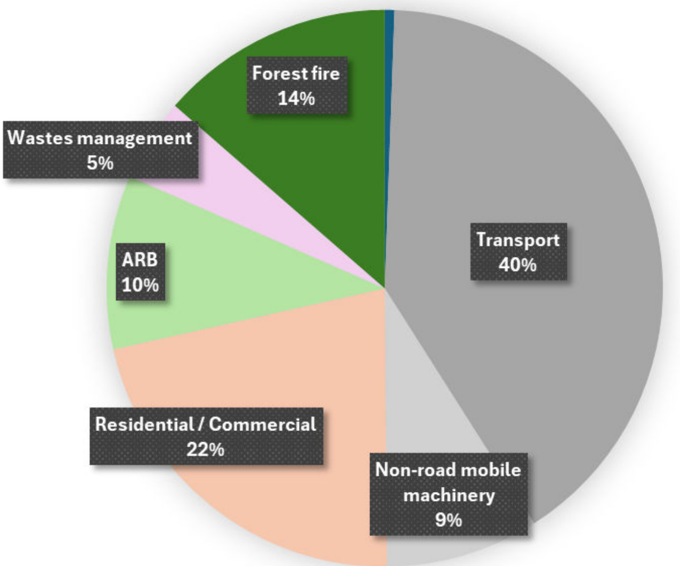
FIGURE 12: SPATIAL DISTRIBUTION OF TOTAL NON-METHANE VOLATILE ORGANIC COMPOUNDS (NMVOCS) EMISSIONS IN CHIANG MAI.

Figure 12 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.

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 responsible for 71% of CO emissions (Figure 13).
- Not controlled combustion from forest fires (14%), Agricultural residue burning (10%) and waste open-burning (5%) as shown in Figure 13.

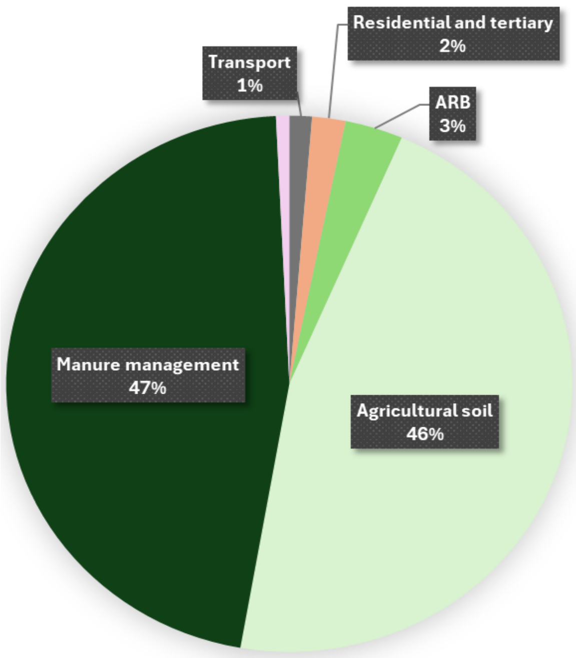


Sector (t/year)	2022
Manufacturing Industry	396
Transport	28,494
Non-road mobile machinery	6,272
Residential and Commercial	15,230
ARB	7,113
Waste management	3,393
Forest fires	9,594
Total	**70,492**

FIGURE 13: MAIN CO EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN T/YEAR

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 45% and 48% of the sector's emissions in 2022. Energy accounts for 3% of emissions in 2022, mainly due to residential/commercial sector in connection with biomass combustion (**FIGURE 14**). Agricultural residue burning and waste management account for the remaining emissions (about 4%).



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: MAIN NH_3 EMITTING SECTORS IN CHIANG MAI PROVINCE IN % AND IN TONS/YEAR

Figure 15 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.

