# Thailand's POPs Inventory Assessment Report

# Part 3:
# Thailand's 2017 UPOPs Inventory

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Prepared by:
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## Part 3: Thailand's 2017 Unintentional POPs Inventory

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Cover image: "Remelting Aluminum Dross" by N. Ramungul (c) 2019

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# List of Acronyms and Abbreviations

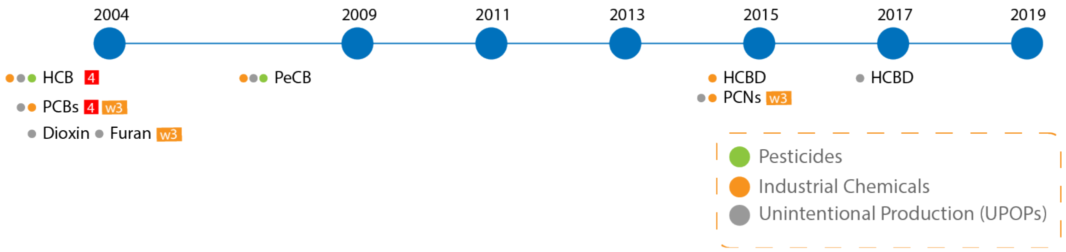
| | |
|---|---|
| AAC | autoclaved aerated concrete |
| ADt | Air dry tonne (pulps and papers) |
| BAT-AEPL | Average environmental performance level associated with BAT |
| AL | Aerated lagoon |
| APC(S) | Air pollution control (system) |
| AS | Activated sludge |
| BAT | Best available technology |
| BEP | Best environmental practices |
| BF | Blast furnaces |
| BL | Biomass fuel load |
| BM | Biomass |
| BOF | Basic oxygen furnaces |
| BREF | Best Available Techniques (BAT) Reference documents |
| CAK | Chlor-alkali |
| CAS | Chemical Abstracts Service |
| CEM | Continuous emission monitoring |
| CF | Combustion factor |
| CHP | Combined heat-power power plant |
| C.I. | Color Index |
| CIF | Cost, insurance and freight |
| CNP | Chloronitrofen |
| CO | Carbon monoxide |
| COD | Chemical oxygen demand |
| CP | Chlorinated paraffins |
| DCA | Dichloroethane |
| DCB | Dichlorobenzene |
| DDF | Deciduous dipterocarp forest |
| DDPM | Department of Disaster Prevention and Mitigation |
| DEDE | Department of Alternative Energy Development and Efficiency |
| DEF | Dry evergreen forest |
| DIW | Department of Industrial Works |
| DLT | Department of Land Transport |
| DNP | Department of National Park, Wildlife and Plant |
| DOA | Department of Agriculture |
| DOE | Department of Energy |
| DOEB | Department of Energy Business |
| DOH | Department of Health |
| DPIM | Department of Primary Industries and Mines |
| e-waste | Electronic waste |
| EAF | Electric arc furnace |

| | |
|---|---|
| ECS | Environment and chemical safety |
| ECU | Electrochemical unit |
| ECVM | European Council of Vinyl Manufacturer |
| EDB | Ethylene dibromide |
| EDC | Ethylene dichloride |
| EF | Emission factor |
| EGAT | Electricity Generating Authority of Thailand |
| EIA | Environmental impact assessment |
| EHA | Environmental health accreditation system |
| EHIA | Environmental health impact assessment |
| ERC | Energy Regulatory Commission |
| ESP | Electrostatic precipitator |
| ETS | Emission trading scheme |
| EU | European Unions |
| FAO | Food and Agriculture Organization of the United Nations |
| FB | Fraction of residues subjected to burning |
| FF | Fabric filter |
| FFCD | Forest Fire Control Division |
| FTI | Federation of Thai Industry |
| G&C Hospital | Green & Clean hospital accreditation initiative |
| GDP | Gross domestic products |
| GGFR | Global Gas Flaring Reduction Partnership |
| GISTDA | Geo-Informatics and Space Technology Development Agency (Public Organization) |
| ha; Mha | Hectare; Million hectare |
| HDG | Hot-dip galvanization |
| HFO | Heavy fuel oil |
| HHW | Household or municipal hazardous waste |
| HS | Hazardous substance |
| HS-Code | Harmonize system (Code) |
| HW | Hazardous waste |
| ID | Identification |
| IEA | International Energy Agency |
| IF | Induction furnace |
| IHW | Industrial hazardous waste |
| IPCC | Intergovernmental Panel on Climate Change |
| ISIC | International Standard Industrial Classification |
| ISIT | Iron and Steel Institute of Thailand |
| ISPM | International Standards for Phytosanitary Measures |
| IW | Industrial waste |
| LAOs | Local Administrative Organizations |
| LF | Landfill |
| LHV | Lower heating value |
| LPG | Liquid petroleum gas |

| | |
|---|---|
| MB | Methyl bromides |
| MDF | Mixed deciduous forest |
| MOAC | Ministry of Agriculture and Cooperatives |
| MODIS | Moderate resolution imaging spectro-radiometer |
| MoEN | Ministry of Energy |
| M-Industry | Ministry of Industry |
| MNRE | Ministry of Natural Resources and Environment |
| MOPH | Ministry of Public Health |
| MSW | Municipal solid waste |
| MT | Million tonnes |
| MTEC | National Metal and Materials Technology Center |
| MW | Medical waste |
| MWA | Metropolitan Waterworks Authority |
| NA | Not applicable |
| ND | No data |
| NEB | National Environment Board |
| NIP | National Implementation Plan |
| NOX | Nitrogen oxides (NO, $NO_2$,$N_2O$, $N_2O_2$, $N_2O_3$, $N_2O_4$,$N_2O_5$) |
| NSO | National Statistical Office |
| OAE | Office of Agricultural Economics |
| OCSB | Office of Cane and Sugar Board |
| OD | Oxidation ditch |
| OIE | Office of Industrial Economics |
| ONEP | Office of Natural Resources and Environmental Policy and Planning |
| OSPAR | Convention for the protection of the marine environment of the north-east Atlantic |
| Pc | Phthalocyanine |
| PCB | Polychlorinated biphenyls |
| PCD | Pollution Control Department |
| PCDD | Polychlorinated dibenzo-p-dioxins |
| PCDD/F | Polychlorinated dibenzo-p-dioxins and furans |
| PCNB | Pentachloronitrobenzene |
| PCP | Pentachlorophenols |
| POP(S) | Persistent Organic Pollutant(s) |
| PPS | Poly(p-phenylene) sulfide |
| PTIT | Petroleum Institute of Thailand |
| PVC | Polyvinyl chloride |
| PWA | Provincial Waterworks Authority |
| RAPEX | EU Rapid Alert System for non-food products |
| RD | Residue density |
| RDF | Refuse derive fuel |
| REACH | Registration, Evaluation, Authorization and Restriction of Chemicals |
| RON | Research octane number |
| RSS | Ribbed smoked sheet rubbers |
| SAO | Sub-district administrative organization |

| | |
|---|---|
| SC | Stockholm Convention |
| SCCPs | Short-chain chlorinated paraffins |
| SEC | Specific energy consumption |
| SME | Small and medium enterprise |
| SK2 | Call name of the DIW waste transfer request form |
| SOX | Sulfur oxides (SO, $SO_2$,$SO_3$, $SO_4$, …) |
| SP | Stabilization pond |
| SPP | Small power producer |
| SRT | State Railway of Thailand |
| SVHC | Substances of very high concerns |
| TCDD | Tetrachlorodibenzo-p-dioxin |
| TCF | Totally chlorine free (bleaching) |
| TCMA | Thai Cement Manufacturers Association |
| TDS | Total dissolved solids |
| TEQ | Toxic equivalent<br>Note: For the purpose of this report, there is no difference if concentrations or emission factors are reported in TEQ or I-TEQ |
| TISI | Thai Industrial Standards Institute |
| TGO | Thailand Greenhouse Gas Management Organization (Public Organization) |
| THTI | Thai Textile Institute |
| TKN | Total Kjeldahl nitrogen |
| TMP | Thermo-mechanical pulp |
| toe, ktoe | Tonnes of oil equivalent, thousand tonnes of oil equivalent |
| TPD | Ton per day |
| TPPIA | Thai Pulp and Paper Industries Association |
| TRC | Tobacco Control Research and Knowledge Management Center |
| TSIC | Thai Standard Industrial Classification |
| TSP | Total suspended particles |
| TSR | Technically specified rubber |
| TSS | Total suspended solids |
| TTIA | Thai Tanning Industry Association |
| ULG | Unleaded gasoline |
| UN | United Nations |
| UNEP | The United Nations Environment Programme |
| UNIDO | The United Nations Industrial Development Organization |
| uPOPs | Unintentional POPs |
| VCM | Vinylchloride monomer |
| V-ETS | Thailand voluntary emission trading scheme |
| VOC | Volatile organic compounds |
| VSPP | Very small power producer |
| WG | Working group |
| WTE | Waste-to-energy |
| WW | Wastewater |
| WWTP | Wastewater treatment plant |

# 3 Unintentionally produced POPs (uPOPs)



*Numbers in square brackets indicate the substances are listed as hazardous substances in Thailand*

## Summary of assessment findings

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Thailand ratified the Stockholm Convention (SC) on Persistent Organic Pollutants (POPs) on 31 January 2005. The Convention initially included 12 substances or groups of substances, 4 of which were listed in Annex C – known as unintentionally produced POPs or uPOPs. As of 2019, the SC has subsequently added 3 more substances to Annex C.

Thailand compiled its first uPOPs inventory in 2006, based on year 2004 data. Based on information gained from the first inventory report, the Thai government had developed and implemented its National Implementation Plan (NIP) to fulfill its obligations under the convention. Since the last study was completed more than 10 years ago, an update of uPOPs inventory is required to better reflect current situations as well as new knowledge accumulated over the years.

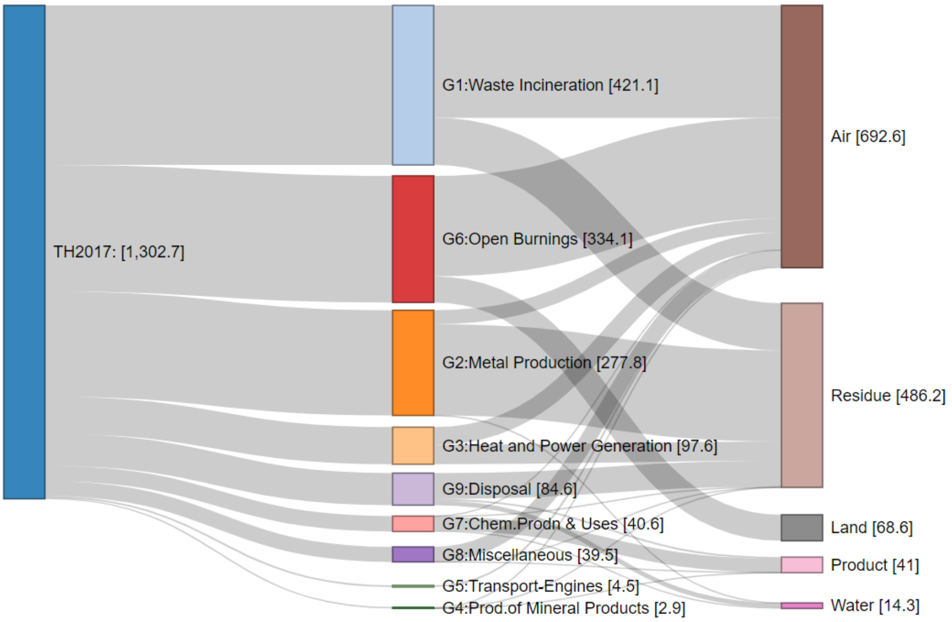
This study is intended to be a preliminary unintentional POPS inventory study, covering relevant activities that took place in Thailand in 2017. It covers the assessment of all of the UNEP identified 9 potential source groups which are further divided into 74 source categories and 237 technology/activity classes.

An overview of the estimated PCDD/F emissions in Thailand for the baseline year 2017 is shown numerically in Table 3-1 and visually in Figure 3-1, where emissions into air, water, land, products and residues are 692.6, 14.3, 68.6, 41, and 486.2 g TEQ/a, respectively – totaling to an overall emission of 1,303 gTEQ/a.

The top 3 highest emission source groups are G1: Waste incineration (421.1 gTEQ/a)), G6: Open Burning Processes (334.1 gTEQ/a) and G2: Ferrous and Non-Ferrous Metal Production (277.2 gTEQ/a). These source groups contribute to 32%, 26% and 21% of Thailand's total PCDD/F emission in 2017, respectively.

**Table 3-1: Overview of the estimated PCDD/F emissions in Thailand in 2017**

| | Source Groups | Annual Releases (g TEQ/a) | | | | | | Destruction (g TEQ/a) |
|---|---|---|---|---|---|---|---|---|
| | | Air | Water | Land | Product | Residue | Subtotal | |
| G1 | Waste Incineration | 296.8 | 0.0 | 0.0 | 0.0 | 124.3 | **421.1** | - |
| G2 | Ferrous and Non-Ferrous Metal Production | 37.0 | 0.2 | 0.0 | 0.0 | 240.7 | **277.8** | **-21.59** |
| G3 | Heat and Power Generation | 46.4 | 0.0 | 0.0 | 0.0 | 51.2 | **97.6** | - |
| G4 | Production of Mineral Products | 2.9 | 0.0 | 0.0 | 0.1 | 0.0 | **2.9** | - |
| G5 | Transportation | 4.5 | 0.0 | 0.0 | 0.0 | 0.0 | **4.5** | - |
| G6 | Open Burning Processes | 265.5 | 0.0 | 68.6 | 0.0 | 0.0 | **334.1** | - |
| G7 | Production of Chemicals and Consumer Goods | 0.2 | 2.2 | 0.0 | 36.4 | 1.8 | **40.6** | - |
| G8 | Miscellaneous | 39.3 | 0.0 | 0.0 | 0.0 | 0.2 | **39.5** | - |
| G9 | Disposal | 0.0 | 11.9 | 0.0 | 4.6 | 68.0 | **84.6** | - |
| | **Total** | **692.6** | **14.3** | **68.6** | **41.0** | **486.2** | **1302.7** | **-21.59** |
| | **Grand Total** | | | **1,303** | | | | **1,281** |



unit: g TEQ/a

**Figure 3-1: Profile of the estimated PCDD/F emissions in Thailand in 2017**

## G1: Waste Incineration

Waste incineration in this report covers 7 source categories that contributed to the release of about 421 g TEQ/a in 2017, with municipal solid waste (MSW) incineration and medical waste (MW) incineration contributing to 83% and 16% of the emission from this source group, respectively. The high releases from MSW incinerators were mostly (75%) contributed by 57 small and inefficient incinerators. While these incinerators helped dispose of only about 0.3% of Thailand's MSW in 2017, they were responsible for over 20% of country's total PCDD/F release.

Emissions from MW incinerators (66.3 gTEQ/a), though only contributing at 5% of the country's total PCDD/F emission, were concentrated in about 10 locations, with one site accounting for more than 50% of the total MW incineration. Because MW management sites play vital roles in the country's waste management and health development plans, these plants, therefore, deserve close attentions to ensure their prudent operations.

### G6: Open Burning Processes

Open burning processes contributed about 334 g TEQ/a. The burning of agricultural residues in paddy and maize fields is the main contributor for this source group, responsible for about 20% of country's total PCDD/F release. The high level of PCDD/F released resulted from the combination of the high activity rates, the relatively poor combustion efficiency, and the involvement of chlorinated herbicides.

A relatively large portion (67 gTEQ/a, or 23%) of PCDD/F generated in agricultural field burnings was released to land, which poses long-term risks to the community that rely on food and feed produced from these land areas. Emissions from biomass open burning are, therefore, identified as a major source of PCDD/F emission that needs to be addressed in the upcoming NIP.

PCDD/F generated from accidental fires at waste dumps is estimated at 37.2 gTEQ/a, or 11% of PCDD/F generated from open burning processes. Although the contribution from this source appears moderate, it illustrates a potential risk of PCDD/F generations and releases from landfill fires, especially for large landfill sites.

### G2: Ferrous and Non-Ferrous Metal Production

PCDD/F emission from metal production ranked first in the 2004 inventory and was hence identified as a major source for actions at the national level. As a result, several air emission standards have been published and the releases from large factories have been monitored. Unfortunately, the actions that were put in places were mainly toward reduction of the emission into air, while the main vector for this source group is the release into residue, which accounts for about 87% of the total release from this source group in 2017.

Emission from metal production ranks third in this 2017 inventory, with about 240 gTEQ/a released into residue; the transfer of which was controlled by Thai law. With an improved waste transfer reporting system, a large portion of residues from metal production plants could be traced. Some (21.6 gTEQ/a) of the PCDD/F embedded in these residues were destroyed via incineration in cement kilns.

### G3: Heat and Power Generation

Heat and power generation contributed 98 gTEQ/a (7.5%) to Thailand's 2017 total PCDD/F emission, with about 48% and 52% released into air and residues, respectively.

Biomass power plants were the key contributor for this source group; responsible for about 48% of the emission, followed by fossil fuel power plants and household cooking with biomass, each contributing to about the same amount of PCDD/F but released into different vectors.

Although ranked 4th for PCDD/F emission, this source group is of high importance due to its close tie to the country's Climate Change Master Plan and Sustainable Development Goal. While biomass has been widely regarded as a green energy source with low carbon footprint, relatively high PCDD/F emission contribution from biomass (73% of this source group's total) deserves national attention. Biomass is a major part of Thailand's renewable energy portfolio. Diverting unused biomass residues from agricultural fields to power plants also help curb biomass open burning problems. However, attention should also be paid to ensure that the risks from unintended PCDD/F generation/emission are under control. Particularly, research and development into new power plant/combustion technology with low PCDD/F generation should be promoted. Moreover, due to high PCDD/F emissions into residues couple with potentially high amount of residue generation from biomass power plants, technology for the ultimate destruction of PCDD/F will be needed.

The high emission from the use of biomass for household cooking is also important from the risk proximity and gender points of view. Again, measures should be put in place to ensure public awareness and the availability and accessibility of efficient, low PCDD/F stoves.

### G9: Disposal

PCDD/F emission from disposal and landfill activities during the year 2017 was 95 g TEQ/a; with the release to residue, water, and products accounted for 80.5%, 14% and 5.5% of the total emission, respectively.

The main contributor (93%) for this source group is from activities related to landfills and waste dumps, particularly landfilling or open dumping of wastes contaminated with hazardous components or mixed wastes, with residue being the main pathway. The emission into residues in engineered or secured landfills does not constitute a release per se, but rather the storage of PCDD/Fs that accumulate and are gradually released into water overtime, and will become important when excavated.

The value reported here for landfill residues appears low because it excludes the portions that are already counted in the respective waste-generating source groups (G1 to G8) to avoid double counting. Thus, the amount of PCDD/F stored in landfills are actually higher than reported in this source group (by about 400 g TEQ/a) and will further accumulate every year unless care is taken to remove contaminated items from waste streams prior to landfilling.

The emission into water, on the other hand, can be released to nearby receptors. The reported value for the release into leachate water from landfills shall not be misinterpret as emission from the entire landfills, but rather only from the portions that were deposited during the 2017 baseline year. The total amount of PCDD/F anticipated to have been released is thus higher, depending on the accumulated amount of waste landfilled over all years.

At the time of this report, there is no requirement to monitor PCDD/F released from landfills or landfill excavations; thus, no preventive action is yet in place to assure public and environmental safety. This gap, particularly for landfills near urban and industrial areas, should be addressed in the upcoming action plans.

### G7: Production of Chemicals and Consumer Goods

The total PCDD/F emission from Source Group 7 during the year 2017 is about 41 g TEQ/a, with the emissions to product, water, and residues accounting for 90%, 5.6% and 4.4% of the emission from this source group, respectively.

The main source for PCDD/F in products were dioxin contamination in chlorinated chemicals, particularly, chlorinated paraffins and dioxazine pigments, and residuals in paper recovered from contaminated paper waste.

Due to the absence of representative EFs into water and residues, the relatively low values for PCDD/F emission into these vectors should be interpreted with caution. The reported emission values do not yet include releases from potential sources, such as textile and leather plants. Therefore, releases from these potential sources should be confirmed via measurement data. Particularly, data related to quantities, method of treatment, fate of wastewater, wastewater sludge and other solid wastes should be recorded and analyzed.

### G8: Miscellaneous

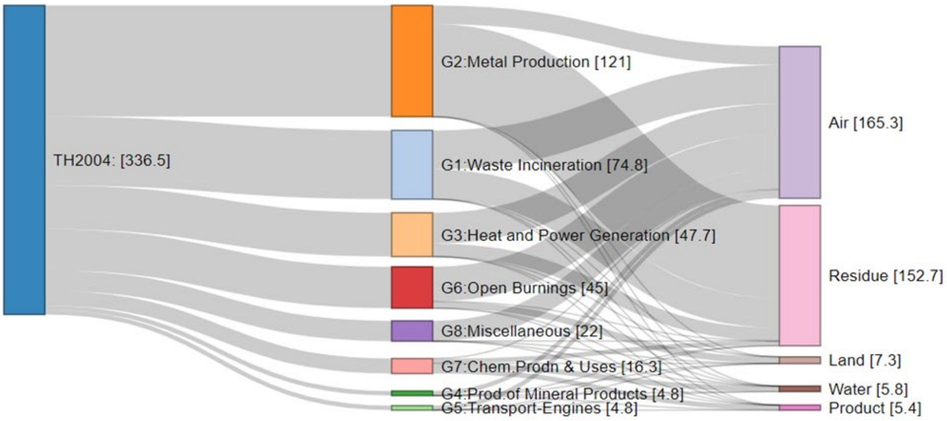
Miscellaneous sources contributed about 40 gTEQ/a (3%) to the total emission in 2017, with crematoria being responsible for almost all (98%) of the PCDD/F released from this source group.

Crematoria was identified in the Thailand's 2006 inventory report as a potential source and actions have been taken to reduce the emission. Consequently, through the efforts laid out by the previous NIP, the number of improved crematoria has increased and Thailand's country-specific emission factors have been made available.

Nevertheless, the improvement appeared moderate because the derived country-specific EFs were still higher than those of UNEP's Class 2 crematoria. This finding points toward the interaction of other important factors, particularly operation and maintenance. As Thailand is planning to upgrade all crematoria to meet PCD's Type-3 specification, it is crucial that responsible agencies put in place measures to ensure that the performance of the upgraded crematoria also meets at least UNEP's Class 2 performance.

## Comparison to emissions in 2004

In 2006, Thailand reported total emission of 1,096.7 g TEQ/a for the 2004 reference year, using UNEP's 2005 EFs. The same set of activities leads to a total emission of 336.5 g TEQ/a when revised using UNEP's 2013 EFs. The profile of the recalculated emissions for the activities reported for the baseline year 2004 is illustrated in Figure 3-2.



unit: g TEQ/a

Note: Estimated with UNEP's 2013 EFs

**Figure 3-2: Profile of the recalculated PCDD/F emissions of Thailand's 2006 inventory report (baseline year 2004)**

Because the 2006 report was Thailand's first attempt to assess PCDD/Fs, the report covered 8 source groups with 31 source categories and 53 unique activity entries. Since current study assesses PCDD/F from 9 source groups with 74 source categories and 237 technology/activity classes, the results from these two baseline years (2004 and 2017) cannot be directly compared.

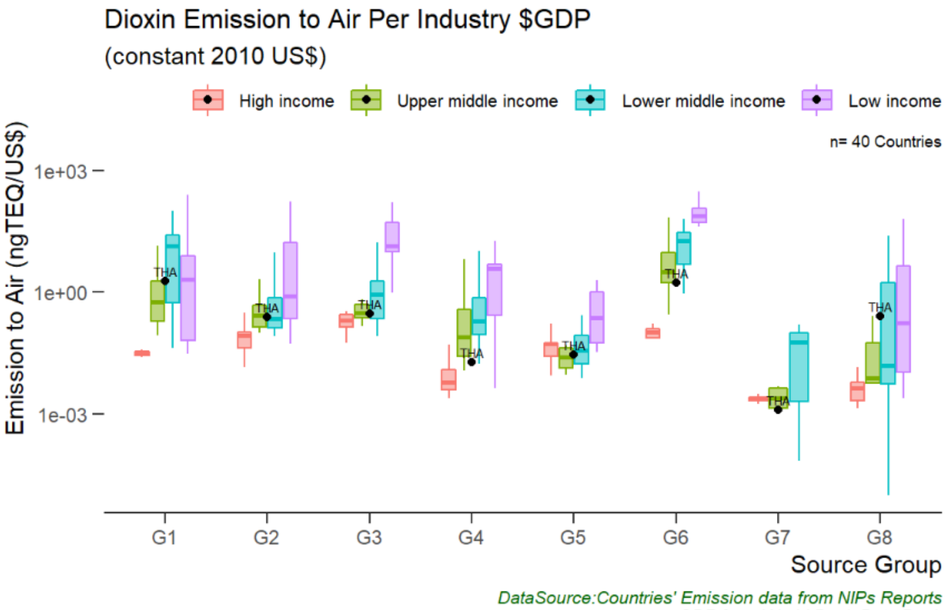
However, when comparing similar sources per unit activity, the emissions per unit activity from several source categories are declining. Activities that were identified with high releases potential were improved and, hence, received better class allocations in this report. Unfortunately, new activities with poor technologies also concurrently took place, leading to only a moderate improvement in the overall national performance.

It is, therefore, important that the upcoming action plans lay down measures to prevent installation of new plants/activities with inferior technology and, instead, to promote the adoption of BAT & BEP.

Comparison with emissions from other countries

Figure 3-3 compares Thailand's dioxin emission to air per unit $GDP with 40 other countries based on income level. Thailand's overall results compare well with those from other upper middle income countries.

Thailand's emissions from Source Groups 4, 6 and 7 were on the lower range among the upper-middle income group, while emissions from Source Groups 1 and 8 were on the high range. As previously stated, the main emission from Source Group 1 was from the improper waste incineration, while crematoria were mainly responsible for the emission from Source Group 8.



*DataSource:Countries' Emission data from NIPs Reports*
*GDP from World Bank Data Bank*

**Figure 3-3: Thailand's PCDD/F emission into air per industry $GDP in comparison with other 40 countries based on income level**

□□□

# Introduction

Thailand ratified the Stockholm Convention (SC) on Persistent Organic Pollutants (POPs) on 31 January 2005. The Convention initially included 12 substances or groups of substances, 4 of which were listed in Annex C – known as unintentionally produced POPs or uPOPs. The SC has subsequently added 3 more substances to Annex C.

Thailand has compiled its first uPOPs inventory in 2006. Based on information gained from the first inventory report, the Thai government had developed and implemented its National Implementation Plan (NIP) to fulfill its obligations under the convention. Since the last study was completed more than 10 years ago, an update of uPOPs inventories is required to better reflect current situations well as new knowledge accumulated over the years.

## Purposes of the study

This study is intended to be a preliminary unintentional POPS (“uPOPs”) inventory study, covering relevant activities that took place in Thailand in 2017.

Up until 2019, the Stockholm Convention (SC) has listed 7 substances in the Annex C. However, emission factors for the 3 latest entries are still undefined. Therefore, this preliminary study focused primarily on assessment of PCDD/F emissions, as recommended by the latest version (2013) of the UNEP Toolkit. Nevertheless, as these UPOPs share common sources, information gained from PCDD/F studies can be considered indicative of the other uPOPs as well.

A main objective of this work has been to revise Thailand’s uPOPs inventory to a new baseline year (2017) as the first (2006) version has never been updated and can no longer serve as the national baseline. This is because:

1) The UNEP Toolkit has been revised since it was used to generate Thailand’s first uPOPs inventory, with some updates on emission factors (EFs) for certain existing source categories/classes, and with the addition of some new source categories/classes which did not exist in its previous versions.
2) Several activity data in the first uPOPs inventory are already obsolete/invalid for several reasons: some activities need to be reclassified (due to the Toolkit’s revision); activity rates for nearly all existing activities need to be updated; activity rates for key emission sources that were absent in the 2006 inventory and/or did not exist back in 2006 need to be addressed, and certain activities that were misplaced in the 2006 inventory need

to be corrected.

This inventory forms a core part for Thailand to make informed policy decisions to mitigate the associated risks and to fulfill its obligations toward the Stockholm Convention.

## Methodology

Inventory procedure

MTEC was assigned by the PCD and endorsed by the National Environment Board's Stockholm Convention Sub-Committee on POPs ("Thai SC-subcommittee") to take charge of this inventory assessment. The inventory team was assisted by 2 external experts on uPOPs. In compiling this inventory study, the following steps were taken to ensure transparency and quality[1] of the assessment.

Working group

The uPOPs Working Group (WG4) with 13 representatives from relevant public and private organizations was officially established and endorsed by the Thai SC-subcommittee to support the inventory study and to work toward the formulation of the NIPs. The director-general of the PCD was appointed as the chair this WG, with PCD and MTEC jointly serving as secretary.

The WG4 was presented with relevant pertinent data, accumulated by MTEC's preliminary research, in order to define the scope of the inventory and formulate a practical work plan at the start of the project.

UNEP Toolkit 2013

UNEP released the Toolkit for the Identification and Quantification of Releases of Dioxins, Furans, and Other Unintentional POPs in January 2013.

The Toolkit aids parties to the SC in evaluating their uPOPs releases by providing a common framework for the identification and classification of various uPOPs sources, as well as the associated EFs, so that the resulting uPOPs estimates are consistent and comparable among member countries. Also, the resulting inventory can serve as a basis for countries to justify their priority areas for necessary actions and be able to track their emission reduction progress over time.

The Toolkit divides uPOPs sources into 9 main "source groups" based on the general features of the activities that contribute to uPOPs emission. Within each source group, "source categories" and finally "classes" are further designated. For each class, a set of uPOPs emission factors (EFs) per unit of "activity rate" for 1 or more relevant uPOPs release vectors (a total of 5 release vectors are defined in the Toolkit: air, water, land, product, and residue), along with class-identification attributes, are provided so that countries without sufficient country-specific uPOPs data

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[1] Consistency, Comparability, Completeness (fit to purpose) and Accuracy

can still estimate their uPOPs release towards generating their national inventories. The Toolkit also provides suggestions for potential sources of data from which countries can obtain or derive their activity rates for the various uPOPs sources.

Note that where applicable and appropriate, actual measurement data were used to estimate uPOPs emissions, in place of adopting Toolkit's default EFs and/or classification protocols, so that Thailand's contexts and conditions are better represented in this national inventory. These substitutions are indicated and discussed in their respective parts of this report.

## Data sources and data collection

There are two aspects of data to be considered for uPOPs inventory: activity rates and attribute data for activity classification.

For activity rates, the main sources are primarily national data/statistics from responsible governmental bodies as well as relevant industrial and business associations, for examples:

- MNRE (PCD, ONEP, DEQP, DNP, Royal Forest Department)
- M-Industry (DIW, OIE, DPIM, OCSB)
- MoEN
- MOA (OAE, Department of Fisheries)
- Thai Customs Department
- NSO
- DLT
- FTI
- ISIT

Data from these sources were obtained via formal data requests and/or from public domain, when available (such as official publications/reports and official websites). For certain emission activities for which activity rates are not available at the national level, estimations were made based on other available circumstantial information. The resulting approximated activity rates and their associated assumptions are described in details in their respective sections.

In addition to the above-mentioned data sources, the attribute data necessary for class assignment were, in several cases, obtained directly from the main stakeholders involved with the respective activities (for examples, by interviewing/visiting manufacturers with significant shares of activity rates in their respective source categories). Certain classification attribute data were also inferred from applicable regulations that stipulate emission limits or actions for relevant pollutants.

More details on specific data sources and assumptions/approximations made are described in relevant sections.

### Data management and evaluation

Data and information gathered during the data collection period were compiled and analyzed. Apparent inconsistency or ambiguity issues were resolved through follow-up consultation with the data providers. The resulting draft uPOPs inventory assessment was presented to WG4 for their comments. Following revision, the draft inventory was presented to the public (relevant stakeholders) at the uPOPs Inventory Validation Workshop on 6 August 2019, which was attended by 66 participants from 32 organizations. Feedbacks received during the workshop and the 1-week comment-gathering period were incorporated into the inventory revision process, and the resulting final draft was once again circulated to WG4 for their endorsement.

### Inventory report preparation

The inventory team was in charge of preparing the inventory report. The final (draft) version of the inventory report was reviewed by the Working Group on Project Supervision and Coordination (WG1) prior to being submitted to UNIDO for review by international expert(s).

## Organization of this report

This report represents part 3 of the 3-parts national inventory report. It comprises 9 sections detailing information gathered for each UNEP specified uPOPs source group. It also provides details on limitations and assumptions made in order to estimate the PCDD/F emissions in Thailand. Data gaps are described in the form of qualitative uncertainty assessment to indicate limitations of the study. Finally, the total emission estimated for each source group is discussed along with a highlight of possible major sources as well as recommended activities/measures to fill existing data gaps and to avoid the unintended releases.

All toxic equivalency values presented in this report are based on the International Toxic Equivalents Scheme (I-TEQ). This is true even when, at times, the unit appears only as TEQ in the text.

The activity rates in this report are presented as numbers that have been rounded to 3 significant figures – i.e., on the order of 0.1% accuracy with respect to the actual data. This is done to increase the legibility of the data. However, the actual, unrounded figures are used for emission calculations.

All air emission standards in Thailand are prescribed on dry air basis at 7% excess $O_2$, while the UNEP Toolkit quotes emission concentrations at 11% excess $O_2$. Concentrations in air expressed at 7% $O_2$ will be approximately 1.4 times higher that at 11% $O_2$. Unless otherwise indicated, all air emission values in this report are based on the Thai standard condition: 7% $O_2$, 25°C, and 1 atm.

□□□

## 3.1 Source Group 1: Waste Incineration

The UNEP Toolkit categorizes emission sources within this group into 7 source categories:

- Municipal solid waste (MSW) incineration (1a)
- Hazardous waste incineration (1b)
- Medical waste incineration (1c)
- Light-fraction shredder waste incineration (1d)
- Sewage sludge incineration (1e)
- Waste wood and waste biomass incineration (1f)
- Destruction of animal carcasses (1g)

Activities within the first 3 source categories took place in Thailand in 2017 and are included in this study. The following waste types associated with the 4 latter source categories are not separately dealt with in this report since they are already addressed as part of other source categories or source groups:

- light-fraction shredder waste is disposed of (illegally) as MSW waste or as industrial waste;
- sewage sludge is used in cement kiln (source group 4) or disposed of as other wastes, including hazardous waste;
- waste wood and waste biomass are disposed of as MSW or industrial waste (e.g., waste from pulp and paper industry is identified as the main source of biomass in industrial waste stream, and is therefore considered in source groups 3 and 7);
- animal carcasses are disposed of as infectious (medical) waste or as non-hazardous industrial waste, since there is no dedicated incinerator for this waste type in Thailand.