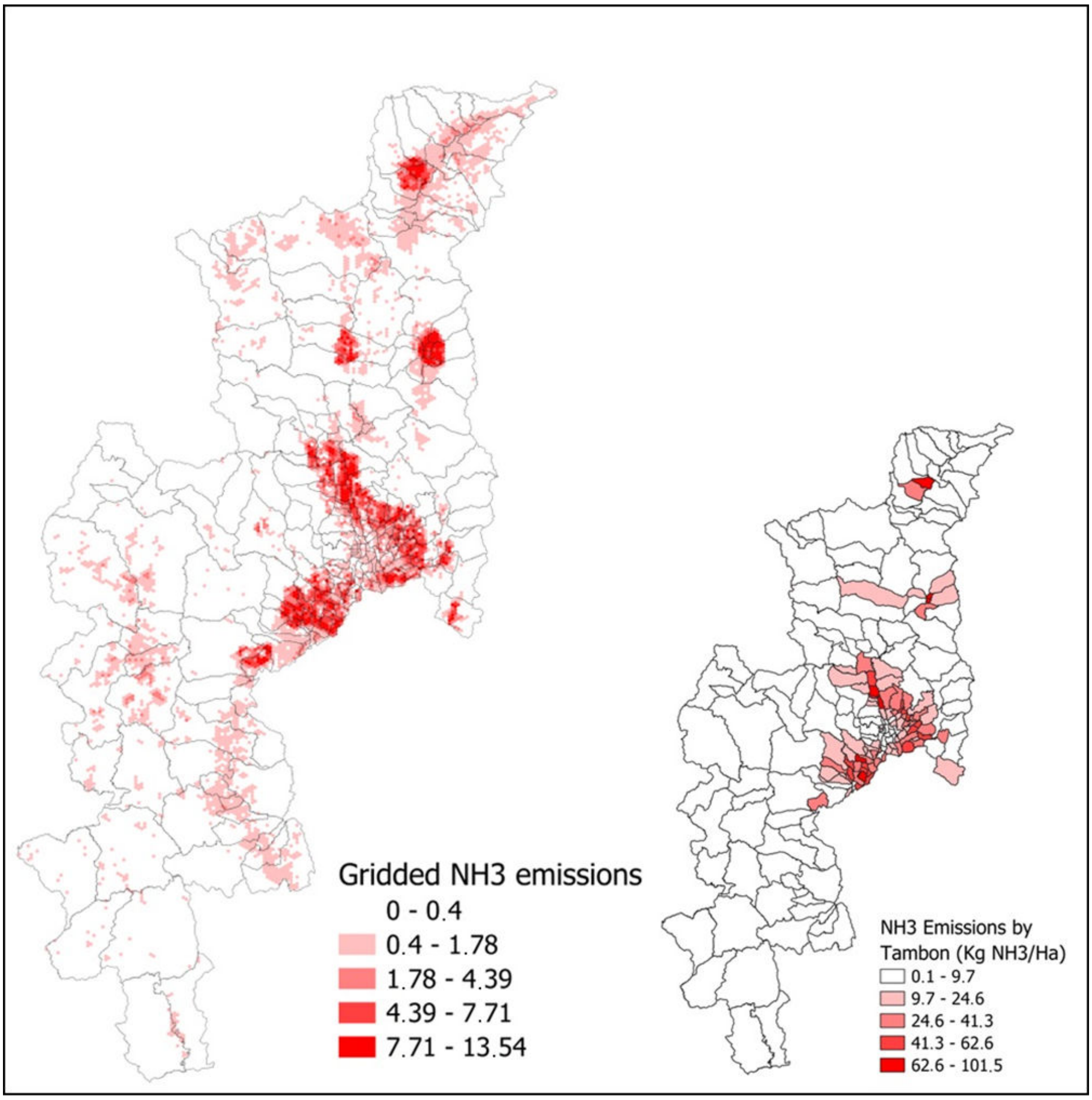


FIGURE 15: SPATIAL DISTRIBUTION OF TOTAL AMMONIA (NH_3) EMISSIONS IN CHIANG MAI

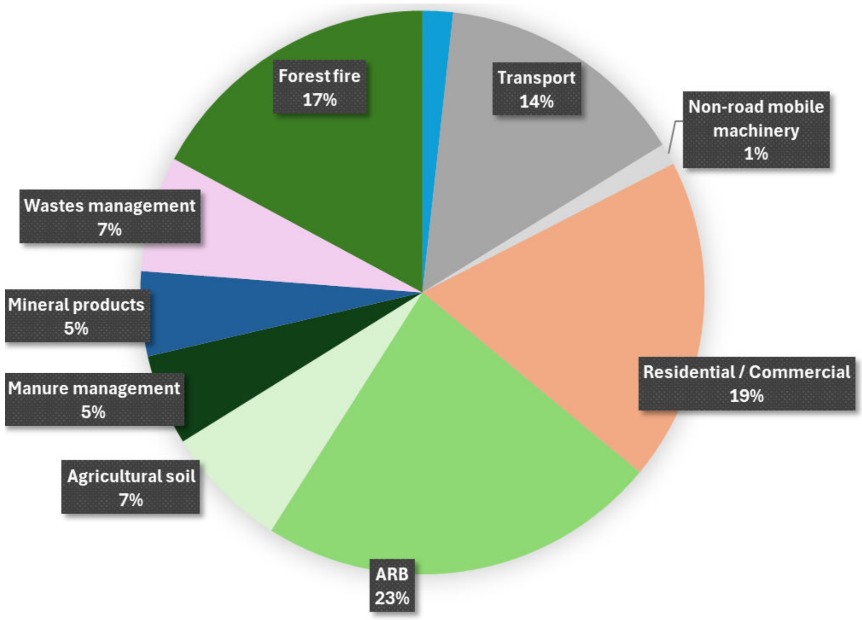
3.2 PARTICULATE MATTER (PM)

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 16) and 85% of $PM_{2.5}$ (Figure 18). 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 16 and Figure 18). 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 17 and Figure 19).

3.2.1 Particles PM_{10}



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: EMISSIONS OF PM_{10} BY MAIN SECTORS IN CHIANG MAI PROVINCE IN % AND TONS/YEAR

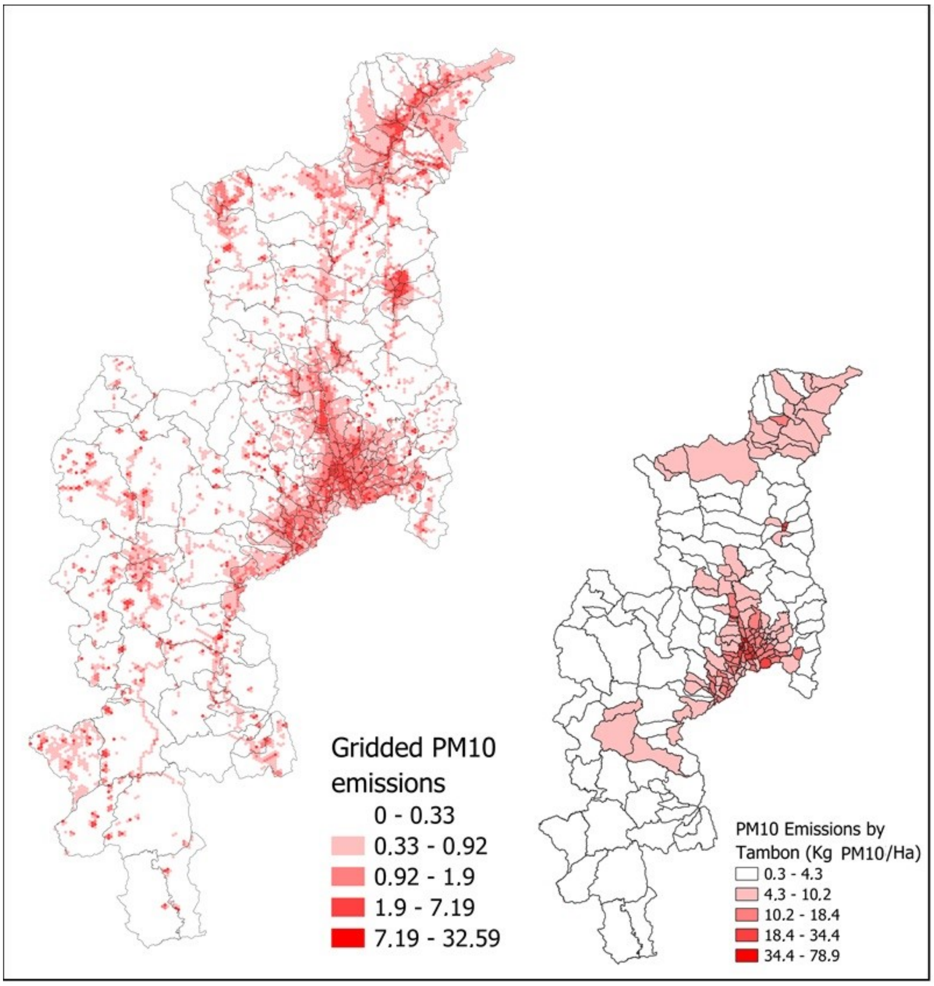
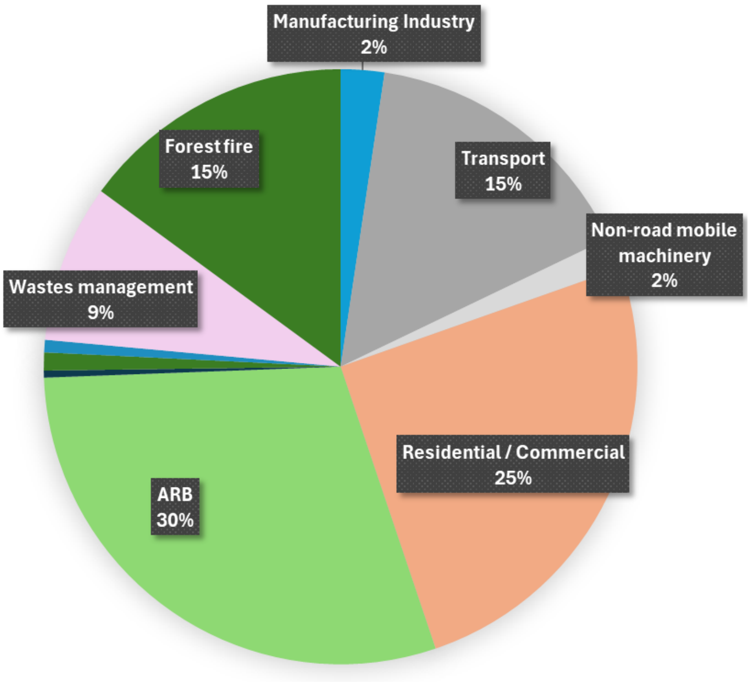