The activity rates for this source group were obtained mainly from the following data sources:

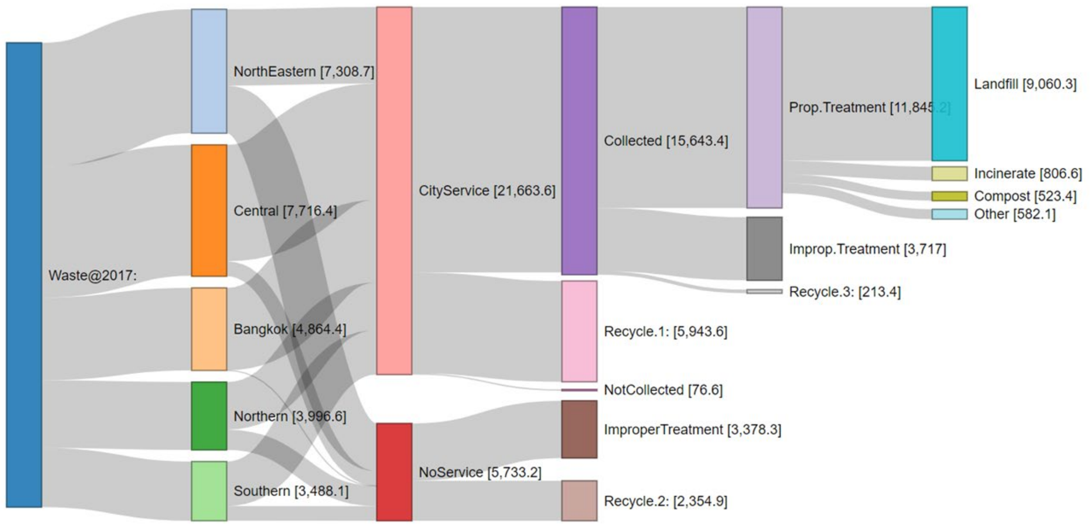
- PCD: Thailand's 2017 municipal solid waste disposal data and Thailand State of Pollution Report 2017
- DIW: Thailand's 2017 industrial waste transfer manifest data
- DOH: Thailand's 2017 medical waste disposal data

According to Thailand State of Pollution Report 2017 [1], Thailand generated 27.4 million tonnes of MSW or about 414 kg per person (per year). Of this amount, 31% were recycled, 43% were collected and treated properly, and the rest (26%) were either beyond sub-district administrative organization (SAO) and city services or improperly managed (see Figure 3-4).

Municipal solid waste (MSW) generation rate in Thailand has been on the rise for over a decade and waste management has been challenging. The amount of waste generated grew beyond SAO/cities' capacities to manage properly, giving rise to large pile-ups of waste throughout the country. PCD estimated about 28 million tonnes and 30.5 million tonnes of MSW stockpiled in Thailand in 2014 [2] and 2016 [3], respectively. The government, hence, declared waste management a National Agenda. This declaration led to nation-wide survey of management capacity and waste situation in every SAO/city. Finally, in 2016, the cabinet approved the Municipal Solid Waste Management Master Plan (2016-2021) [3], a plan based on 3 frameworks: encouraging waste reduction at the source; establishing proper disposal facilities; and promoting public-private partnership in MSW management.

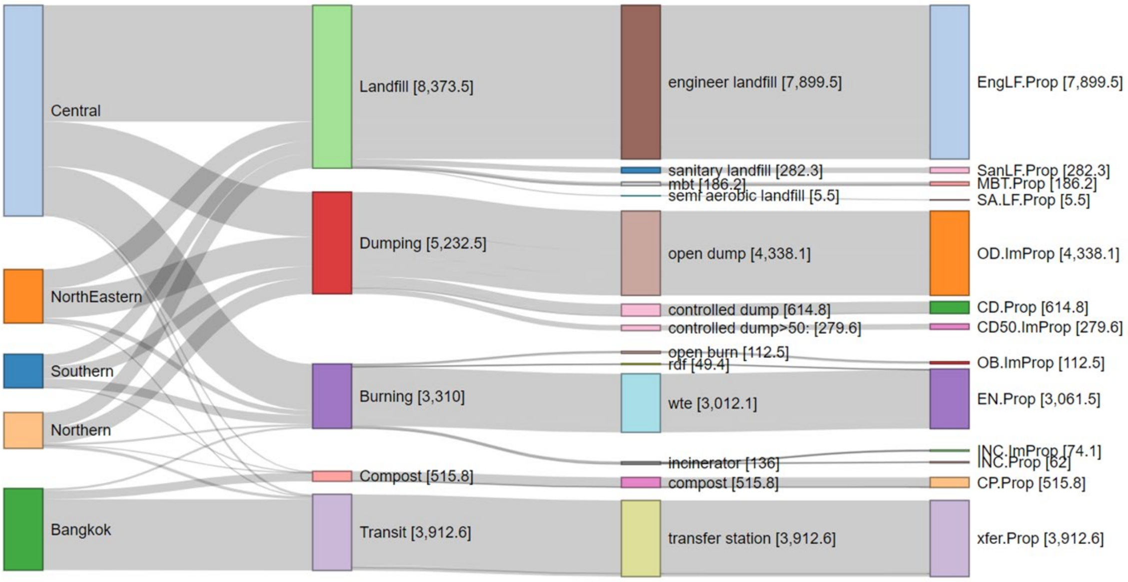
The MSW Management Master Plan aims to appropriately manage all of the 30.5 million tonnes of stockpiled MSW by 2019. It also aims to properly manage all infectious (medical) and industrial hazardous waste by 2020, 30% of household hazardous waste by 2021, 75% of MSW by 2021; and to have 50% of local authorities (SAO/cities) put in place systems for waste separation at the source by 2021. To kick-start the master plan, the government approved a one-year "Thailand Minimal Wastes Action Plan" (2016-2017) according to the Participatory State Principle. Through this action plan, important management infrastructures for all targeted waste streams have been established [4], making it possible to monitor waste flow and waste management at SAO/city level.

According to PCD 2017 waste treatment database, typical disposal routes are landfill (48%), dumping (30%, mostly improper), burning (19%), and compost (3%). Since there were stockpiles of unmanaged waste accumulated through the years, the Thailand Minimal Wastes Action Plan also covered activities to properly dispose all these waste stocks; which included landfill re-habitation and recovery of combustible waste to convert to energy.



*Data Source: PCD 2017 [5]*

**Figure 3-4: Thailand’s municipal solid waste management profile in 2017 (unit: kTonnes)**



*Data source: PCD 2017 [5]*

LF=Landfill, OD=Open dump, CD=Control dump, Inc=Incineration, xfer=Transfer

**Figure 3-5: Thailand’s municipal solid waste disposal profile in 2017 (unit: kTonnes)**

### 3.1.1 Municipal solid waste incineration

Relevant activities

The UNEP Toolkit defines 4 classes of municipal solid waste (MSW) incineration based on technology level (including type of APCS used) and operational practice (i.e., combustion control, batch vs. continuous feeding)

- Class 1: low technology, batch combustion, no APCS
- Class 2: controlled continuous combustion, minimal APCS
- Class 3: controlled continuous combustion, good APCS
- Class 4: high technology, sophisticated APCS

For Thailand, the activities that make up 'municipal solid waste incineration' comprise 3 main groups, namely: the general incineration of regular municipal solid waste (MSW), the incineration of municipal solid waste with energy recovery (waste-to-energy (WTE)), and the incineration of non-hazardous industrial waste in generic incinerators. The first 2 activity groups are under PCD supervision, while the latter is regulated by DIW.

According to MNRE's B.E. 2553 (2010) Notification on Air Emission Standards for Municipal Solid Waste Incinerators [6], all MSW incinerators with capacities between 1 and 50 tonne/day must comply with the 0.5 ng TEQ/$m^3$ at 7% $O_2$ and 25°C (equivalent to 0.389 ng TEQ/$Nm^3$ at 11% $O_2$ and 0°C) PCDD/F air emission limit. This limit applied to all 2017 incinerators for regular MSW and non-hazardous industrial waste in Thailand, as the existing MSW incinerators were within this capacity range.

However, the same MNRE Notification stipulates a more stringent 0.1 ng TEQ/$m^3$ (7%, 25°C) PCDD/F air emission limit for MSW incinerators with capacities above 50 tonne/day (that were registered after July 2010). This more stringent limit applied to the 6 waste-to-energy (WTE) incinerators operating in 2017. In addition, incinerators of any size without APCs are considered "improper" by the PCD. However, in spite of the existing regulation, PCDD/F emission data are still generally unavailable for MSW incineration activities in Thailand.

Note that all air emission standards in Thailand are prescribed at 7% $O_2$ and 25°C. PCDD/F concentrations expressed at this condition will be about 1.3 times lower if expressed at 11% $O_2$ and 0°C. Unless otherwise indicated, all air emissions in this report are referred to values measured under Thai standard conditions.

### Emission factors

Despite having an active regulation on PCDD/F emission in place, relevant measurement data from Thai MSW incinerators is still generally unavailable. Therefore, Thailand's EFs could not be estimated for use in this report. The 2013 UNEP Toolkit's emission factors for MSW incinerators, as displayed in Table 3-2, are adopted for the estimation of the emissions of PCDD/F from waste incinerations

The Toolkit classifies MSW incinerators into 4 classes based on technology level and operational practices:

- Class 1 refers to small, batch-type incinerator without flue gas abatement system.
- Class 2 covers controlled, continuously fed incinerators with some APC system, such as electrostatic precipitators, multi-cyclones and/or simple scrubbers. Emissions from incinerator in

this Class 2 are in the order of 50 ng TEQ/Nm³ (at 11% $O_2$).

- Class 3 incinerators are similar to Class 2 but with improved combustion efficiency and more efficient APC systems (such as a combination of electrostatic precipitators and multiple scrubbers, a combination of spray-dryers and baghouse). Emissions from incinerator in this Class 2 are in the order of 5 ng TEQ/Nm³ (at 11% $O_2$).
- Class 4 refers to state-of-the-art MSW incinerators equipped with sophisticated APC technologies capable of achieving 0.1 ng TEQ/Nm³ (at 11% $O_2$) air emission standard.

**Table 3-2: UNEP's PCDD/F emission factors for municipal solid waste incinerators**

| 1a | Municipal Solid Waste Incinerators | Emission Factor (µg TEQ/t MSW incinerated) | | |
|---|---|---|---|---|
| | Classification | Air | Fly Ash | Bottom Ash |
| 1 | Low technology combustion, no APCS | 3,500 | No Data | 75 |
| 2 | Controlled combustion with minimal APCS | 350 | 500 | 15 |
| 3 | Controlled combustion with good APC | 30 | 200 | 7 |
| 4 | High technology combustion, sophisticated APCS | 0.5 | 15 | 1.5 |

## Activity rates

**Incineration of typical MSW:**

According to PCD 2017 data [5], there were 94 waste incinerators (excluding waste-to-energy power plants) that burned 136,038 tonnes of regular MSW in 2017 (see Figure 3-5). Fifty seven (57) of these incinerators were without APCS, and therefore are considered Class 1 according to the Toolkit. In 2017, these PCD-defined "improper" incinerators burned a combined total of approximately 74,100 tonnes of MSW. The remaining 37 MSW incinerators were either smaller incinerators (burning less than 10 tonne/day) with basic APCS or larger incinerators (burning up to 40 tonne/day) with proper APCS. Among these 37 "proper" incinerators, the smaller ones burned about 38,900 tonnes and the larger incinerators burned 23,100 tonnes in 2017.

Even though there is a law that limits emissions, relevant PCDD/F air emission data from Thai MSW incinerators is not available. Nevertheless, PCD has issued a guideline for efficient management of MSW by incineration [7]. This guideline provides a set of tiered minimum requirements for 4 incinerator groups based on their daily capacity: below 3, 3-30, 30-50, and above 50 tonne/day, respectively. Incinerators classified as "properly operated" by PCD are expected to meet the following management and performance criteria:

a) Sorting out incombustibles, infectious and hazardous waste

b) Reducing moisture by removing food wastes or by prior natural evaporation in controlled waste storage areas

c) Controlling feeding rate to keep combustion stable

d) Controlling warm-up time (30-90 minutes) or start-up temperature (above 750°C)

e) Maintaining minimum burning time and temperature in the final combustion chamber above 850°C for at least 2 seconds

f) Having exhaust air pollution control system

g) Incinerators with capacity greater than 3 tonne/day should also meet following requirements:

  i Means to warm up combustion chamber to temperature above 850°C during start-up

  ii Measuring and controlling amounts of $O_2$, CO, and $CO_2$ in combustion chamber

  iii Having air pollution control system to treat dioxins and furans

h) Incinerators with capacity greater than 30 tonne/day are required to have a system to reduce bottom ash temperature to prevent the *de novo* synthesis of PCDD/Fs.

i) Incinerators with capacity greater than 50 tonne/day also required to have a system for rapid quenching of flue gas to 200-300°C within 5 seconds

Based on the above performance criteria, the 57 "improper" and the 37 "proper" incinerators can be assigned into the Toolkit Classes as shown in Table 3-3.

Note that Annex 9 of the 2013 Toolkit quoted a range of air EF values for one Thai MSW incinerator based on sources published in 2001 and 2002, which led to a suggestion that this particular incinerator be classified as Class 3. This incinerator predated the MNRE's air emission standards and has been out of service. The previous study and the new standard led to installation of improved incinerators. Unfortunately, while the previous facilities were upgraded to meet the next class's performances, newer, smaller facilities emerged and formed a significant portion of Thailand's 2017 MSW incinerators.

**Table 3-3: Mapping PCD's criteria of Thailand's MSW incinerators into Toolkit Classes**

| PCD group | Toolkit Class | No of incinerators | Activity Rate (tonne/year) | Key PCD Criteria for classification |
|---|---|---|---|---|
| Improperly operated | 1 | 57 | 74,100 | No APCS |
| Properly operated 1 (<3 TPD) | 2 | 23 | 13,366 | e), f) |
| Properly operated 2 (3-30 TPD) | 3 | 13 | 34,153 | e), f), g) |
| Properly operated 3 (30-50 TPD) | 3 | 1 | 14,454 | e), f), g), h) |

**Incinerations of MSW with energy recovery ("waste-to-energy",**

**WTE):**

In 2017 there were 6 private waste-to-energy (WTE) power plants in operation in 6 provinces in Thailand. These plants incinerated in total 3.012 million tonnes of waste to convert to energy (Figure 3-5). The emission of PCDD/Fs from these plants were controlled by MNRE's B.E. 2553 (2010) air emission standards [6]. As mentioned previously, these WTE power plants, with capacity greater than 50 tonne/day, had to comply with the corresponding limit of 0.1 ng I-TEQ/$m^3$ (7%, 25°C).

Table 3-4 displays PCDD/F emissions data obtained from DIW for 5 WTE plants (associated identities for these plants are unknown to the inventory team). The data illustrated median PCDD/F concentration of 0.082 ng TEQ/$m^3$ (7%, 25°C), with no entry exceed the regulatory limit. Unfortunately, other necessary data associated with these emission values are not available; thus, the total PCDD/F emission for these plants could not be calculated.

A search in ONEP EIA database[2] found one company filed EIA monitoring reports starting from 2017 [8]. Monitoring data for 2017 was not available. However, in June 2019, this plant reported a total PCDD/F emission at 0.048 ng I-TEQ/$m^3$ (at 7% $O_2$, 25°C). This plant accounted for about 30% of all WTE incineration load in 2017. Again, other necessary data associated with this emission value are not available; thus, the total PCDD/F emission for this plant could not be calculated.

Nonetheless, assuming comparable performance between the years 2017 and 2019, the available information help justify that the performance of the WTE plants meet Class-4 standard according to the Toolkit. And since there is no data to proof otherwise, based on the aforementioned emission limit, all WTE incineration activities in 2017 (from all 6 plants) are therefore assigned to Class 4.

**Table 3-4: Reported dioxin emissions from 5 different WTE power plants**

| CID | Report Year | Period | Stack | Input | Dioxin (ng I TEQ/$m^3$)* | Exhaust Rate ($m^3$/hr) |
|---|---|---|---|---|---|---|
| 1 | 2016 | 2 | 1 | RDF from MSW | 0.0073 | 240,807 |
| 2 | 2016 | 2 | 1 | MSW | 0.0820 | 87,838 |
| 3 | 2017 | 1 | 1 | MSW | 0.0875 | 34,330 |
| 4 | 2017 | 2 | 1 | MSW | 0.0700 | 35,447 |
| 5 | 2018 | 1 | 1 | MSW | 0.0947 | 45,488 |

Note: * values at 7% excess oxygen, 25°C and 1 atm

*Data source: Data obtained from DIW*

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[2] http://www.onep.go.th/eia/

**Incinerations of non-hazardous industrial waste in MSW incinerators:**

Certain non-hazardous industrial waste (IW), such as agricultural wastes, packaging, wood and paper, etc., can be disposed of by incineration, but only with prior approval from DIW. Among the several requirements, this approval process requires information about the characteristics of the industrial waste, as well as the qualification of the waste management operators. The approval for this disposal route [under waste treatment code 074] is only granted to those with incinerators that meet the DIW requirements. Based on data from DIW waste transfer manifest, there were 42,500 tonnes of industrial wastes disposed via incineration in 2017.

Non-hazardous industrial waste incineration is carried out only by DIW-approved waste treatment operators (Factory Category 101), of which the PCDD/F emission limit is generally 0.5 ng TEQ/m$^3$. Therefore, the 2017 incineration of the 42,500 tonnes of non-hazardous industrial wastes is assigned to Toolkit's Class 3.

## Releases of dioxins and furans

The estimated 2017 PCDD/F emissions from Thailand's MSW incineration activities are summarized in Table 3-5. The Toolkit's default emission factors were used to calculate these emission values, resulting in the total emission to air being approximately 3 times that of the combined emission to residue.

Contribution from the 57 Class 1 MSW incinerators is significant. While these incinerators burned only 2.3% of total waste incinerated in 2017 (3.2 million tonnes), they were responsible to most (75.8%) of the PCDD/F emissions from MSW incinerations. Clearly, these incinerators are major sources that need to be addressed in the upcoming plan.

Upgrading these incinerators (improve combustion, install APC) to limit emission to 50 ng TEQ/m$^3$ could drastically cut down the emission (200 g/a). However, emission to fly ash would increase 37.1 g/a, and fly ash would become the dominant route for this source category.

Also, care should be taken to not allow new installation of Class 1 MSW incinerators.

**Table 3-5: Estimated PCDD/F emission from combined MSW incineration activities in 2017**

| **1a** | **Municipal Waste incineration** | **Activity Rate** | **Emission (g TEQ/a)** | | | |
|---|---|---|---|---|---|---|
| | Classification | (tonne)$^{1)}$ | Air | Fly ash | Bottom Ash | **Sub total** |
| 1 | Low technology combustion, no APCS | 74,100 | 259.350 | - | 5.558 | **264.91** |
| 2 | Controlled combustion with minimal APCS | 13,400<br>(0-62,000) | 4.678<br>(0-21.7) | 6.683<br>(0-31) | 0.200<br>(0-0.93) | **11.56**<br>**(0-53.6)** |
| 3 | Controlled combustion with good APC | 91,100*<br>(91.1-750k) | 2.733<br>(2.7-22.5) | 18.222<br>(18-150) | 0.638<br>(0.6-5) | **21.59**<br>**(21.6-177.8)** |
| 4 | High technology combustion, sophisticated APCS | 3,012,000<br>(2.3M) | 1.506<br>(1.1-1.5) | 45.182<br>(34.5-45.2) | 4.518<br>(3.5-4.5) | **51.21**<br>**(39.1-51.2)** |
| | **Total Municipal solid waste incineration** | **3,191,000** | **268.28**<br>**(264-305)** | **70.10**<br>**(66-216)** | **10.92**<br>**(10.8-15.2)** | **349.29**<br>**(340-536)** |

* MSW 48,600 tonnes; non-hazardous IW 42,500 tonnes.

1): numbers rounded to 3 significant figures for legibility.

Values in parenthesis represent (best-worst cases) range (see detail below)

## Uncertainty

Uncertainty for PCDD/F estimations from MSW incinerations can be classified into 3 main sources: uncertainty associated with the estimation of activity rate, uncertainty associated with the emission factor, and uncertainty associated with class assignment.

**Activity rates:**

All the above activity rates for 2017 incineration of MSW are given a high level of confidence as they are national data officially reported by the PCD and the DIW. The PCD data were aggregated from a country wide data entry system. SAO/Cities have a responsibility to regularly report their activities to the system. It is assumed that the data integrity, including data quality control, of the entries was routinely monitored by the responsible agencies.

It shall be noted, however, that the DIW waste manifest data were from the so-call “SK2” the dataset which recorded firms annual requests (or plan) to transfer wastes to the authorities for their approval. Well-established firms with good data keeping tended to provide accurate predictions. Newer firms or firms with lower number of waste tracking records may opt to a slight over estimation to avoid disruption (in case the amount to be transferred exceeds the approved allowance). Nevertheless, the contribution of industrial waste to the overall waste incinerated within this source category is less than 1.5%, hence considered insignificant to the overall confidence level.

**Emission factors:**

The emission factors for MSW incineration are given a medium level of confidence by the Toolkit due to low data coverage and disagreement among different datasets.

**Class Assignment:**

Due to the lack performance based data for the relevant incinerators, a number of assumptions have been made. Because of the large gap between classes, the contribution to the uncertainty of estimation from class assignment is high, especially for activities with high activity rates. The sensitivity of the class assignment to the overall emission estimations is evaluated with two extreme scenarios as follows:

**Worst-case scenario:**

Following scenarios are considered the worst case possible for MSW incineration in Thailand.

- Performances of all of the 37 "proper" MSW incinerators were similar to those of Class 2 (minimal APC).
- 4 WTE plants (with combined capacities of about 0.7 million tonnes/year) with operations closely tied to SAO/Cities' MSW collection operations, though with sophisticated APCS installed failed to meet Class 4. (same situation as the reference case as described in Annex 9 of the Toolkit)

The overall emissions from this source category would increase by 53% to 535 g/a (see Table 3-12 for more detail). Particularly, the 4 under-performed WTE plants would lead to more than 300% (132 g/a) increase in PCDD/F emission into fly ash. This situation, therefore, warrants close attentions from responsible agencies.

Additionally, if the 37 "proper" MSW incinerators performed below expectation, they would increase the emission from this source from 23 g to 53.5 g (230% increases), a 30.5 g increase to the overall emissions.

**Best-case scenario:**

The best case scenario is anticipated if all the 37 "proper" MSW incinerators met Class 3 performance. The overall emissions in this case would be lowered by about 2.5% (see Table 3-13 for more detail).

### 3.1.2 Hazardous waste incineration

Relevant activities

There are 2 main sources of hazardous waste (HW) in Thailand: municipal and industrial. Household HW (HHW) includes electronic waste (e-waste), light bulbs, batteries, chemicals containers, and spray cans, etc. End-of-life products with some residual values (such as ewaste or empty containers) can be sold to waste dismantlers or 'recycle shops' for small money. Small items or HHWs without monetary values are in danger of being disposed of in the municipal solid waste.

The PCD estimated that there were about 0.58 million tonnes of HHW in 2014 [3], about 65% were e-waste. Only 11 provinces had set up HHW collection centers. In 2015, there were 12 provinces with high (>4000 t/a) HHW generation rate. The National Municipal Management Master Plan 2016-2021 acknowledged the problems and had set up plans to prevent HHW from being dispose of in MSW and, instead, to manage them properly. By 2017, all 7,852 SAO/cities were expected to provide drop-off stations within their communities and 10% of the HHWs were expected to be properly managed. The percentage of properly managed HHW is expected to increase to 30% by 2021.

The incineration of industrial HW is regulated by M-Industry's B.E. 2545 (2002) Notification on the Air Emission Standards for Incinerators of Hazardous Industrial Waste [9], which sets an upper PCDD/F air emission limit of 0.5 ng TEQ/$m^3$ (7% $O_2$ and 25°C).

A related regulation is M-Industry's B.E. 2548 (2005) Notification on Industrial Waste Disposal[10], which defines hazardous industrial wastes as those containing or contaminated with hazardous substances, or having hazardous characteristics as described in Annex 2 of the notification. One dioxin congener (2,3,7,8-TCDD) is included as a specified hazardous substances, for which the notification sets a 'total threshold limit concentration' at 0.01 mg/kg and a 'soluble threshold limit concentration' at 0.001 mg/L (via waste extraction test). In spite of these regulatory limits, and the fact that hazardous industrial waste must be treated/disposed of according to DIW standards, no PCDD/F measurement data for industrial wastes (including fly ash and bottom ash from industrial incinerators) were obtained during the course of this study. This absence of the analysis data for TCDD in industrial wastes is may be because of the high analysis cost and the availability of other indicative characteristics. (Waste with this high TCDD contents may also have other indicative characteristics (such as halogen contents or the characteristic of the process that generates it) that are easier and cheaper to evaluate).

## Emission factors

The UNEP Toolkit defines 4 Classes of hazardous waste (HW) incineration based on technology level (including APCS used) and operational practice (e.g., combustion control)

- Class 1: low technology, batch-fed, no APCS
- Class 2: controlled combustion, minimal APCS
- Class 3: improved combustion, good APCS
- Class 4: high technology combustion, sophisticated APCS

Only Class 3 and Class 4 are relevant to Thailand.

The Toolkit's Class 3 HW incinerator is defined as an incinerator with improved combustion efficiency which results in a reduced PCDD/F concentration to about 1 ng TEQ/$Nm^3$(at 11% $O_2$) and a reduced specific flue gas flow rate to about 10,000 $Nm^3$/t HW.

According to the Toolkit, Class 4 HW incinerator is the state-of-the-art HW incinerator with PCDD/F concentration significantly less than 0.1 ng TEQ/$Nm^3$ (at 11% $O_2$) and releases only 7,500 $Nm^3$/t HW.

There is currently only one incinerator for solid HW in operation in

Thailand. This incinerator is a Co-current Rotary Furnace with a Rotary Kiln for the first chamber operating at temperature above 850°C and a Secondary Combustion Chamber operating at 1,100-1,300°C, using natural gas as fuel for combustion [11]. The compositions of HW in the feedings are controlled to make sure that there is enough energy to destruct the hazardous contents within the waste. Although classified as solid HW incineration, this facility accepts both liquid and solid HW.

This incinerator is subjected to the aforementioned PCDD/F emission control at 0.5 ng TEQ/$m^3$ (at 7% $O_2$) by DIW, which make its performance exceeds the Toolkit's Class 3 but not quite meet Class 4 of the Toolkit. However, monitoring data, shown in Table 3-53 (Annex), obtained from DIW and from the firm's EIA monitoring report [11][12] indicate that the plant's actual concentrations were kept below the regulatory limit. More interestingly, the specific flue gas flow rate reported from this facility was about 20% of those specified for the Toolkit's Class 4.

Assuming that the incinerator operated 8,000 hours/year, the corresponding PCDD/F air emission rates from this facility range from 0.138 to 0.589 µg I-TEQ/tonne HW with a median value of 0.228 µg I-TEQ/tonne HW.

PCDD/Fs in fly ash have not been mentioned in the firm's EIA assessment study. There is no other data available to estimate emission factor into residues (fly ash). Therefore, the default emission factor for Class 4 is used for this HW incinerator.

The emission factors to be used for HW incinerators are summarized in Table 3-6).

**Table 3-6: Toolkit's PCDD/F emission factors for hazardous waste incinerators**

| 1b | Hazardous Waste Incinerators | | Emission (µg TEQ/t HW burned) | |
|---|---|---|---|---|
| | Classification | Air (UNEP) | Air (Site specific) | Fly Ash |
| 1 | Low technology combustion, no APCS | 35,000 | - | 9,000 |
| 2 | Controlled combustion with minimal APCS | 350 | - | 900 |
| 3 | Controlled combustion with good APCS | 10 | - | 450 |
| 4 | High technology combustion, sophisticated APCS | 0.75 | 0.23<br>(0.14 to 0.59) | 30 |

## Activity rates

In 2017, there was only one operating incinerator for solid HW and another operating incineration plant for liquid HW.

According to data from DIW waste transfer manifest, the amounts of solid and liquid HW incinerated in 2017 were 95,873 tonnes and 5,800 tonnes, respectively.

Regarding the incineration of liquid HW in 2017, since no PCDD/F measurement data was available, the activity rate from this activity is assigned Class 3 of the Toolkit by virtue of the 0.5 ng TEQ/$m^3$ (at 7% $O_2$

and 25°C) PCDD/F limit applied by the applicable M-Industry Notification.

### Releases of dioxins and furans

The estimated PCDD/F emissions from HW incineration activities in Thailand in 2017 are summarized in Table 3-7. There are only two activities for this source category. The default emission factors were used to estimate emissions from the liquid HW incinerator, which was assigned to Class 3. For the solid HW incinerator, emission into air was estimated using the derived EF based on the site reported data while the emission into residue was estimated using the default EF for Class 4.

**Table 3-7: Estimated PCDD/F emissions from hazardous waste incineration in 2017**

| | **Hazardous waste incineration** | **Activity Rate** | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|
| | Classification | (tonne)1) | Air | Fly Ash | **Subtotal** |
| 1 | Low technology combustion, no APCS | 0 | 0.000 | 0.000 | **0.00** |
| 2 | Controlled combustion with minimal APCS | 0 | 0.000 | 0.000 | **0.00** |
| 3 | Controlled combustion with good APCS | 5,800 | 0.058 | 2.610 | **2.67** |
| 4 | High technology combustion, sophisticated APCS | 95,800 | 0.0218* | 2.874 | **2.90** |
| | **Total Hazardous waste incineration** | **101,600** | **0.08** | **5.48** | **5.56** |

* Calculated using EF derived from site specific data (see Table 3-53.)

1): numbers rounded to 3 significant figures for legibility.

### Uncertainty

Activity rates for 2017 incineration of hazardous industrial waste are given a high level of confidence as they are national data reported by the responsible agency (DIW).

The level of confidence for the emission from the solid HW incinerator is high due to the use of EF derived from site specific data.

The default emission factors are given a low level of confidence by the Toolkit, based on several assumptions made and the lack of bottom ash concentration data.

## 3.1.3 Medical waste incineration

### Relevant activities

The 2013 Toolkit distinguishes medical waste (MW) incinerators into the following 4 classes based on technology level (including the type of APCS used) and operational practice (combustion control)

- Class 1: uncontrolled batch combustion, no APCS
- Class 2: controlled batch combustion, no or minimal APCS
- Class 3: controlled batch combustion, good APCS
- Class 4: high technology, controlled combustion >900°C, sophisticated APCS

With more than 26,800 hospital and health care service providers, the amount of medical or infectious waste in Thailand is growing, causing challenges for proper management. According to PCD, 70% of infectious wastes generated in 2014 were properly incinerated while the fates of the remaining 30% were unclear. The National Municipal Management Master Plan 2016-2021 had set up plans to have all infectious waste properly managed by the year 2020. This target will be achieved through the increase of collection rate, strictly enforce the waste manifest system, and increase number of appropriate disposal sites [3].

Operations related to infectious wastes are controlled by Department of Health (DOH), Ministry of Public Health (MOPH) under the MOPH B.E. 2545 (2002) Ministerial Order on Disposal of Infectious Wastes [13] and MOPH B.E. 2558 (2015) Notification on Criteria and condition for infectious wastes transfer and disposal in local cities and SAOs [14]. Currently the Notification only allowed disposal by 3 methods: Autoclave, Incineration, and Thermal disinfection. For incinerations, only DOH approved incinerators are allowed. The basic requirements for the incinerators stipulated in the MOPH's Notification include a minimum temperature of 760°C in the combustion chamber and at least 1,000°C in the secondary flue gas burner and an APC.

The air emission from infectious waste incinerators in Thailand is controlled by MNRE's B.E. 2546 (2003) Notification on Air Emission Standards for Infectious Waste Incinerators [15]. This Notification prescribes maximum limits for the release of $SO_2$, $NO_2$, HCl, HF, Hg, Cd, Pb, particulate matters, and dioxins. For the release of dioxins to air, the limit is set at 0.5 ng TEQ/$m^3$ (7% $O_2$ and 25°C).

In addition to the legislative measures, the National Municipal Management Master Plan also includes measures to improve hospitals and health-care service providers' and SAO/cities' capacity to holistically address the waste management issues. These measures include, among others, DOH GREEN & CLEAN Hospital Accreditation Initiative and Environmental Health Accreditation (EHA) system for SAO/cities. Systematic management of infectious wastes forms a key element in both G&C Hospital and EHA system. The DOH had set targets for number of government run hospitals that pass G&C Hospital accreditation at 75% by 2017 and 100% by 2018 [16]. These initiatives also parts of the 12th Five-Year National Health Development Plan (2017-2021) [17].

### Emission factors

Despite having an active regulation on PCDD/F emission in place, relevant measurement data for Thai MW incinerators is still generally unavailable. Therefore, the default emission factors prescribed in the UNEP Toolkit, as displayed in Table 3-8, are used to estimate PCDD/F emissions from MW incinerators in Thailand.

The Toolkit classifies MW incinerators into 4 Classes based levels of combustion controls and APCs:

- Class 1 refers to small, box type incinerators operated intermittently without any control. This Class of incinerators releases about 2,000 ng TEQ/Nm³ (at 11% $O_2$).
- Class 2 refers to two chambers incinerators with combustion control but operate in batch mode. This Class of incinerators releases about 200 ng TEQ/Nm³ (at 11% $O_2$).
- Class 3 still refers to batch-type plants with good combustion control but with good APC system. This Class of incinerators is expected to meet the 35 ng TEQ/Nm³ (at 11% $O_2$) emission level.
- Class 4 refers to state-of-the art MW incinerators with 0.1 ng TEQ/$Nm^3$ (11% $O_2$) capability.

Unlike MSW incinerators, plants operations (batch or continuous) are considered less important provided the combustion chambers are preheated above 900°C before feeding wastes into the furnace.