FIGURE 17: SPATIAL DISTRIBUTION OF TOTAL PARTICLES (PM_{10}) EMISSIONS IN CHIANG MAI

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 (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**

FIGURE 18: EMISSIONS OF $PM_{2.5}$ BY MAIN SECTORS IN CHIANG MAI PROVINCE IN % AND TONS/YEAR

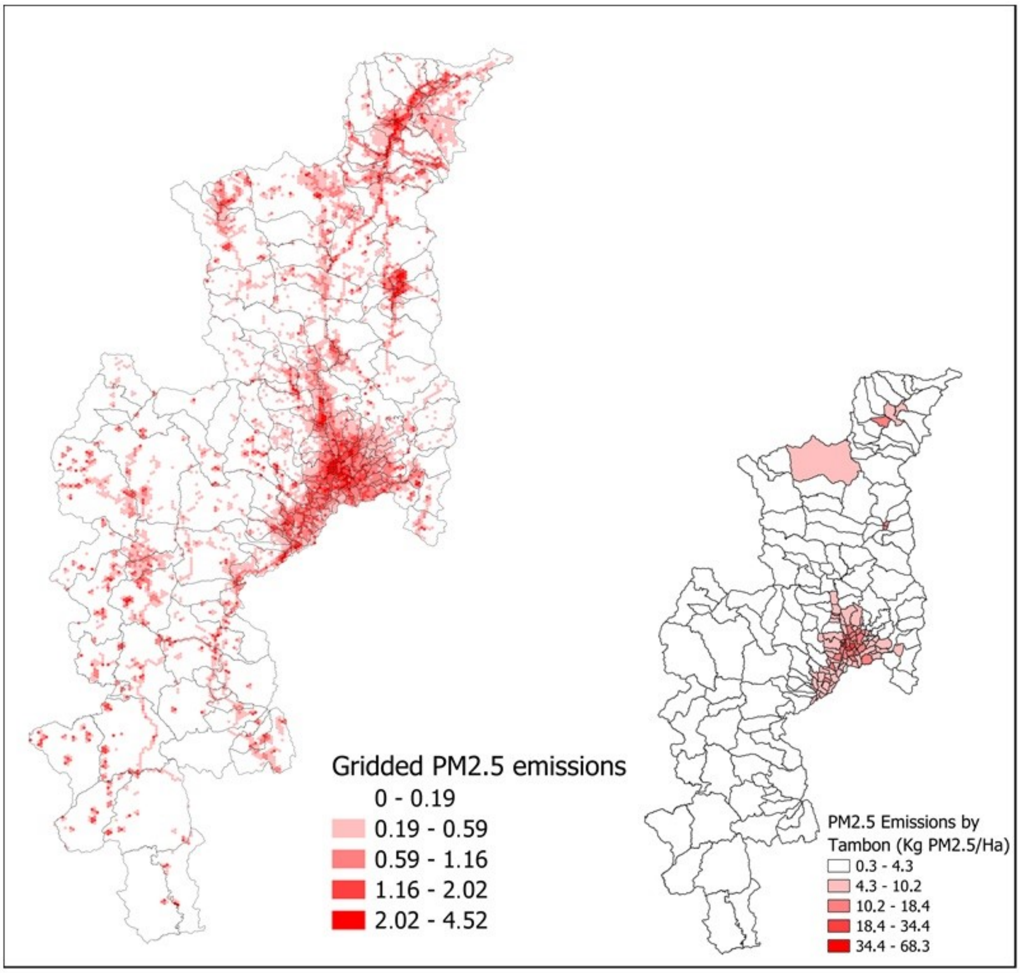
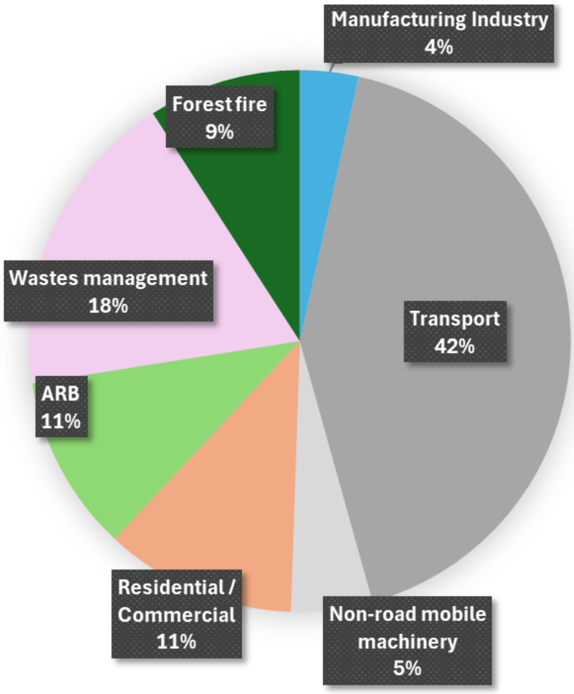


FIGURE 19: SPATIAL DISTRIBUTION OF TOTAL PARTICLES ($PM_{2.5}$) EMISSIONS IN CHIANG MAI

3.2.3 Black Carbon (BC)

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 20).



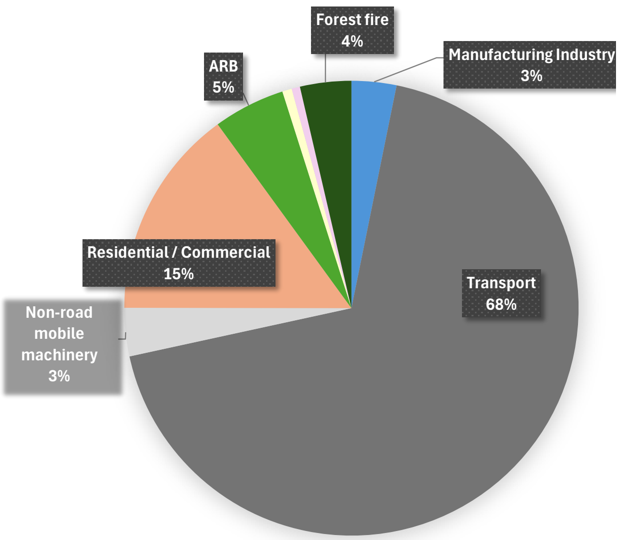
Sector (t/year)	2022
Manufacturing Industry	27
Transport	326
Non-road mobile machinery	38
Residential/Commercials	88
ARB	81
Waste management (open-burning)	142
Forest fire	71
Total	**773**

FIGURE 20: EMISSIONS OF BC BY MAIN SECTORS IN CHIANG MAI PROVINCE IN % AND TONS/YEAR

3.3 GHGS

3.3.1 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 21.



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: EMISSIONS OF CO_2 BY MAIN SECTORS IN CHIANG MAI PROVINCE IN % AND TONS/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 22).

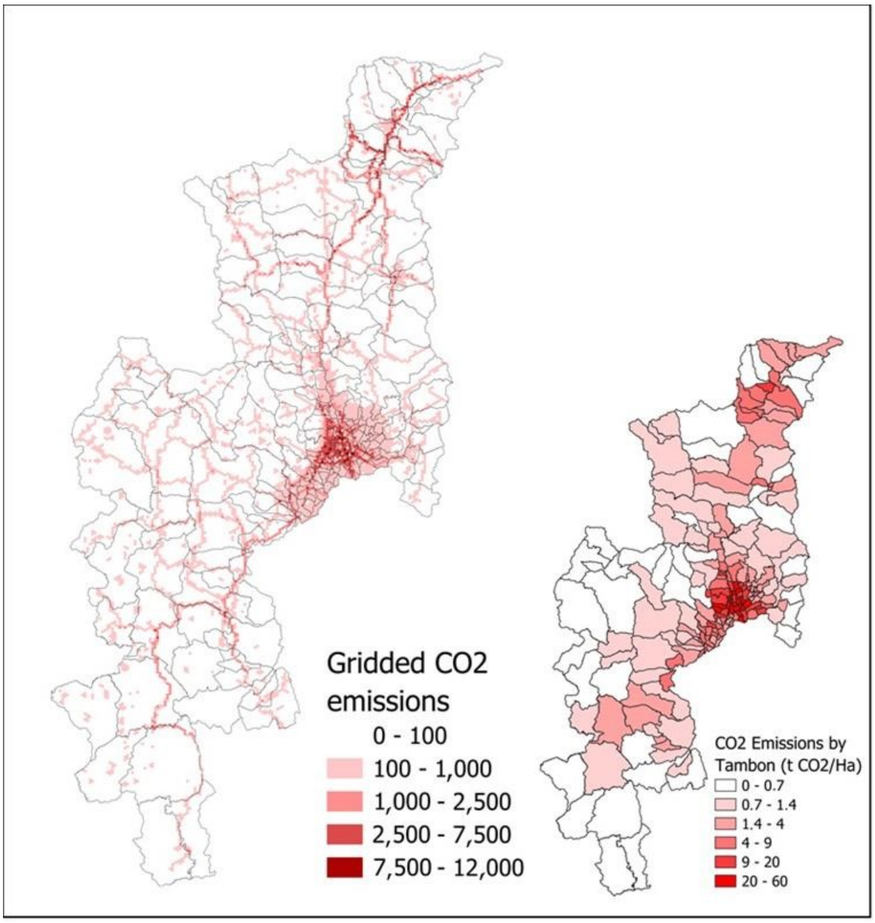
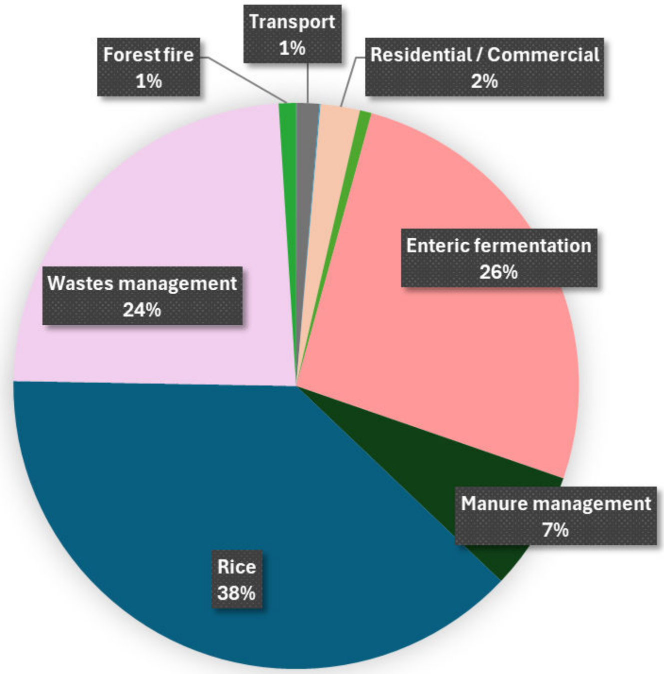


FIGURE 22: SPATIAL DISTRIBUTION OF TOTAL CARBON DIOXIDE (CO2) EMISSIONS IN CHIANG MAI

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 23).

Methane emissions are mainly due to agriculture and waste management and are therefore distributed throughout rural and urban areas (Figure 24).



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: EMISSIONS OF CH_4 BY MAIN SECTORS IN CHIANG MAI PROVINCE IN % AND TONS/YEAR

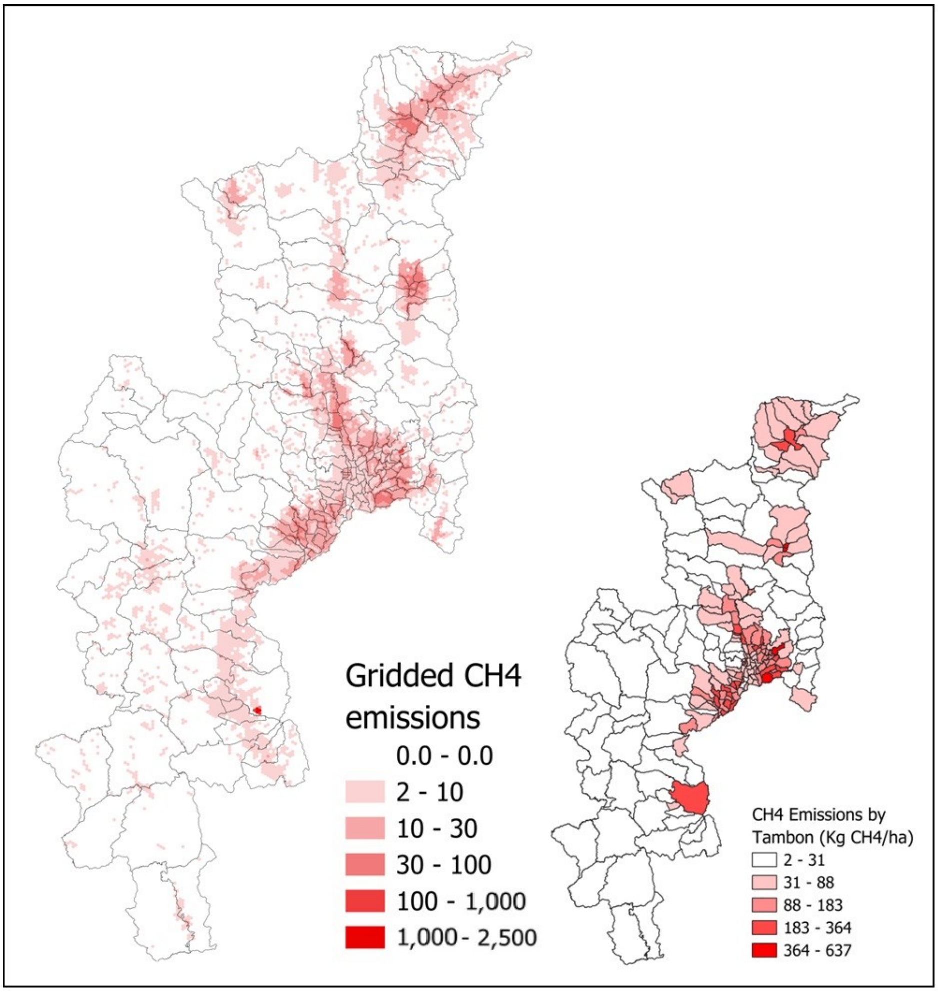


FIGURE 24: SPATIAL DISTRIBUTION OF TOTAL METHANE (CH4) EMISSIONS IN CHIANG MAI

3.4 WHAT ARE THE MOST EMITTING SOURCES OF AIR POLLUTANTS IN CHIANG MAI PROVINCE 2022

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 PM2.5 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 PM2.5 during smoke-free periods.