**Table 3-8: PCDD/F emission factors for medical waste incinerators**

| **1c** | **Medical waste incineration** | **Emission Factors (µg TEQ/t MW incinerated)** | | |
|---|---|---|---|---|
| | Classification | Air | Fly Ash | Bottom Ash |
| 1 | Uncontrolled batch type combustion, no APCS | 40,000 | 0 | 200 |
| 2 | Controlled, batch type combustion, no or minimal APCS | 3,000 | 0 | 20 |
| 3 | Controlled, batch type combustion, good APCS | 525 | 900 | 20 |
| 4 | High technology, controlled combustion >900°C, sophisticated APCS | 1 | 150 | 0 |

## Activity rates

For the year 2017, DOH reported a total of 57,954 tonnes of infection (medical) waste being generated, of which about 51,300 tonnes (88.5%) were registered and disposed of properly, while the remaining 6,654 tonnes (11.5%) were unaccounted for and presumed improperly managed (e.g., mixed into municipal waste stream) [1].

According to DOH, among the registered amount, about 41,040 tonnes (80% of 2017 total MW) were collected from their sources and transported to regional MW management center for final disposal. In 2017, there were 10 city-operated and 7 private MW management centers. DOH had regularly audited all facilities. Based on information on the incinerators' characteristics from obtained DOH (see Table 3-15), all incinerators meet or exceed DOH specifications. Based on information from an interview with the responsible agency, all ashes were directed to secured landfill, as specified by the law.

Unfortunately, despite having stack flue gas sampling for analysis every 6 months and dioxin being one of the prescribed parameters, PCDD/F measurement data from these incinerators is still unavailable. The high cost of PCDD/F analysis has been identified as the main cause for this deficiency.

Due to the lack of evidence to support the claim for Class 4, all these 'proper' MW incinerators are assigned to Class 3.

An estimated 4.5% of all MW in 2017 (2,309 tonnes) were incinerated by 61 on-site incinerators due to certain limitations, such as remoteness of some rural medical operations. Based on information from DOH, all these incinerators were two-chambers incinerators operated in batch-mode. However, due to their relatively small size and limited budget for fuel, their operation controls were generally poor. These MW incinerators are, therefore, assigned to Class 2.

Note that Annex 11 of the 2013 Toolkit quotes a set of EF values for one Thai MW incinerator based on data sources published in 2001 and 2002. This incinerator predated the MOPH's 2002 Ministerial Order and the MNRE's Notification. Since this type of incinerator is against the law and there are other options available, it is highly unlikely that this type of incinerator (and practice) still existed and operational in 2017.

### Releases of dioxins and furans

In the absence of relevant emission data for Thailand's MW incinerators, the Toolkit's EF's are adopted for PCDD/F emission calculation. The resulting emission values for Thailand's MW incineration are shown in Table 3-9.

The relatively high amount of PCDD/F released into fly ash and the relatively high PCDD/F concentration in fly ash (estimated at 30,000 ng TEQ/kg) raise management and safety concerns that should be addressed.

Despite the fact that the estimated amounts of the PCDD/F releases are not so significant in comparison with the releases from other source categories, the releases from MW incinerators are originated from only a few sites. The burden to nearby communities can be relatively high. As shown in Table 3-10, one site contributes to more than half of the release and the 4 private sites combined contributes to about 70% of the total releases from Class 3 MW incinerators. If these sites fail to meet stringent emission standards, they can become major sources for UPOPs releases. Since these plants are vital element to the country's infectious waste management and the National Health Development Plan, they deserve close attentions to ensure their prudent operations.

**Table 3-9: Estimated PCDD/F emissions from medical waste incineration in 2017**

| | **Medical waste incineration**<br>Classification | **Activity Rate**<br>(tonne)[1)] | Air | Fly Ash | Bottom Ash | **Subtotal** |
|---|---|---|---|---|---|---|
| | | | | | **Emission (g TEQ/a)** | |
| 1 | Uncontrolled batch combustion, no APCS | 0 | 0.000 | 0.000 | 0.000 | **0.00** |
| 2 | Controlled, batch combustion, no or minimal APCS | 2,310 | 6.927 | 0.00 | 0.046 | **6.97** |
| 3 | Controlled, batch combustion, good APCS | 41,000 | 21.546 | 36.936 | 0.821 | **59.30** |
| 4 | High tech, continuous, sophisticated APCS | 0 | 0.000 | 0.000 | 0.000 | **0.00** |
| | **Total Medical waste incineration** | **43,310** | **28.47** | **36.94** | **0.87** | **66.27** |

1): numbers rounded to 3 significant figures for legibility.

**Table 3-10: Relative contribution for the PCDD/F released from sites with Class 3 MW incinerators**

| **Operator** | **Site** | **Number of Kiln** | **Capacity (t/day)** | **Contribution (%)** |
|---|---|---|---|---|
| Private | A | 3 | 117.6 | 51.1 |
| Private | B | 4 | 21.3 | 9.2 |
| Private | C1 | 1 | 20.0 | 8.7 |
| Private | C2 | 1 | 20.0 | 8.7 |
| Government | A | 2 | 16.8 | 7.3 |
| Government | G | 2 | 12.0 | 5.2 |
| Government | D | 1 | 8.4 | 3.7 |
| Government | B | 1 | 7.2 | 3.1 |
| Government | F | 1 | 3.6 | 1.6 |
| Government | C | 3 | 3.2 | 1.4 |

## Uncertainty

Activity rates for 2017 medical waste incineration are given a high level of confidence because they were national data aggregated from data collected by the responsible agency (DOH).

The level of confidence for class assignment is high due to the availability of attributed data each kiln and the fact that these operations were routinely monitored by responsible agency.

The emission factors are given a low level of confidence by the Toolkit for Class 2 and medium for Class 3 incinerators.

It shall be noted that Class 3 EF into air was derived from European data with stack flue gas PCDD/F concentration and specific flue gas flow rate of 35 ng TEQ/Nm³ (at 11% $O_2$) and 15,000 Nm³/t waste, respectively. Without actual measurement data from representative kilns currently in operation within the country, the overall uncertainty for estimation of emission from Class 3 kilns in Thailand can be high.

## Options for improvement

**Upgrade the relevant facilities:**

If all Class 3 kilns were improved to meet Toolkit Class 4 kilns' 0.1 ng I TEQ/$Nm^3$ (11% $O_2$) standard, the emission from this source would be drastically reduced (90% or 53.1 gTEQ), leaving only 6.2 gTEQ/a remaining from this activity.

However, upgrading all Class 2 kilns to meet Class 3 standards (installing

APCs) would save the communities 3.6 gTEQ/a, but the operators would have to bear the burden to manage the 2.1 gTEQ/a of PCDD/F in the collected fly-ash, which could be counterproductive for operators with limited capacity.

**Ensure proper operations:**

If all the Class 3 kilns were in fact kept at Thailand's 0.5 ng I TEQ/Nm$^3$ (7% $O_2$, 25°C) standard, assuming EFs for these kilns are comparable to those of Class 3 HW incinerators, the estimated emission would be at 19.7 g TEQ (33% of the baseline case).

For operators who opt for Class 2 kilns due to limited capacity, options that do not involve any burning could ensure that the 7 g TEQ of PCDD/F be removed without creating a new contaminated source.

### 3.1.4 Summary

Thailand's total PCDD/F emission from waste incineration during the year 2017 is summarized in Table 3-11 and Figure 3-6, where the emission to air (296.82 g-TEQ/a) accounts for about 70% of the total emission from this source group, and approximate 30% are released into residue (mainly fly ash).

MSW incinerators contributed to 83% of the total emission from waste incineration, with Class 1 MSW incinerators the main source for this source group, contributing about 63%. Medical waste incineration, though contributing only 15.7%, also deserves attention due to concentrated nature of the MW management sites. Since they are vital to the country's waste management and health development plans, these plants deserve attention to minimize the risks.

Although not the most dominant vector, fly ash is also an import pathway that demands consideration.

**Table 3-11: Summary of estimated PCDD/F emission from waste incineration in 2017**

| **G1** | **Waste incineration** | | | | **Emission (g TEQ/a)** |
|---|---|---|---|---|---|
| | Category | Air | Fly ash | Bottom ash | **Subtotal** |
| a | Municipal solid waste incineration | 268.28 | 70.10 | 10.92 | **349.29** |
| b | Hazardous waste incineration | 0.08 | 5.49 | - | **5.56** |
| c | Medical waste incineration | 28.47 | 36.94 | 0.87 | **66.27** |
| | **Total Waste incineration** | **296.83** | **112.52** | **11.78** | **421.11** |

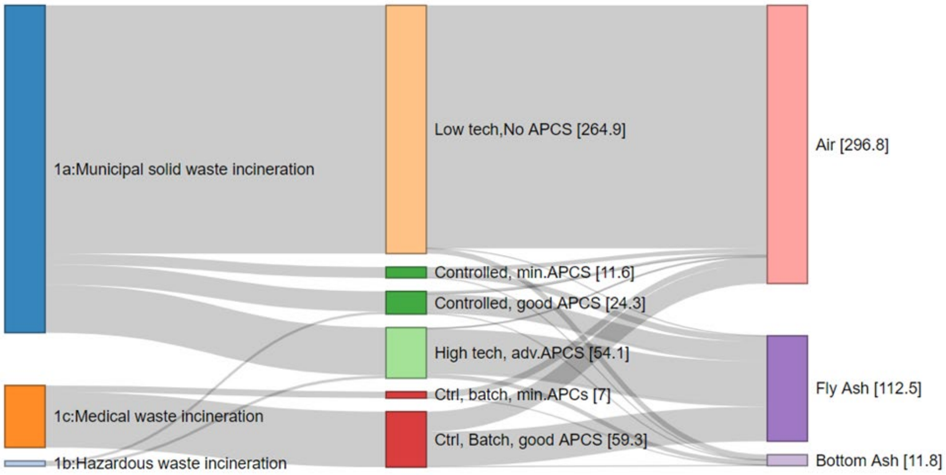

**Figure 3-6: Summary of PCDD/F emissions from waste incineration in 2017 [unit: g TEQ/a]**

□□□

# Annex 1. Supporting information for Source Group 1

### Table 3-12: Upper bound estimations for 2017 PCDD/F emissions from MSW incineration

| **1a** | **Municipal Waste incineration** | **Activity Rate** | | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|---|
| | Classification | (tonne) 1) | Air | Fly ash | Bottom Ash | **Sub total** |
| 1 | Low technology combustion, no APCS | 74,100 | 259.350 | - | 5.558 | **264.91** |
| 2 | Controlled combustion with minimal APCS | 62,000 | 21.700 | 31.000 | 0.930 | **53.63** |
| 3 | Controlled combustion with good APC | 750,000* | 22.510 | 150.064 | 5.252 | **177.83** |
| 4 | High technology combustion, sophisticated APCS | 2,304,000 | 1.152 | 34.563 | 3.456 | **39.17** |
| | **Total Municipal solid waste incineration** | **3,191,000** | **304.71** | **215.63** | **15.20** | **535.53** |

* MSW 0 tonnes; non-hazardous IW 42,500 tonnes, WTE. 709,000 tonnes

1): numbers rounded to 3 significant figures for legibility.

### Table 3-13: Lower bound estimations for 2017 PCDD/F emissions from MSW incineration

| **1a** | **Municipal Waste incineration** | **Activity Rate** | | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|---|
| | Classification | (tonne) 1) | Air | Fly ash | Bottom Ash | **Sub total** |
| 1 | Low technology combustion, no APCS | 74,100 | 259.350 | - | 5.558 | **264.91** |
| 2 | Controlled combustion with minimal APCS | 0 | 0 | 0 | 0 | **0** |
| 3 | Controlled combustion with good APC | 104,500* | 3.135 | 20.900 | 0.732 | **24.77** |
| 4 | High technology combustion, sophisticated APCS | 3,012,000 | 1.506 | 45.180 | 4.518 | **51.20** |
| | **Total Municipal solid waste incineration** | **3,191,000** | **263.99** | **66.08** | **10.81** | **340.88** |

* MSW 62,000 tonnes; non-hazardous IW 42,500 tonnes

1): numbers rounded to 3 significant figures for legibility.

### Table 3-14: Reported PCDD/F emissions to air, and the associated EFs, for Thailand's incinerator of solid hazardous industrial waste during 2014-2018

| **Year** | **Period** | **PCDD/F (ng I-TEQ/$m^3$) 1)** | **Exhaust rate ($m^3$/hr) 3)** | **Total Emission (µg I-TEQ)** | **Waste Incinerated (tonne) 3)** | **Specific Flue gas volume (m3/t HW)** | **Calculated EF (µg I-TEQ/ton)** |
|---|---|---|---|---|---|---|---|
| 2010 | 1 | 0.446 2) | No data | - | No data | - | - |
| 2011 | 1 | 0.057 2) | No data | - | No data | - | - |
| 2011 | 2 | 0.318 2) | No data | - | No data | - | - |
| 2012 | 1 | 0.283 2) | No data | - | No data | - | - |
| 2012 | 2 | 0.270 2) | 27,039 | 29,202 | No data | - | - |
| 2014 | 1 | 0.220 2) | No data | - | No data | - | - |
| 2014 | 2 | 0.490 2) | No data | - | No data | - | - |
| 2015 | 1 | 0.179 2) | 29,212 | 20,916 | No data | - | - |
| 2015 | 2 | 0.153 2) | 28,049 | 17,166 | No data | - | - |
| 2016 | 1 | 0.349 3) | 16,684 | 23,291 | 54,785 | 1,218 | 0.425 |
| 2016 | 2 | 0.096 3) | 19,906 | 7,644 | 55,374 | 1,438 | 0.138 |
| 2017 | 1 | 0.114 3) | 19,096 | 8,708 | 46,063 | 1,658 | 0.189 |
| 2017 | 2 | 0.343 3) | 21,386 | 29,341 | 49,810 | 1,717 | 0.589 |
| 2019 | 1 | 0.160 3) | 19,355 | 12,387 | 54,251 | 1,427 | 0.228 |

1) 7% $O_2$, 25°C and 1 atm

2) Data extracted from EIA monitoring report [11][12]

3) Data obtained from DIW

### Table 3-15: Characteristics of medical waste incinerators in operation in 2017

| ID[1)] | Type | Capacity | Unit | Combustion Chamber | Flue gas burner | APC | Monitoring |
|---|---|---|---|---|---|---|---|
| G.A1 | Rotary Kiln | 7.2 | t/d | 760-900°C | 1,000-1,200°C | Bag House Filter | Air Sampling every 6 months |
| G.A2 | Rotary Kiln | 9.6 | t/d | 760-900°C | 1,000-1,200°C | Dry Scrubber and Wet Scrubber | CEM & Air Sampling every 6 months |
| G.B1 | Rotary Kiln | 7.2 | t/d | 760-900°C | 1,000-1,200°C | Dry Scrubber and Wet Scrubber | CEM & Air Sampling every 6 months |
| G.C1 | Stoker | 100 | kg/hr | 900-1,300°C | 900-1,300°C | Cyclone and Bag House Filter | Regional Environmental Office & PCD audit |
| G.C2 | Stoker | 100 | kg/hr | 900-1,300°C | 900-1,300°C | Cyclone and Bag House Filter | Regional Environmental Office & PCD audit |
| G.C3 | Stoker | 200 | kg/hr | 900-1,300°C | 900-1,300°C | Cyclone and Bag House Filter | Regional Environmental Office & PCD audit |
| G.D1 | Rotary Kiln | 8.4 | t/d | > 900°C | > 1,000°C | Cyclone and Bag House Filter | Air Sampling every 6 months |
| G.F1 | Rotary Kiln | 3.6 | t/d | 760-900°C | 1,000-1,200°C | Dry Scrubber and Wet Scrubber | CEM & Air Sampling every 6 months |
| G.G1 | Rotary Kiln | 6 | t/d | 760-900°C | 1,000-1,200°C | Dry Scrubber and Wet Scrubber | CEM & Air Sampling every 6 months |
| G.G1 | Rotary Kiln | 6 | t/d | 760-900°C | 1,000-1,200°C | Dry Scrubber and Wet Scrubber | CEM & Air Sampling every 6 months |
| P.A1 | Pyrolysis | 57.6 | t/d | 760-900°C | 1,000-1,200°C | Wet Scrubber and Bag House Filter | Air Sampling every 6 months |
| P.A2 | Pyrolysis | 48.0 | t/d | 760-900°C | 1,000-1,200°C | Wet Scrubber and Bag House Filter | Air Sampling every 6 months |
| P.A3 | Pyrolysis | 12.0 | t/d | 760-900°C | 1,000-1,200°C | Wet Scrubber and Bag House Filter | Air Sampling every 6 months |
| P.B1 | Pyrolysis | 500 | kg/hr | 760-900°C | 1,000-1,200°C | No data | Air Sampling every 6 months |
| P.B2 | Pyrolysis | 500 | kg/hr | 760-900°C | 1,000-1,200°C | No data | Air Sampling every 6 months |
| P.B3 | Pyrolysis | 830 | kg/hr | 760-900°C | 1,000-1,200°C | No data | Air Sampling every 6 months |
| P.B4 | Pyrolysis | 830 | kg/hr | 760-900°C | 1,000-1,200°C | No data | Air Sampling every 6 months |
| P.C1 | Rotary Kiln | 20 | t/d | >900°C | >1,200°C | Cyclone and Bag House Filter | Air Sampling every 6 months |
| P.C2 | Pyrolysis | 20 | t/d | 800-850°C | > 1,200°C | Bag House Filter and Activated Carbon | Air Sampling every 6 months |

1) G: City-run, P: Private-run

*Data Source: Data obtained from Department of Health*

## 3.2 Source Group 2: Metal Production

The UNEP Toolkit categorizes emission sources within this source group into 12 source categories:

- Iron ore sintering (2a)
- Coke production (2b)
- Iron and steel production and foundries (2c)
- Copper production (2d)
- Aluminum production (2e)
- Lead production (2f)
- Zinc production (2g)
- Brass and bronze production (2h)
- Magnesium production (2i)
- Other non-ferrous metal production (2j)
- Shredders (2k)
- Thermal wire reclamation (2l)

Activities within the following 7 source categories took place in Thailand in 2017 and are included in this study: iron and steel production, copper production, aluminum production, lead production, zinc production, brass and bronze production, and thermal wire reclamation.