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.

Regarding GHGs (Figure 26), 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

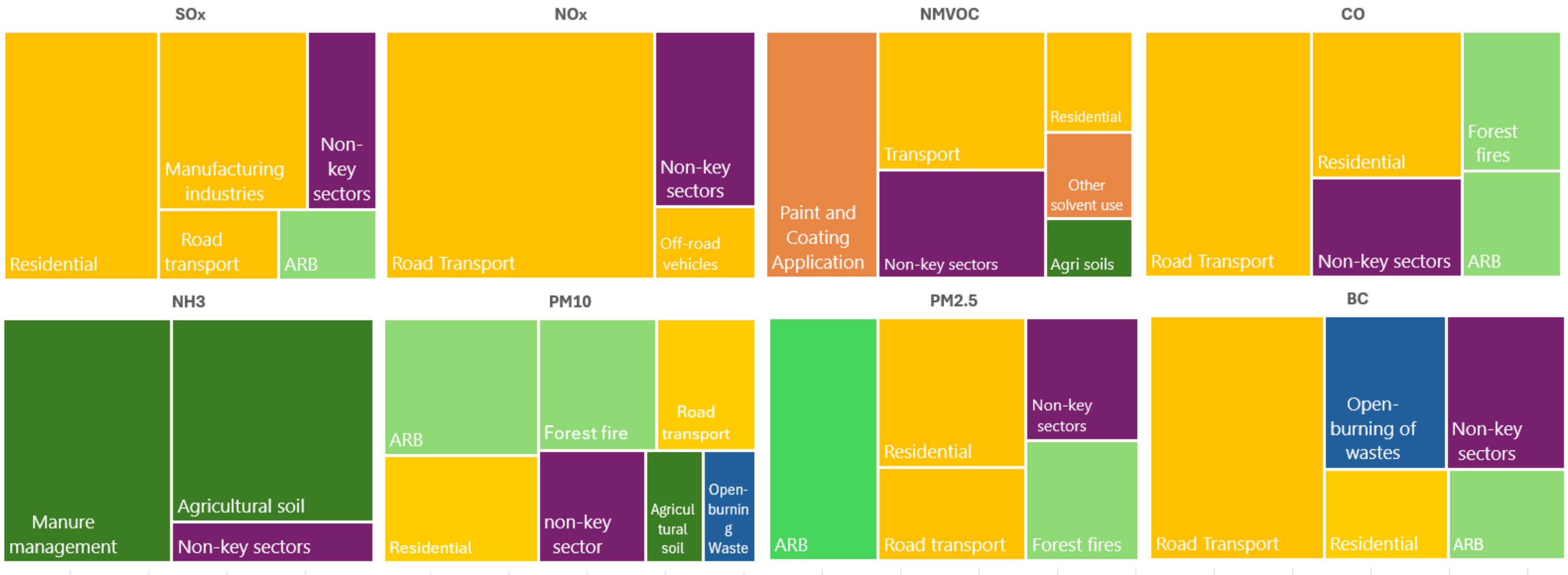


FIGURE 25: KEYS SOURCES OF AIR POLLUTANTS IN CHIANG MAI PROVINCE

3.4.2 GHGs

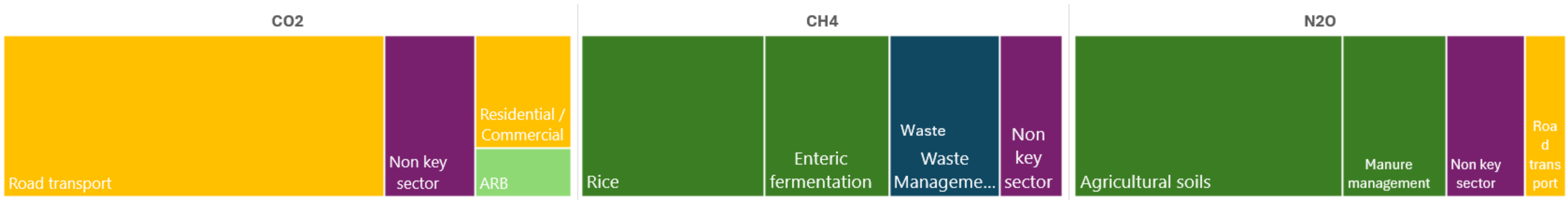


FIGURE 26: KEYS SOURCES OF GHG IN CHIANG MAI PROVINCE

4 POLICIES AND MEASURES TO SETTLE BASED ON EI ANALYSIS

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, this Chapter targets $PM_{2.5}$ and its precursors and policies and actions to effectively tackling the region's air quality problems.

4.1 MEASURES TO REDUCE EMISSIONS FROM BIOMASS BURNING

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. Indeed, open burning (ARB, Waste open-burning and forest fire) is responsible for 47%, 53%, 38% and 58% of PM_{10}, $PM_{2.5}$, BC and OC of annual total emissions in 2022 in Chiang Mai (Figure 27).

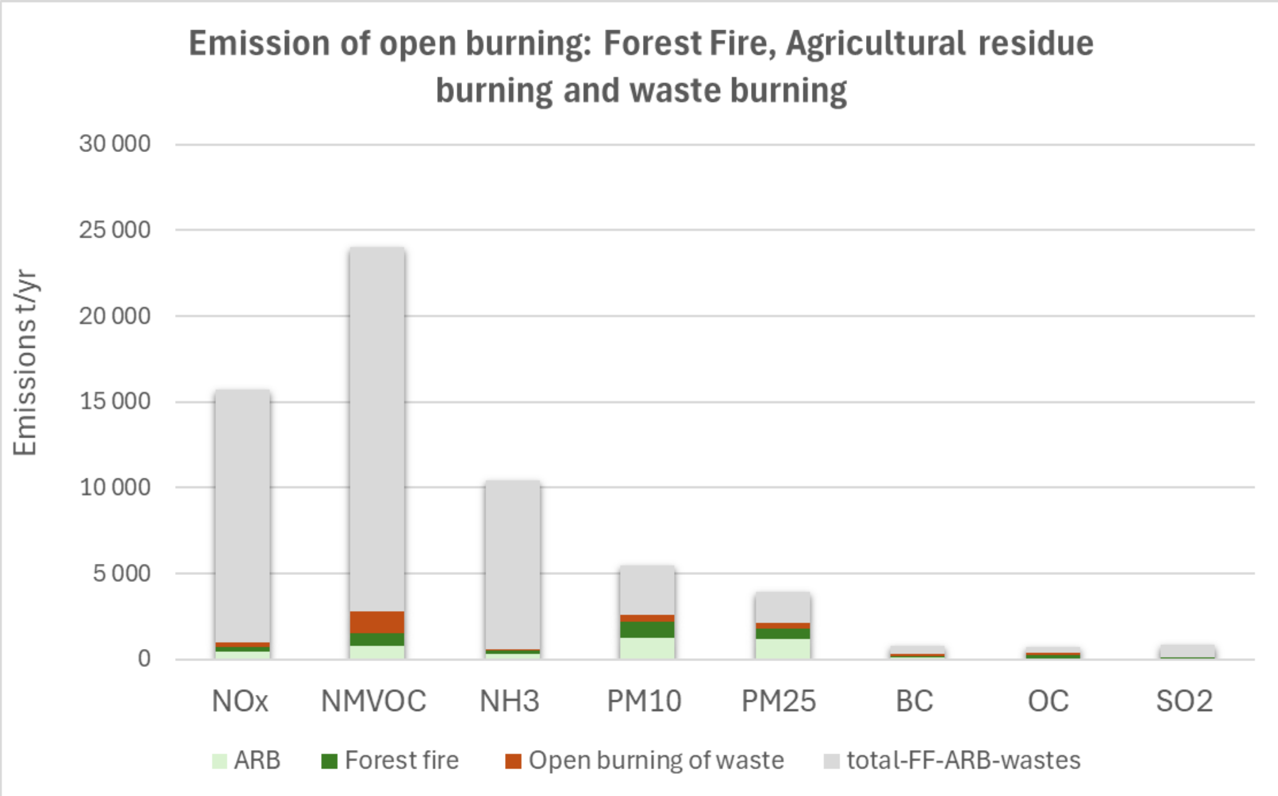


FIGURE 27: EMISSIONS OF AIR POLLUTANTS FROM OPEN-BURNING: FOREST-FIRE, AGRICULTURAL RESIDUE BURNING AND WASTE BURNING COMPARED WITH OTHER SECTORS

On an annual basis, biomass combustion is the primary source of fine particulate matter (PM2.5) emissions. Specifically, **53% of PM2.5 emissions are attributed to open burning**, with 30% resulting from agricultural residue burning (ARB), 17% from forest fires, and 9% from the open burning of waste (Figure 28).

Mitigation measures are being implemented by the Thai Government and the districts of Chiang Mai Province to reduce the impact of forest fires. The number of hotspots significantly decreased between 2020 and 2022 (Figure 1); however, it remains unclear whether this trend is attributable to weather conditions, forest fire mitigation efforts, or a combination of both.

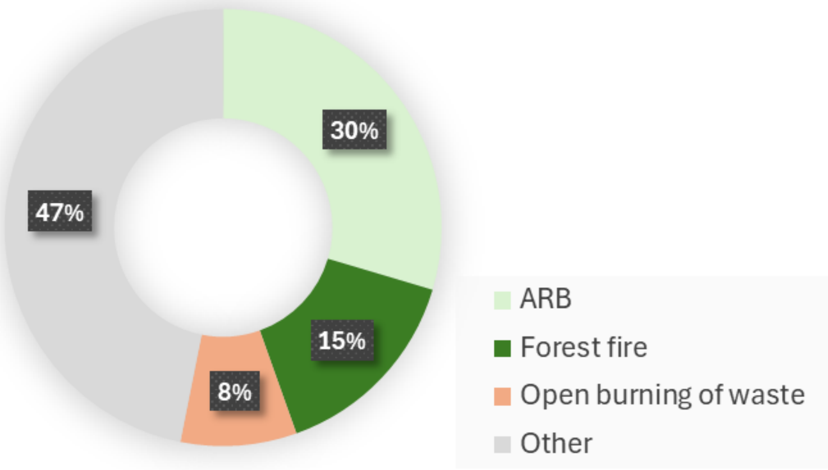


FIGURE 28: SOURCES OF PM2.5 WITH A FOCUS ON OPEN-BURNING

In Chiang Mai Province, open waste burning accounted for 8% of total $PM_{2.5}$ emissions in the base year 2022. This result is based on calculations involving several assumptions, with much of the data derived from national sources. Additionally, proxies such as population were used to estimate emissions specific to Chiang Mai Province. As illustrated in Figure 29, 14% of the total waste generated in 2022 was either burned outdoors or incinerated (hospital waste), contributing significantly to PM emissions from waste management.

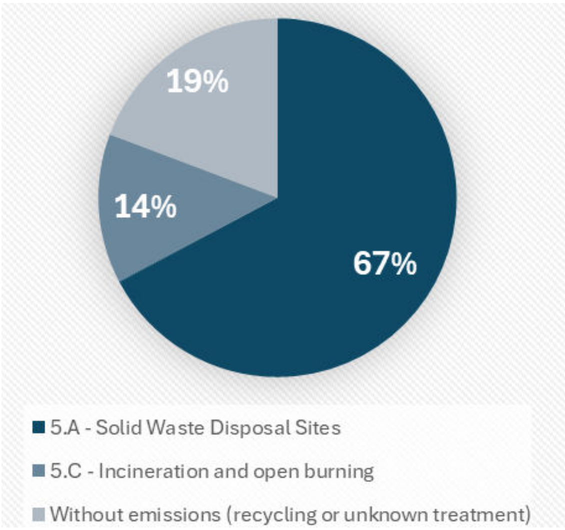


FIGURE 29: DISTRIBUTION BY TYPE OF SOLID WASTE TREATMENT IN CHIANG MAI

It would therefore be interesting to take this result a step further by estimating the amount of waste burnt specifically in Chiang Mai province. A survey could be set up to obtain better estimates of the quantity of waste burned. If this quantity is significant, measures should be taken to reduce this practice, which is a significant source of PM but is also easily avoidable.

4.2 MEASURES TO REDUCE EMISSIONS FROM ROAD TRANSPORT

Various measures can be implemented to mitigate the impact of road transport on air pollutant emissions, most of which are summarized in Table 1.

In this section, we will focus primarily on the results of the traffic survey and the insights that can be drawn from the composition of the vehicle fleet.

Indeed, as shown on Figure 4, Figure 5 and Figure 6:

- 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 4).
- 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 5).
- 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 6).

Figure 30 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.

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 non-motorized modes (cycling, walking) such as investments on infrastructures (construction of sidewalks and bike lanes, parking), urban planning and pedestrian-oriented development, education, and awareness-raising campaigns.