The following 5 source categories are not included in this report:

- Iron ore sintering, as Thailand does not process iron ores;
- Coke production, as this activity does not exist in Thailand;
- Magnesium production, as this activity did not exist in Thailand in 2017 (to the best of the inventory team’s knowledge);
- Production of other non-ferrous metal, as there is insufficient data for evaluation;
- Shredders, as Thailand has no registered shredding plants for end-of-life vehicles or consumer goods.

The activity rates for this source group, as well as certain attribute data used for their classification, were primarily obtained from the following sources:

- OIE background data for the derivation of OIE industrial indices (as of 29 May 2019) [18]
- DIW “Factory Registration Data” (last access February 2019) [19]
- DIW “Industrial Waste Transfer Manifest” [20]
- ISIT report on yearly steel production [21], ISIT provided data, including attribute data, hot-dip galvanization volumes, and

series of interview with the institute's assigned expert.

- EIA reports from Office of Natural Resources and Environmental Policy and Planning (ONEP) [online data on ONEP web portal[3], last retrieved October 2019]
- Thai Customs: raw material import and export data for iron foundries, copper production, and brass/bronze production
- Information gained from an interview with DPIM's officers
- Information gained from interviews with relevant stakeholders

At the time of this report, Thailand still has had no direct law to control PCDD/F emission from metal production plants. An existing related regulation is the M-Industry's 2005 Notification that stipulates a 0.5 ng TEQ/$m^3$ at 7% $O_2$ and 25°C (equivalent to 0.389 ng TEQ/$Nm^3$ at 11% $O_2$ and 0°C) PCDD/F air emission limit for plants (including metal production plants) that use 'processed used oils' or 'synthetic fuel from waste blending' to heat their furnaces [22].

### 3.2.1 Iron and steel production

Relevant activities

The UNEP Toolkit defines a total of 11 classes for this source category, which, for the purpose of this report, are further grouped into the following 3 subcategories:

**Iron- and steel-making:**

This subcategory comprises the following 4 classes, based on technology (type of furnace and APCS used) and operational practice (quality of scrap input):

- Class 1: dirty scrap, scrap preheating, limited control (excluding basic oxygen furnaces (BOF) and blast furnaces (BF))
- Class 2: clean scrap/virgin iron or dirty scrap, afterburner and fabric filter (excluding BOF and BF)
- Class 3: clean scrap/virgin iron or dirty scrap, electric arc furnaces (EAF) with APCS designed for low PCDD/F emission, and BOF
- Class 4: BF with APCS

Class 4 of this subcategory does not apply to Thailand as there is no blast furnace operation in the country. And according to information from ISIT, Class 1 is also not relevant since Thai steel makers generally use clean, oil-free scrap as their inputs, along with bag filters for gas cleaning.

As Thai steel makers employ either electric arc furnaces (EAF) or induction furnaces (IF), the M-Industry regulation on plants that use 'processed used oils' or 'synthetic fuel from waste blending' to heat their furnaces therefore does not apply to them.

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[3] http://eia.onep.go.th/index.php

### Iron foundries:

This subcategory comprises the following 4 classes, based on the type of furnace and type of gas cleaning:

- Class 1: cold or hot air cupola or rotary drum furnaces, no APCS
- Class 2: rotary drum furnaces with fabric filters or wet scrubbers
- Class 3: cold air cupolas with fabric filters or wet scrubbers
- Class 4: hot air cupolas or IF's with fabric filters or wet scrubbers

The above Class 1 is not applicable to Thailand since all lawful iron foundries are required to use APCS. Class 2 is also irrelevant as Thai foundries generally employ cupola or induction furnaces. According to an ISIT report [23], there were approximately 179 iron foundries in Thailand in 2004, most of which were situated outside industrial estates and were of medium sizes (100-500 tonne/month capacity), while 19 were of the large-size category (above 500 tonne/month capacity).

### Hot-dip galvanizing (HDG) plants

This subcategory comprises the following 3 classes based on technology (APCS used) and operational practice (degreasing step):

- Class 1: facilities without APCS
- Class 2: facilities with good APCS but no degreasing step
- Class 3: facilities with good APCS and degreasing step

According to data obtained from ISIT, Thai HDG plants practice degreasing as a common surface preparation step prior to galvanization, and most key players in this industry have fume control in place. Therefore, Classes 1 and 2 are considered irrelevant to Thailand.

## Emission factors

An overview of the 2013 UNEP Toolkit's emission factors for the 3 subcategories under the iron and steel production source category is shown in Table 3-16 to Table 3-18, respectively. Due to the lack of available measurement data, Thailand's EFs could not be estimated for this source category.

**Table 3-16: UNEP's PCDD/F emission factors for iron- and steel-making**

| 2ca | Iron and steel plants | Emission factor (µg TEQ/tonne liquid steel) | |
|---|---|---|---|
| | Classification | Air | Residue |
| 1 | Dirt scrap, scrap preheating, limited control | 10 | 15 |
| 2 | Clean scrap/virgin iron or dirty scrap, afterburner and fabric filter | 3 | 15 |
| 3 | Clean scrap/virgin iron or dirty scrap, EAF with APCS designed for low PCDD/F emission, and BOF | 0.1 | 0.1 |
| 4 | Blast furnaces with APCS | 0.01 | No data |

**Table 3-17: UNEP's PCDD/F emission factors for iron foundries**

| 2cb | Iron foundries | Emission factor (µg TEQ/tonne liquid steel) | |
|---|---|---|---|
| | Classification | Air | Residue |
| 1 | Cold or hot air cupola or rotary drum, no gas cleaning | 10 | No data |
| 2 | Rotary drum, fabric filter or wet scrubber | 4.3 | 0.2 |
| 3 | Cold air cupola, fabric filter or wet scrubber | 1 | 8 |
| 4 | Hot air cupola or induction furnace, fabric filter or wet scrubber | 0.03 | 0.5 |

**Table 3-18: UNEP's PCDD/F emission factors for hot-dip galvanization**

| 2cc | Hot-dip galvanization | Emission Factor (µg TEQ/tonne galvanized iron/steel) | |
|---|---|---|---|
| | Classification | Air | Residue |
| 1 | Facilities without APCS | 0.06 | 0.01 |
| 2 | Facilities with good APCS but without degreasing step | 0.05 | 2 |
| 3 | Facilities with good APCS and with degreasing step | 0.02 | 1 |

## Activity rates

Two sources of information are available, OIE and ISIT. Data from OIE (Table 3-39) represents downstream semi-finished steel productions which are irrelevant to PCDD/F emission. ISIT data, on the other hand, refers to midstream steel productions (billets and slabs) which are the target activities for this assessment. Therefore, data from ISIT is used in this study.

Steel production plants with capacity over 100 tonnes/day are subjected to the EIA reporting under the MNRE's EIA regulation [24]. Searches using relevant keywords (in Thai) found 10, 35, and 16 projects related to billets, casting, and hot-dip galvanized, respectively. When necessary, information from these reports are used to cross-check the validity of activity data and technology classification.

**Iron- and steel-making plants:**

According to information from ISIT, there were 27 steel production plants operating in Thailand in 2017 that produced a combined total of 6,761,808 tonnes of steel. Sixteen of these plants used electric arc furnaces (EAF), and the remaining 11 plants used induction furnaces (IF).

Based on information from firms' EIA reports, Thai steel plants generally use scraps from manufacturing sectors as well as discarded materials sourced from recycle shops as their inputs. Apart from material type segregation and size reduction, there is no indication of dedicated scrap cleaning process to remove oil or paints before feeding them into the furnaces.

Plants with capacity over 100 tonne/day are required by DIW to routinely monitor and report their air and water emissions [25]. For steel plants without fuel burnings, exhaust air qualities to be reported include particulate matters and CO. As a result, all plants employ hoods, cyclones and bag house filters for cleaning exhaust gas, but are not equipped with APCS specifically designed for PCDD/F emission reduction.

Typical Thai steel plants are, therefore, assigned to Class 2 of the Toolkit by default (Table 3-16). However, the Thai government (DIW and PCD) in collaboration with UNIDO had conducted projects to monitor PCDD/F emissions from various sources as identified in the previous 2005 UPOPs inventory report.

Data from 4 Thai steel plants (2016-2017 data from 3 plants, and 2009-2011 data from 1 plant) indicate that their PCDD/F concentrations were below the 0.1 ng TEQ/m$^3$ benchmark value for Class 3. The combined 2017 steel production value of these 4 plants (about 1,046,468 tonnes) is therefore assigned to Class 3 of the Toolkit, while the rest (5,715,340 tonnes) remain in Class 2.

### Iron foundries:

There are about 120 iron foundries in DIW factory registration database; about 35 of these factories are large firms with combined capital investments over 90% of total investment in this sector.

A search in ONEP EIA database with relevant keywords (in Thai) found 35 projects from 11 firms, with combined iron scraps demands of about 500,000 tonnes/year. All plants use induction furnaces to melt irons.

According to ISIT, there are 4 main types of raw materials used in iron foundries in Thailand: pig iron, imported cast iron scraps, domestic cast iron scraps, and ferroalloys. In 2017, approximately 32,677 tonnes of imported pig iron went to iron foundries, while the net import of cast iron scraps amounted to about 486,148 tonnes. These 2 imported inputs combine to a total of 518,825 tonnes. With quantities of ferroalloys and domestic cast iron scraps unknown, the inventory team therefore proposes an upper-bound estimate of 800,000 tonnes as the total iron foundry activity rate for Thailand for the year 2017, with 90% assigned to Class 4 (foundry with IF or hot air cupola) and 10% to Class 3 (foundry with cold air cupola).

### Hot-dip galvanizing plants:

There are about 75 factories with hot-dip galvanization process mentioned in DIW factory registration database[4]. 15 of these factories are large firms with combined capital investments over 95% of total investment in this sector.

According to ISIT data, a total of 1,026,047 tonnes of hot-dip galvanized (HDG) steel was produced in Thailand in 2017 by 11 operating HDG

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[4] Factory types: 59, 63(2), 63(3), 64(6), 64(8), 64(10), 64(14), 100(5) and 100(6)

plants.

A search on HDG relevant keywords (in Thai) in ONEP EIA database found 16 projects from 8 firms, with combined capacity of about 2 million tonnes per year. All HDG plants employ series of treatment to remove oil and prepare surface for efficient galvanization. Typical surface treatment process includes alkaline cleaning followed by washing, acid (HCl) pickling and annealing.

Air emissions from factories are generally controlled by MNRE and M-Industry's air emission limits [26][27]. Typical parameters include total suspended solids (TSP), $SO_2$ and $NO_2$. Air emissions from large, EIA relevant, HDG plants, however, are more stringent with TSP in the order of 10 to 25 mg/Nm$^3$, about an order of magnitude lower than regulatory limits.

Releases of dioxins and furans

The estimated 2017 PCDD/F emissions from Thailand's iron and steel production activities are summarized in Table 3-19 to Table 3-21. The Toolkit's default emission factors were used to calculate these emission values, indicating steel-production residue as the largest emission vector of this source category.

**Table 3-19: Estimated PCDD/F emission from iron- and steel-making plants in 2017**

| **2ca** | **Steel-making** Classification | **Activity Rate** (tonne)[1)] | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|
| | | | Air | Residue | **Sub total** |
| 2 | Clean scrap/virgin iron or dirty scrap, afterburner and fabric filter | 5,720,000 | 17.146 | 85.730 | **102.88** |
| 3 | Clean scrap/virgin iron or dirty scrap, EAF with APCS designed for low PCDD/F emission, and BOF | 1,050,000 | 0.105 | 0.105 | **0.21** |
| | **Total Steel making** | **6,770,000** | **17.25** | **85.83** | **103.09** |

1): numbers rounded to 3 significant figures for legibility.

**Table 3-20: Estimated PCDD/F emission from iron foundries in 2017**

| **2cb** | **Iron foundries** Classification | **Activity Rate** (tonne)[1)] | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|
| | | | Air | Residue | **Sub total** |
| 3 | Cold air cupola, fabric filter or wet scrubber | 80,000 | 0.080 | 0.640 | **0.72** |
| 4 | Hot air cupola or induction furnace, fabric filter or wet scrubber | 720,000 | 0.022 | 0.360 | **0.38** |
| | **Total Iron foundries** | **800,000** | **0.10** | **1.00** | **1.10** |

1): numbers rounded to 3 significant figures for legibility.

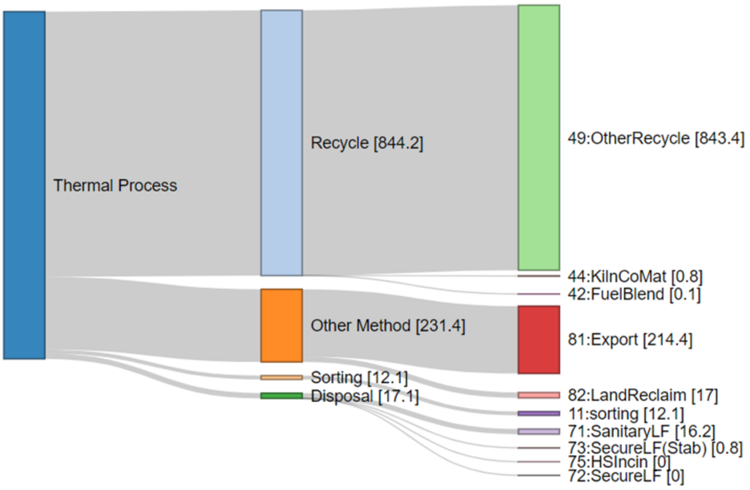
**Table 3-21: Estimated PCDD/F emission from hot-dip galvanizing plants in 2017**

| **2cc** | **Hot-dip galvanizing plants** Classification | **Activity Rate** (tonne)[1)] | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|
| | | | Air | Residue | **Sub total** |
| 3 | Facilities with good APCS and with degreasing step | 1,030,000 | 0.021 | 1.026 | **1.05** |
| | **Total** | **1,030,000** | **0.02** | **1.03** | **1.05** |

1): numbers rounded to 3 significant figures for legibility.

## Fate of residues

Based on data from DIW waste transfer requests [20], in 2017 iron and steel related production plants reported about 1.6 million tonnes of wastes from their thermal processes; about 1.1 million tonnes were slags and dusts. The fate of these residues can be illustrated in Figure 3-7.



Unit: thousand ton,

*Data source: DIW (data from SK 2 form)*

**Figure 3-7: Destinations of slags and dusts from iron and steel production plants in 2017**

## Uncertainty

The level of confidence for the activity rates for steel making and HDG is high due to the relatively comprehensive coverage of production data gathered by ISIT. The level of confidence for iron foundries activity rate is medium as it includes an approximation for the missing amounts of input materials (domestic cast iron scrap and ferroalloys).

The level of confidence in the class assignment for steel making and HDG is high due to the coverage of attribute data by ISIT and existence of technology-related information from firms’ EIA reports. For iron foundries, the level of confidence is medium to high. Although attribute data are available (from EIA reports) for the type of technology employed by large firms, data on technology used by the bottom 10% firms are lacking.

For steel making, the level of confidence for emission factors for the classes relevant to Thailand is high, with the exception of Class 3 residue which is associated with medium level of confidence. For iron foundries, the EF level of confidence for the classes relevant to Thailand is medium, with the exception of Class 3 residue which is given low level of confidence. And for hot-dip galvanization, the air EFs level of confidence is medium, while residue EFs level of confidence is low.