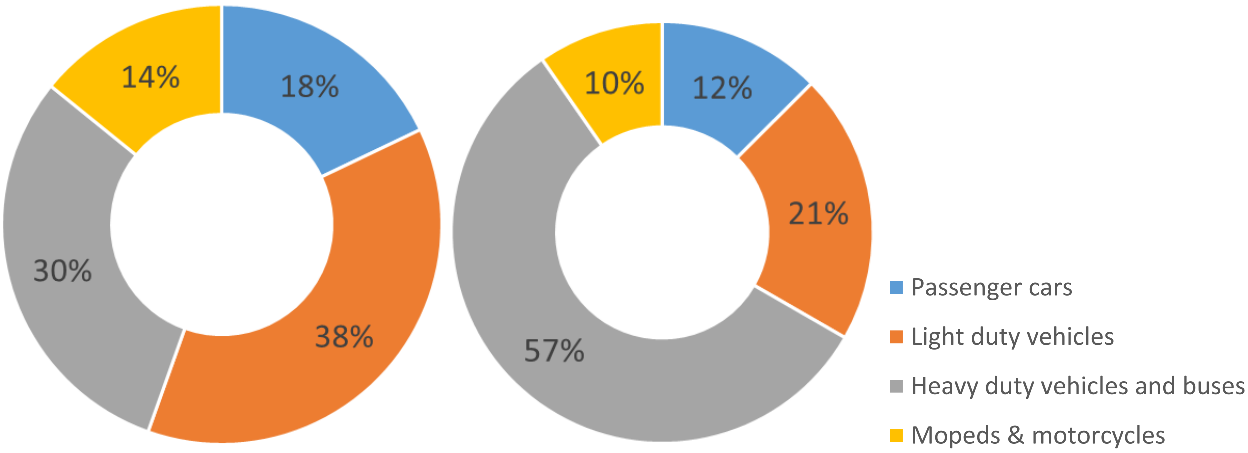


FIGURE 30: EMISSION OF PM2.5 AND NOx FROM ROAD TRANSPORT IN CHIANG MAI PROVINCE

Figure 31 illustrates the spatial distribution of NOx emissions by vehicle type: motorcycles, passenger cars, light-duty vehicles, and heavy vehicles. As depicted, emissions from motorcycles and passenger cars are concentrated in the city center, whereas emissions from light and heavy-duty vehicles are highest along major roads outside the city. Transitioning to electric power for two-wheelers could significantly reduce particulate and NOx emissions in urban areas.

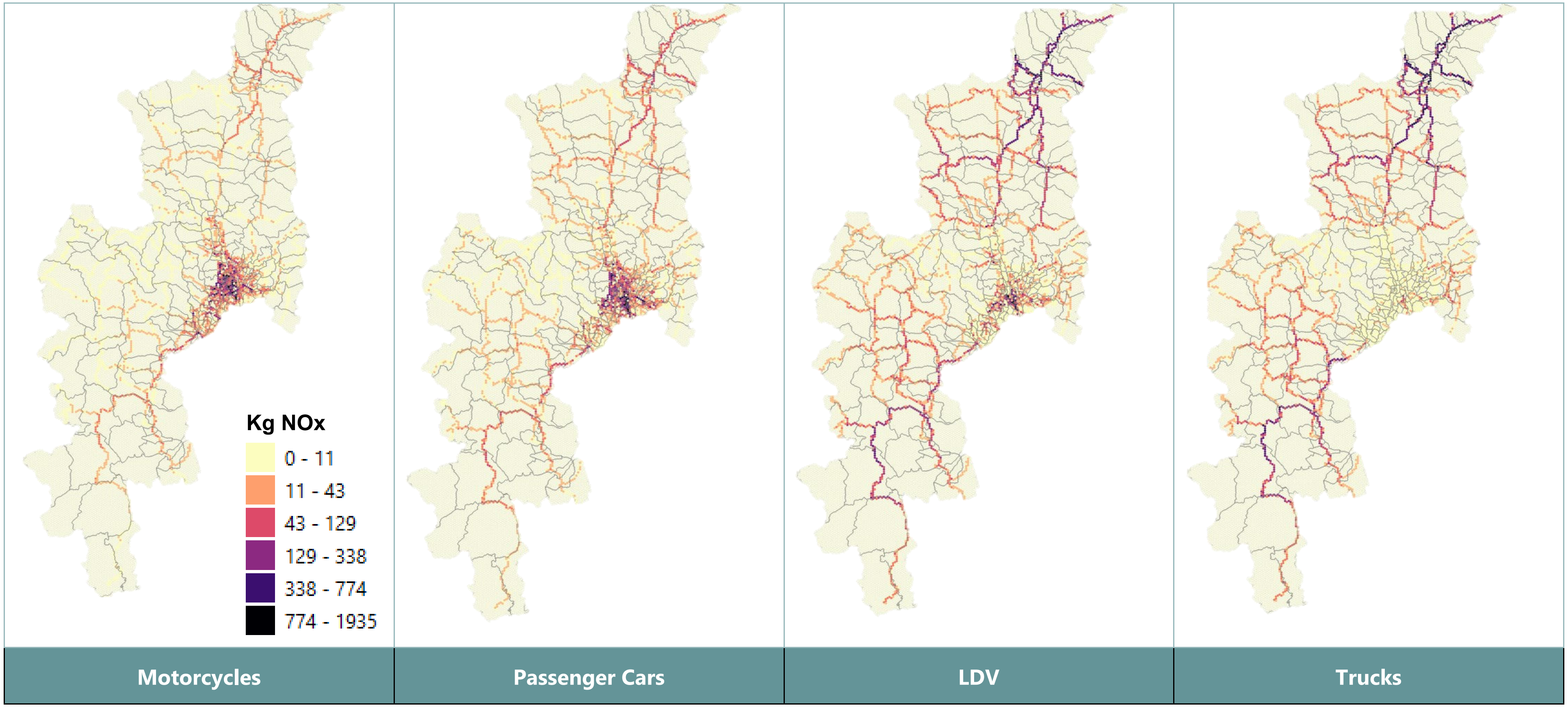


FIGURE 31: SPATIALISED EMISSIONS OF NO_x IN CHIANG MAI PROVINCE (KG OF NOX), IN 2022

4.3 MEASURES TO REDUCE AIR POLLUTION FROM ALL SECTORS – ACTIONS PLAN

As indicated in the inventory, particulate precursors (NH_3, SO_2 and NOx) are emitted by a variety of sectors. Therefore, it is crucial to reduce emissions across all sectors to improve air quality. Proposals for emission reduction measures in Chiang Mai Province are presented in Table 1.

Additionally, although not included in the table, it is vital to continually improve and update the emissions inventory by enhancing the accuracy of activity data and developing specific emission factors for Thailand. Establishing a better reporting system for industries would also contribute to improving the emissions inventory and monitoring trends over time. Enhanced emissions data would facilitate the accurate identification of key sources and enable the tracking of sectoral emissions over time.

By regularly updating the emissions inventory, authorities in Chiang Mai Province can utilize it as a tool for planning emission reduction strategies for both pollutants and greenhouse gases, as well as for evaluating the effectiveness of implemented actions and policies.

TABLE 1: MEASURES TO REDUCE AIR POLLUTION IN CHIANG MAI PROVINCE.
TIMELINE: S: SHORT (WITHIN 2 YEARS); M: MEDIUM (2-5 YEARS), L: LONG TERM (> 5 YEARS)

Sector	Action N°	Action	Timeline	Impact on Air pollution
Small and medium Industrial facilities	**IND 1**	Improvement of the database on industrial emissions and improvement of the emission calculation for this sector.	S	No direct impact
	IND 2	Capacity building for operators of industrial plants on pollution control systems, emissions monitoring, and reporting.	S; M	Medium
	IND 3	Regular inspections of small and medium-sized industrial installations by local authorities.	S; M	Medium
	IND 4	Strengthening of emission limit values and ensuring compliance with these standards.	M	High
	IND 5	Conducting surveys of craft villages to better assess fuel types and associated emissions.	S	Medium
Residential and commercial sector	**RES 1**	Financial incentives for replacing outdated residential equipment with modern, lower-emission alternatives. ▪ Transition from biomass/charcoal to LPG, natural gas (NG), or biogas in rural areas. ▪ Promote the use of electric stoves where feasible. ▪ Encourage street food vendors to switch from charcoal to LPG or NG.	S	Medium
	RES 2	Enhancement of fuel quality and increased inspections.	M	High
	RES 3	Awareness campaigns on indoor air pollution from residential combustion, its health impacts, and methods to improve domestic heating/	S; M	High on citizen exposure

Sector	Action N°	Action	Timeline	Impact on Air pollution
		cooking efficiency, as well as kitchen and home ventilation.		
	RES 4	Development of a best practices guide on wood and charcoal use for both professionals and the public.	M	Medium
	RES 5	Measures to alleviate fuel poverty: ensuring access to affordable clean energy	S; M	Medium
Transport	**TRA 1**	Gradual transition of public transport (buses, minibuses) and community service vehicles to lower-emission alternatives, such as CNG, electric vehicles, or those meeting Euro IV standards.	S; M	High
	TRA 2	Incentives for vehicle fleet renewal: ■ Financial support for scrapping older diesel vehicles. ■ Incentives for purchasing Euro 5 or electric vehicles.	S; M	High
	TRA 3	Implementation of Low Emission Zone in the City Centre.	S; M	High
	TRA 4	Promotion of soft mobility: development of pedestrian areas and bicycle lanes, and organization of events such as 'Pedestrian Sundays' to raise public awareness.	S; M	High
	TRA 5	Traffic management improvements.	S; M	Medium
	TRA 6	Street cleaning to reduce particle resuspension during dry conditions.	S	Medium
	TRA 7	Promotion of public transportation and the implementation of a Sustainable Urban Mobility Plan.	S; M	High
	TRA 8	Regular vehicle inspections to ensure compliance.	S; M	Medium
Agriculture	**AGR 1**	Reducing NH_3 emissions from poultry housing through improved manure management practices.	S; M	High
	AGR 2	Promotion of natural crust formation during manure storage for dairy cattle and other livestock.	M; L	High
	AGR 3	Adoption of low-emission fertilizer application techniques.	S	High

Sector	Action N°	Action	Timeline	Impact on Air pollution
	AGR 4	Implementation of Alternate Wetting and Drying (AWD) in rice cultivation to reduce CH_4 emissions, along with the use of biochar as a soil amendment, crop rotation, and other practices to minimize the need for synthetic fertilizers.	S, M	Medium
Agricultural Residue Burning	**ARB 1**	Mapping and monitoring to identify the burned area, utilizing both satellite and on-ground monitoring techniques.	S	Medium
	ARB 2	Education of farmers on soil quality, crop yields and the economic benefits of non-burning methods.	S; M	High
	ARB 3	Development of regulations in conjunction with farmer education and extension services, including potential incentives for adoption and equipment loan guarantees.	S; M	High
	ARB 4	Investigation of alternatives to agricultural residue burning (ARB) and their feasibility in Chiang Mai Province, including ex-situ uses of crop and forest residues, animal feed and bedding, and bioenergy, with enforcement of these alternatives.	S; M	High
Forest Fire	**F1**	Enhancement of forest fire management.	S	High
Waste management	**W1**	Assessment of the quantity of waste burned in Chiang Mai Province. A survey may be established to obtain more accurate estimates of the amount of waste burned.	S; M	No direct impact
	W2	Implementation of measures to reduce open burning of waste and to improve waste collection systems.	M	Medium

CONCLUSIONS

As part of the AQIP programme, an integrated gridded emission inventory has been developed for Chiang Mai province of Chiang Mai. This integrated emission 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 emission inventory details the location and magnitude of emissions across Chiang Mai province for the year 2022.

The development of this inventory employed the most suitable methodologies, drawing on EMEP/EEA, IPCC guidelines, ABC-EIM and relevant scientific literature. Emission calculation for road transport is based on a traffic survey and modelling conducted by EGIS, which offers a better description of the in-use vehicle fleet composition (passenger cars, light duty vehicles, heavy-duty vehicles and two-wheel vehicles) and traffic pattern. This modeling enables accurate assessment of kilometers driven per vehicle type and along major roads.

Collaboration between AIT and Citepa facilitated the collection of pertinent data for other sectors, including agriculture, waste, industrial processes, and energy. While data gaps necessitated some simplifications or assumptions, these were addressed through a detailed methodological guide, "Comprehensive Inventory Methodology Report for Chiang Mai Province, Thailand (2022)." Regular maintenance and updating of this inventory are crucial, as it serves as a key tool for policy formulation and for tracking progress in emission reduction efforts.

The inventory has identified key sources of pollutants and GHGs. For particulate matter—Chiang Mai's primary air quality challenge—and its precursors (SO_2, NOx, NH_3), significant sources include 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.

The inventory highlights the necessity for targeted mitigation measures in the road transport sector, which is a significant source of particulate matter and its precursors. This finding is supported by the study by Chansuebsri et al. (2024), which identified open burning as the primary contributor to fine particulate matter during the smoke period, while road transport remains the dominant source throughout the rest of the year. Consequently, it is essential to prioritize mitigation efforts on road transportation to address its substantial impact on air quality.

Proposed measures to mitigate transport emissions include reducing the number of old heavy vehicles (buses, coaches, and trucks), which would lower fine particulate emissions and NOx levels. Accelerating the renewal of passenger cars and light-duty vehicle fleets, especially following the introduction of Euro 5 vehicle and fuel standards in January 2024, would also be beneficial. Euro 5 vehicles are equipped with particle filters that significantly reduce emissions. Additionally, promoting walking, cycling, and public transportation can alleviate air pollution, GHG emissions, noise pollution, and urban heat islands. A modal shift towards electric mobility is crucial for reducing CO2 emissions, as road transport is the primary source of CO2 in the province

In conclusion, this integrated gridded emission inventory is a valuable asset for formulating and implementing effective policies to reduce air pollution. The more detailed and accurate the inventory, the more targeted and impactful the policies and actions will be. While this project has provided valuable insights into the vehicle fleet composition, further data on other sectors, such as industrial processes and waste management, as well as a comprehensive provincial energy balance, would enhance the inventory's utility. Developing specific emission factors for different source sectors in Chiang Mai will also refine emission estimates. Regular updates and improvements to this inventory will facilitate the assessment of emission trends and the effectiveness of policies, allowing for the implementation of more ambitious measures to further reduce GHGs and air pollutants.

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