### 3.2.2 Copper production

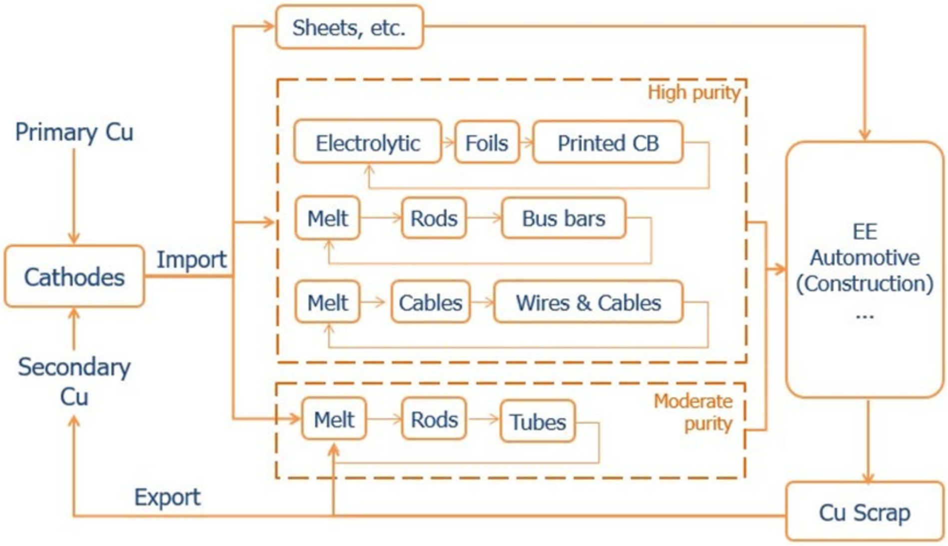
Relevant activities

The UNEP Toolkit defines 6 classes of copper production based on technology level and raw materials used:

- Class 1: secondary Cu – basic technology
- Class 2: secondary Cu – well controlled
- Class 3: secondary Cu – optimized for PCDD/F control
- Class 4: smelting and casting of Cu and Cu alloys
- Class 5: primary Cu – well controlled, with secondary feed materials
- Class 6: pure primary Cu smelter with no secondary feed materials

As the inventory team found no secondary copper production plant in Thailand, Classes 1 to 3 are thus deemed irrelevant. Similarly, Classes 5 and 6 are also considered irrelevant as Thailand no longer engages in primary copper production.

Copper production activities in Thailand involve processing (imported) semi-finished copper into parts (rods, tubes, wires, cables) for electronic/electrical, automotive, and construction applications. A flowchart representing Thailand's copper value chain is shown in Figure 3-8.



Source: *Adapt from ISIT* [28]

**Figure 3-8: Value chain of Thailand's copper industry**

Emission factors

An overview of UNEP Toolkit's emission factors for copper production is shown in Table 3-22. Due to the lack of accessible measurement data, Thailand's EFs could not be estimated for this source category.

**Table 3-22: UNEP's PCDD/F emission factors for copper production**

| 2d | Copper Production<br>Classification | Emission factors (µg TEQ/t copper)<br>Air | <br>Water | <br>Residue |
|---|---|---|---|---|
| 1 | Secondary Cu – basic technology | 800 | 0.5 | 630 |
| 2 | Secondary Cu – well controlled | 50 | 0.5 | 630 |
| 3 | Secondary Cu – optimized for PCDD/F control | 5 | 0.5 | 300 |
| 4 | Smelting and casting of Cu and Cu alloys | 0.03 | 0.5 | No data |
| 5 | Primary Cu – well controlled, with secondary feed materials | 0.01 | 0.5 | No data |
| 6 | Pure primary Cu smelter with no secondary feed materials | No data | 0.5 | Not applicable |

Part 3

## Activity rates

Imported copper cathodes make up the largest fraction of raw materials for copper production in Thailand. The 2017 net import values of the follow raw materials (and their 6-digit HS codes) are considered (Table 3-23): unrefined copper (740200), cathodes and sections of cathodes (740311), wire bars (740312), billets (740313), other refined copper (740319), other copper alloys (740329), copper waste and scrap (740400). These values combine to 291,802 tonnes; therefore, an activity rate of 300,000 is approximated for Thailand's copper production in 2017. Note that most Thai copper scrap is presumed to be exported for conversion into semi-finished forms (e.g., cathodes) in other countries.

Among copper products, copper tubes can tolerate higher impurity than electric wires and cables. According to DIW factory registration database, there were 5 registrations in 2017 with two factories accounting for 97% of total investment in this sector. Based on EIA reports from these 2 factories, about 25-35% of external scrap coppers can be accepted, but with a tight quality control. The amount of external scrap coppers consumed by these 2 firms was about 33,000 tonnes/year.

**Table 3-23: Thailand's imports and exports of copper in 2017 (tonne)**

| HS Code | Description | Import | Export | Net |
|---|---|---|---|---|
| 740200 | Unrefined copper; copper anodes for electrolytic refining. | 852 | 2,733 | **(1,881)** |
| 740311 | Cathodes and sections of cathodes | 351,463 | 115 | **351,348** |
| 740312 | Wire-bars | 0 | 0 | **0** |
| 740313 | Billets | 7,835 | 0 | **7,835** |
| 740319 | Other | 3,449 | 205 | **3,244** |
| 740329 | Other copper alloys (other than master alloys of heading 74.05) | 263 | 1,381 | **(1,118)** |
| 740400 | Copper waste and scrap | 15,387 | 83,013 | **(67,626)** |
| | **Total** | **379,250** | **87,447** | **291,802** |

*Data source: Thai Customs*

## Releases of dioxins and furans

The estimated PCDD/F emissions from copper production activities in Thailand in 2017 are summarized in Table 3-24.

**Table 3-24: Estimated PCDD/F emissions from copper production in 2017**

| **2d** | **Copper Production** | **Activity Rate** | | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|---|
| | Classification | (tonne) | Air | Water | Residue | Total |
| 4 | Smelting and casting of Cu and Cu alloys | 300,000 | 0.009 | 0.150 | No data | **0.16** |

Uncertainty

The level of confidences for Thailand's copper production is medium for activity rate as it is a projection based on combined net import of raw materials, and high for class assignment as Thailand does not produce its own copper cathodes, either from primary or recycled raw materials.

The level of confidence for Class-4 EFs to air and water is medium according to the 2013 Toolkit.

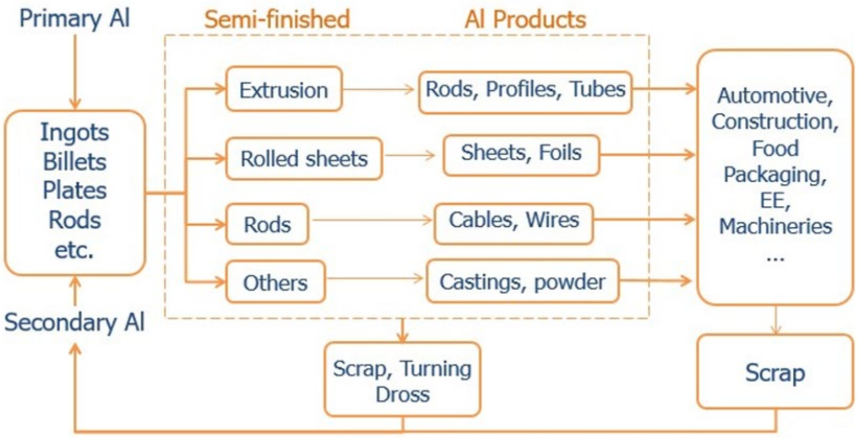
### 3.2.3 Aluminum production

Relevant activities

The 2013 Toolkit distinguishes 6 classes of aluminum production based on technology level and raw materials used:

- Class 1: thermal scrap processing, minimal input treatment, simple dust removal
- Class 2: thermal processing, scrap pre-treatment, well controlled, fabric filters with lime injection
- Class 3: optimized process for PCDD/F control – afterburners, lime injection, fabric filters, activated carbon
- Class 4: drying of shavings/turnings (simple plants)
- Class 5: thermal de-oiling of turnings, rotary furnaces with afterburners and fabric filters
- Class 6: pure primary Al production

Activities in all classes are considered relevant to Thailand, except for Class 6 as the country does not produce primary aluminum due to the lack of bauxite and the high cost associated with primary production [29]. Thailand produces aluminum products such as rods, profiles, tubes, sheets and foils, wires and cables, and castings from semi-finished aluminum (billets, ingots, etc.) in order to serve demands from construction, electronic/electrical, automotive, and packaging industries. A flowchart representing Thailand's Al value chain is shown in Figure 3-9.



*Source: Adapt from ISIT*

**Figure 3-9: Value chain of Thailand's aluminum industry**

## Emission factors

An overview of UNEP Toolkit's emission factors for aluminum production is shown in Table 3-25. Due to the lack of available measurement data, Thailand's EFs could not be estimated for this source category.

**Table 3-25: UNEP's PCDD/F emission factors for aluminum production**

| 2e | **Aluminum Production** | **Emission factor (µg TEQ/t Al)** | |
|---|---|---|---|
| | Classification | Air | Residue |
| 1 | Thermal scrap processing, minimal input treatment, simple dust removal | 100 | 200 |
| 2 | Thermal processing, scrap pre-treatment, well controlled, fabric filters with lime injection | 4 | 400 |
| 3 | Optimized process for PCDD/F control – afterburners, lime injection, fabric filters, activated carbon | 0.5 | 100 |
| 4 | Drying of shavings/turnings (simple plants) | 5 | Not applicable |
| 5 | Thermal de-oiling of turnings, rotary furnaces with afterburners and fabric filters | 0.3 | Not applicable |
| 6 | Pure primary Al production | No data | No data |

## Activity rates

In 2017, there were more than 250 aluminum related factories in DIW factory registration database. Most of these factories were SMEs. However, there were about 50 large firms, with combined investment contributed to about 95% of overall investment in this sector.

There are no official records of Al productions and consumptions in Thailand. The activity rate data presented here was derived primarily from import/export statistics, EIA reports submitted by major producers, and the amount of waste transferred from DIW waste manifests database, as follows.

In 2017, Thailand's net import quantity of aluminum raw material was about 650,000 tonnes[5], as shown in Table 3-26. There was no record of end-uses of these materials or records of amounts of secondary materials available. However, a search in DIW waste transfer requests yielded about 100,000 tonnes of aluminum wastes from shaping processes available. Assuming equal amount of Al scraps was available from other sources, the total amount of relevant raw materials is estimated at 850,000 tonnes.

A search in ONEP EIA database found 33 projects from 22 firms. Only aluminum smelters were taken into account. An approximate production value of 600,000 tonnes is assigned to Class 3, based on a major Al producer's EIA report that indicates the use of state-of-the-art process with dioxin burners for their exhaust air.

About 200,000 tonnes are placed in Class 2 to represent mid-sized Al smelters whose operational practices are presumably in line with that class. An additional 50,000 tonnes is estimated for Class 1, to account for the existing smaller Al smelters using basic technology with minimal input selection and treatment.

Additionally, data gathered from DIW's waste transfer manifest indicated approximately 100,000 tonnes of Al shavings and turning in 2017. However, the inventory team instead proposes an upper-bound value of 500,000 tonnes for use in this inventory. 20% and 80% of this proposed amount are placed into Classes 4 and 5, respectively.

**Table 3-26: Thailand's import and export of unwrought and scrap aluminum in 2017 (tonne)**

| HS Code | Description | Import | Export | Net |
|---|---|---|---|---|
| 7601 | Unwrought aluminum | 710,282 | 56,095 | **654,187** |
| 7602 | Waste and scrap, of aluminum | 108,252 | 111,298 | **(3,046)** |
| | **Total** | **818,534** | **167,393** | **651,141** |

*Data source: Thai Customs*

## Releases of dioxins and furans

The estimated PCDD/F emissions from HW incineration activities in Thailand in 2017 are summarized in Table 3-27, indicating that emission from Al production was the leading contributor among Thailand's metal production sector, with residues being the main release vector.

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[5] Note: Not all of these quantities are relevant to PCDD/F emission. Aluminum scraps can be anticipated to be used by smelters but not all unwrought aluminum can.

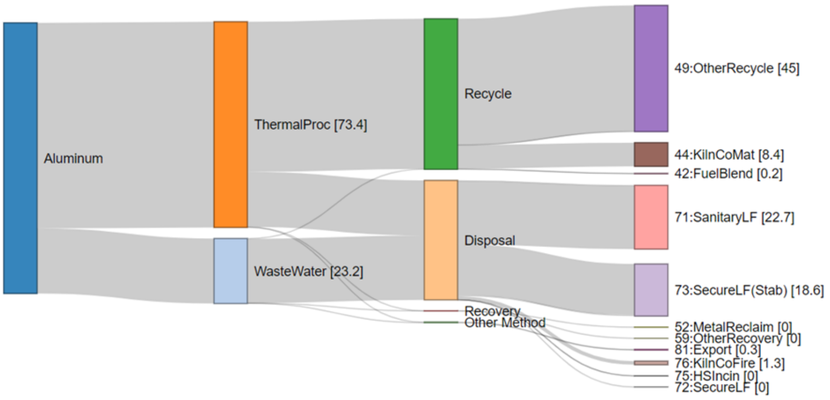
**Table 3-27: Estimated PCDD/F emission from Source Category 2e - aluminum production in 2017**

| 2e | **aluminum production**<br>Classification | **Activity Rate**<br>(tonne) | Air | **Emission (g TEQ/a)**<br>Residue | **Sub total** |
|---|---|---|---|---|---|
| 1 | Thermal scrap processing, minimal input treatment, simple dust removal | 50,000 | 5.000 | 10.000 | **15.00** |
| 2 | Thermal processing, scrap pre-treatment, well controlled, fabric filters with lime injection | 200,000 | 0.700 | 80.000 | **80.70** |
| 3 | Optimized process for PCDD/F control – afterburners, lime injection, fabric filters, activated carbon | 600,000 | 0.300 | 60.000 | **60.30** |
| 4 | Drying of shavings/turnings (simple plants) | 100,000 | 0.50 | 0 | **0.50** |
| 5 | Thermal de-oiling of turnings, rotary furnaces with afterburners and fabric filters | 400,000 | 0.12 | 0 | **0.12** |
| | **Total** | **1,350,000** | **6.62** | **150.00** | **156.62** |

## Fate of residues

Based on data from DIW waste transfer manifests [30], in 2017 aluminum industry reported about 96,500 tonnes of wastes from their thermal processes and treatment plants; most of them were dross and dusts. The fate of these residues can be illustrated in Figure 3-10.

Based on this data, about 9,700 tonnes of the residues were sent to cement kilns, which can be regarded as final sink for PCDD/Fs. Based on simple allocation based on activity rates, this treatment was responsible for reduction of 21.24 g TEQ/a.



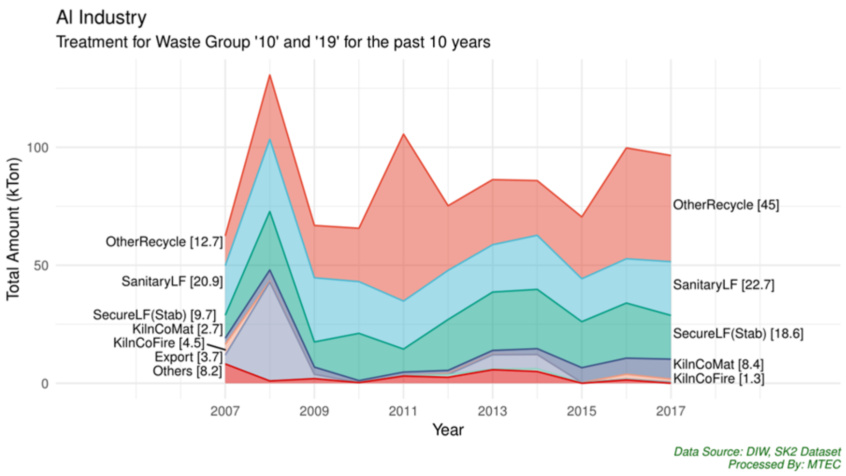
Unit: thousand ton,

*Data source: DIW (data from SK 2 form)*

**Figure 3-10: Destinations of slags and dusts from aluminum production plants in 2017**

Figure 3-11 displays time trends for the preferred routes for the treatment of slags and dust for Thailand's aluminum industry. The overall ratios for the amount treated with the main routes were very much the same, except that the portion that used to be exported was diverted to 'other recycle'. Due to the lack of specificity of the recorded data, the fate of these 'other recycle' residues is unknown.

Since residues are the major sources for PCDD/F emission for metal productions, it is important to monitor the fate of production residues to make sure that the unintended releases of PCDD/F via these residues are accounted for.


Al Industry

Treatment for Waste Group '10' and '19' for the past 10 years

*Data Source: DIW, SK2 Dataset*
*Processed By: MTEC*

Waste group:
10=residues from thermal process, 19= residues from wastewater treatment
*Data source: DIW waste transfer manifests*

**Figure 3-11: Treatment routes for slags and dusts from aluminum production plants in the past 10 years.**

Uncertainty

The level of confidence for Thailand's Al production activity rates for Classes 2 and 3 is medium as they are estimated based on firms' capacities as reported in their EIA reports. These values should also represent upper-limit figures for these Al smelters since in several cases clean/purified Al is also used as their inputs.

The confidence level for Classes 1, 4, and 5 activity rates is low as their values were estimated based on circumstantial information/conditions.

The EF level of confidence is medium for all classes, except for Class 2 EF to air which were given a high confidence level by UNEP.

The level of confidence in class assignment is high due to the available attribute data (including the EIA reports).

### 3.2.4 Lead production

Relevant activities

The 2013 Toolkit describes 4 classes of lead production based on technology level and raw materials used:

- Class 1: lead production from scrap containing PVC
- Class 2: lead production from PVC/$Cl_2$-free scrap, some APCS
- Class 3: lead production from PVC/$Cl_2$-free scrap in highly efficient furnaces, with APCS including scrubbers
- Class 4: pure primary lead production

Activities in all classes are considered relevant to Thailand, except for Class 4 as the country does not produce primary lead. The main application that demands lead production and circulation in Thailand is lead-acid batteries.

Factories that recover lead from lead-acid batteries is designated high environmental impact by DIW [31]–[34]. Relevant air emissions, including $SO_2$, CO, Pb, HCl, and TSP concentrations must be reported on a regular basis.

## Emission factors

An overview of UNEP Toolkit's emission factors for lead production is shown in Table 3-28. Due to the lack of available measurement data, Thailand's EFs could not be estimated for this source category. (Note that Annex 21 of the 2013 Toolkit quotes a range of air EF values for one Thai secondary lead smelter based on a 2002 publication. These EF values are not adopted for use in this report since they are most likely no longer representative of Thailand's situation in 2017.)

UNEP classification is based on the degree of PVC/$Cl_2$ contamination in the incoming materials, the existence of APCs and the efficiency of the furnace. As batteries cases are now made primarily of PP, e-waste is considered the only source of lead that contains PVC.

**Table 3-28: UNEP's PCDD/F emission factors for lead production**

| **2f** | **lead production** | **Emission factors (µg TEQ/t lead)** | |
|---|---|---|---|
| | Classification | Air | Residue |
| 1 | Lead production from scrap containing PVC | 80 | No data |
| 2 | Lead production from PVC/$Cl_2$-free scrap, some APCS | 8 | 50 |
| 3 | Lead production from PVC/$Cl_2$-free scrap in highly efficient furnaces, with APCS including scrubbers | 0.05 | No data |
| 4 | Pure primary lead production | 0.4 | No data |

## Activity rates

Due to the lack of data, Thailand's secondary lead production for this inventory was estimated based on nation-wide amount of lead in car batteries. It is assumed that each car battery contains 10 kg of lead. Given that there were about 16 million registered cars in Thailand in 2017 [35], and that each car battery lasted about 2 years, the annual amount of lead in spent car batteries is then approximated at 80,000 ton. Based on information from firms' EIA reports [36], DPIM, and DIW, 20% and 80% of this amount are assigned to Classes 2 and 3, respectively. A small amount (80 tonnes) of lead from solder recycling is also assigned to Class 2, based on DIW data.

Despite the fact that e-wastes are generally not burnt to recover their lead contents, the inventory team still proposes a scenario that contaminated lead from e-waste is also recycled. Assuming that 1% of total Thai e-waste (400,000 tonne/year) is lead, an amount of 4,000 tonnes of lead is therefore assigned to Class 1.

Releases of dioxins and furans

The estimated PCDD/F emissions from lead production in Thailand in 2017 are summarized in Table 3-29. Emissions into residues may be under estimated due to the absent of EFs for Class 1 and 3. Nevertheless, due to high concentration of heavy metals, residues from Pb recycling facilities are considered hazardous waste which should already be safeguarded by the law.

**Table 3-29: Estimated PCDD/F emission from Source Category 2f - lead production in 2017**

| **2f** | **Lead production** | **Activity Rate** | | | **Emission (g TEQ/a)** |
|---|---|---|---|---|---|
| | Classification | (tonne) | Air | Residue | **Sub total** |
| 1 | Lead production from scrap containing PVC | 4,000 | 0.320 | - | **0.32** |
| 2 | Lead production from PVC/$Cl_2$-free scrap, some APCS | 16,100 | 0.129 | 0.804 | **0.93** |
| 3 | Lead production from PVC/$Cl_2$-free scrap in highly efficient furnaces, with APCS including scrubbers | 64,000 | 0.003 | - | **0.00** |
| | **Total** | **84,000** | **0.45** | **0.80** | **1.26** |

Uncertainty

The level of confidence for lead production activity rates for Classes 2 and 3 is medium since the values are estimates based on official data as well as circumstantial information. The confidence level for Class 1 activity rate is medium to low as it is a rough upper-limit approximation.

The level of confidence in class assignment is medium due to the available attribute data.

The EF level of confidence is high for Class 2 emissions, and is medium for Class 1 and Class 3 air emissions, according to the Toolkit.

### 3.2.5 Zinc production

Relevant activities

The 2013 Toolkit designates 4 classes for zinc smelting processes and melting of mixed scrap as follows:

- Class 1: kiln with no APCS
- Class 2: hot briquetting/rotary furnaces, basic dust control
- Class 3: secondary zinc production with comprehensive APCS
- Class 4: zinc melting and primary zinc production

Activities in all 3 secondary zinc production classes are irrelevant as there is no report of Zn recycling in Thailand. Class 4 is applicable due to zinc melting (but not primary zinc production).

Emission factors

An overview of UNEP Toolkit's emission factors for zinc production is shown in Table 3-30. Due to the lack of available measurement data, Thailand's EFs could not be estimated for this source category.

**Table 3-30: UNEP's PCDD/F emission factors for zinc production**

| 2g | Zinc production | Emission Factors (µg TEQ/t zinc) | |
|---|---|---|---|
| | Classification | Air | Residue |
| 1 | Kiln with no APCS | 1,000 | 0.02 |
| 2 | Hot briquetting/rotary furnaces, basic dust control | 100 | 1 |
| 3 | Comprehensive APCS | 5 | 1 |
| 4 | Zinc melting and primary zinc production | 0.1 | No data |

## Activity rates

Thailand's imports and exports of zinc products in 2017 are shown in Table 3-31. Thailand no longer has any zinc mine, and there was no primary zinc production in 2017. As seen in Table 3-31, zinc import is the main source for zinc for Thailand.

Zinc is a main material for hot-dip galvanization of steel. Annual zinc consumption in this application is estimated at about 30,000 tonnes. However, emission from melting zinc in hot-dip galvanization process is already counted in Source Category 2a.

Zinc is an important alloying material, particularly for making brass and welding wires. A search in DIW factory registration database found only one factory that produces zinc ingots on commercial basis. This factory, built in 2012 with an annual capacity of about 17,500 tonnes, filed an EIA report in 2018 to increase their capacity to 25,000 tonnes.

Based on this information, Thailand's zinc melting amount in 2017 is estimated at about 20,000 tonnes.

## Releases of dioxins and furans

The estimated PCDD/F emissions from zinc production in Thailand in 2017 are summarized in Table 3-32.

**Table 3-31: Thailand's imports and exports of zinc products in 2017 (tonne)**

| HS Code | Product label | Import | Export | Net |
|---|---|---|---|---|
| 7901 | Unwrought zinc : | 119,861 | 5,221 | 114,640 |
| 7902 | Zinc waste and scrap (excluding ash and residues from zinc production "heading 2620", ingots ... | 508 | 31,427 | (30,919) |
| 7903 | Zinc dust, powders and flakes (excluding grains of zinc, and spangles of heading 8308) | 2,458 | 3,348 | (890) |
| 7904 | Zinc bars, rods, profiles and wire, n.e.s. | 1,748 | 5,492 | (3,744) |
| 7905 | Zinc plates, sheets, strip and foil | 2,124 | 935 | 1,189 |
| 7907 | Articles of zinc, n.e.s. | 1,696 | 3,741 | (2,045) |
| | Total | 128,395 | 50,164 | 78,231 |

*Data source: trademap.com*

**Table 3-32: Estimated PCDD/F emission from Source Category 2g -zinc production in 2017**

| 2g | zinc production | Activity Rate | Emission (g TEQ/a) | | |
|---|---|---|---|---|---|
| | Classification | (tonne) | Air | Residue | **Total** |
| 4 | Zinc melting and primary zinc production | 20,000 | 0.002 | - | 0.00 |

## Uncertainty

The levels of confidence for zinc melting activity rate as well as class assignment are medium to high since they are estimated from the only

stakeholder's EIA report.
The EF level of confidence is medium for Class 4, according to the Toolkit.

### 3.2.6 Brass and bronze production

Relevant activities

The 2013 Toolkit distinguishes 4 classes of brass and bronze production based on technology level and raw materials used:

- Class 1: thermal de-oiling of turnings, afterburner, wet scrubber
- Class 2: simple melting furnaces
- Class 3: mixed scrap, induction furnaces, fabric filters
- Class 4: sophisticated equipment with APCS

Brass and bronze are primarily used to make plumbing fittings and bathroom accessories (the marketing of which is dominated by 3 competing brands) as well as water and gas valves. Brass also finds uses in furniture fittings, constructions and household items.

Emission factors

An overview of UNEP Toolkit's emission factors for brass and bronze production is shown in Table 3-33. Due to the lack of available measurement data, Thailand's EFs could not be estimated for this source category. (Note that Annex 23 of the 2013 Toolkit quotes a range of air EF values from one Thai brass smelter based on 2001 and 2002 publications. These EF values are considered for this report's classification purpose, but are not used directly as Thailand's EFs because they were obtained from only 1 site at least 15 years prior to 2017, and are therefore considered not representative.)

**Table 3-33: UNEP's PCDD/F emission factors for brass and bronze production**

| **2h** | **brass and bronze production** | **Emission Factor (µg TEQ/t material)** | |
|---|---|---|---|
| | Classification | Air | Residue |
| 1 | Thermal de-oiling of turnings, afterburner, wet scrubber | 2.5 | Not applicable |
| 2 | Simple melting furnaces | 10 | No data |
| 3 | Mixed scrap, induction furnaces, fabric filters | 3.5 | 125 |
| 4 | Sophisticated equipment with APCS | 0.1 | No data |

Activity rates

According to a major producer of brass and bronze fittings and bathroom accessories, the majority of raw materials for Thai brass and bronze production are imported due to insufficient quality of domestic supplies. Therefore, 2017 net import amounts of the brass and bronze were gathered.

As shown in Table 3-34, the net import quantities combine to about 17,000 tonnes; thus, a total activity rate of 20,000 was estimated for Thailand's brass and bronze production in 2017, to also account for domestic raw materials. Of this total value, an estimated 80% is assigned to Class 3 of the Toolkit to account for industrial-scale production, while 20% is assigned to Class 2 to account for simpler, small-scale production activities.

**Table 3-34: Imports and exports of brass and bronze in 2017 (tonne)**

| HS Code | Description | Import | Export | Net |
|---|---|---|---|---|
| 74032100 | Copper-zinc base alloys (brass) | 1,558 | 3,932 | **(2,374)** |
| 74032200 | Copper-tin base alloys (bronze) | 4,817 | 5 | **4,812** |
| 74050000 | Master alloys of copper. | 143 | 0 | **142** |
| 74072100 | Bars, rods and profiles of copper-zinc base alloys (brass) | 12,675 | 514 | **12,161** |
| 74082100 | Wire of copper-zinc base alloys (brass) | 2,166 | 6 | **2,161** |
| 74112100 | Tubes and pipes of copper-zinc base alloys (brass) | 822 | 99 | **723** |
| 74122091 | Tube or pipe fitting of copper-zinc base alloys (brass) | 993 | 1,419 | **(426)** |
| | Total | **23,173** | **5,975** | **17,198** |

*Data source: Thai Customs*

Releases of dioxins and furans

The estimated PCDD/F emissions from brass and bronze production in Thailand in 2017 are summarized in Table 3-35.

**Table 3-35: Estimated 2017 PCDD/F emission from Source Category 2h -brass and bronze production**

| **2h** | **Brass and bronze production** | **Activity Rate** | **Emission (g TEQ/a)** | | |
|---|---|---|---|---|---|
| | Classification | (tonne) | Air | Residue | **Sub total** |
| 2 | Simple melting furnaces | 4,000 | 0.040 | - | 0.04 |
| 3 | Mixed scrap, induction furnaces, fabric filters | 16,000 | 0.056 | 2.000 | 2.06 |
| | **Total** | **20,000** | **0.10** | **2.00** | **2.10** |

Uncertainty

The levels of confidence for brass and bronze production activity rates and class assignment are medium since they are estimates based on net import values and information from stakeholder interview.

The EF level of confidence is medium, except for Class 3 air emission, according to the Toolkit.

### 3.2.7 Thermal wire reclamation and e-waste recycling

Relevant activities

The 2013 Toolkit defines 4 classes for this source category:

- Class 1: open burning of cables
- Class 2: open burning of circuit boards
- Class 3: basic furnaces with afterburners and wet scrubbers
- Class 4: burning electric motors and brake shoes, etc., with afterburners

Classes 3 and 4 are considered irrelevant to Thailand, and are therefore not included in this inventory report.

Emission factors

An overview of UNEP Toolkit's emission factors for thermal wire reclamation and e-waste burning is shown in Table 3-36. Due to the lack of available measurement data, Thailand's EFs could not be estimated for this source category.

**Table 3-36: UNEP's PCDD/F emission factors for thermal wire reclamation and e-waste burning**

| **21** | **Thermal wire reclamation and e-waste burning** | **Emission Factor (µg TEQ/t materials)** | |
|---|---|---|---|
| | **Classification** | **Air** | **Residue** |
| 1 | Open burning of cables | 12,000 | No data |
| 2 | Open burning of circuit boards | 100 | No data |
| 3 | Basic furnaces with afterburners and wet scrubbers | 40 | No data |
| 4 | Burning electric motors and brake shoes, etc. with afterburners | 3.3 | No data |

## Activity rates

Due to high prices of copper, open burning of cables, especially small ones, is still relevant in Thailand even though there are legal campaigns against this activity. Although efficient wire stripping tools are becoming accessible to waste collectors and despite the fact that burned copper receives price penalty by about 10-20%, burning of copper wires is still practiced. Based on telephone interviews with prominent secondary copper suppliers, open burning is often associated with stolen cables and/or the sudden rise of copper price.

Since there is no official record for this activity, the inventory team made an effort to obtain an upper bound estimate based on the following information.

- Thailand does not have any copper smelter. Burned copper wires are either collected for export or feeding copper tube factories that can use copper with lower purity. Based on information from EIA reports from 2 major copper tube producers in Thailand, burned copper wires up to 2% (by weight) can be tolerated as the input amounts. Tube producers in Thailand used about 35,000 tonnes of copper scraps annually. Therefore, for the purpose of this report, an upper-bound value of 1,000 tonnes is assigned to Class 1 to account for this activity.

- Open burning of circuit boards for copper is rare in Thailand due to the availability of other outlets that offer better prices for the boards. These boards are destined to specialized facilities to recover precious metals. Nevertheless, a rough upper bound of 4,000 tonnes is allocated to Class 2 to account for a worst-case scenario where 1% of the 400,000 tonnes/year of e-waste generated in Thailand is openly burned.

Releases of dioxins and furans

The estimated PCDD/F emissions from thermal wire reclamation and e-waste burning in Thailand in 2017 are summarized in Table 3-37. Due to the high EF for open burning of cables, this activity has high potential to generate and release PCDD/F to air, even with relatively small amount of materials.

Though UNEP Toolkit could not provide EF for PCDD/F in open burning residue, high level of PCDD/F contamination in soil at burning sites has been reported [37]. There is not enough information to assess open cable burning activities in Thailand. However, areas where these activities have taken place should be regarded as potential sources and appropriate actions should be taken to control risks.

**Table 3-37: Estimated PCDD/F emission from Source Category 2l - thermal wire reclamation and e-waste burning in 2017**

| 2l | Thermal wire reclamation and e-waste burning<br>Classification | Activity Rate<br>(tonne) | Emission (g TEQ/a)<br>Air |
|---|---|---|---|
| 1 | Open burning of cables | 1,000 | 12.00 |
| 2 | Open burning of circuit boards | 4,000 | 0.4 |
| | **Total** | 5,000 | 12.40 |

Uncertainty

The level of confidence for Class 1 activity rate is medium as it is an estimated upper limit based on manufactures' information. For Class 2, the confidence level is medium to low since it is a rough upper-limit approximation.

The EF level of confidence is medium for all classes, according to the Toolkit.

### 3.2.8 Summary

Thailand's total PCDD/F emission from metal production during the year 2017 is summarized in Table 3-38 and Figure 3-12, where the emission to residue accounts for about 87% of the total emission from this source group, while approximately 13% are released into air.

With annual releases of about 240 g I-TEQ (close to 20% of country's total emission), residues from metal productions is a major source of PCDD/F emission for Thailand. Based on results from Thailand's 2006 inventory, the government has imposed measures to curb PCDD/F emissions. However, most of the efforts were directed toward air emissions and, thus, information related to PCDD/F in residues are still lacking. This data gap should be filled by the upcoming action plans.

All residues generated by factories are subjects to DIW control. The fate for some of the relevant residues were traceable, leading to an estimated PCDD/F destruction of about 21.6 g TEQ (21.2 g TEQ from Al related residues). Nevertheless, due to the lack of specificity of the recorded data, the final destinations for a large portion of these residues are unclear. It is, thus, important to determine and monitor the fate of these residues to ensure that proper measures are put in place to avoid possible unintended releases.

While it is clear from the estimated emissions that residues are the major source of PCDD/F emission from metal production, the readers should be reminded of the uncertainty of this estimation. Due to lack of EFs for several important activities and release vectors, the presented estimated figures could be an under estimation of the actual releases.

It also should be noted that, at the time of this report, Thailand (via DPIM and UNIDO) is engaged in another GEF-funded project entitled "Greening the Scrap Metal Value Chain through Promotion of BAT/BEP to Reduce U-POPs Releases from Recycling Facilities". Findings from this ongoing study should help portray a more detailed status of Thailand's metal production industry.

**Table 3-38: Summary of estimated PCDD/F emission from metal production in 2017**

| **G2** | **Metal Production** | **Emission (g I-TEQ/a)** | | | | |
|---|---|---|---|---|---|---|
| | **Source Category** | **Air** | **Water** | **Residue** | **Subtotal** | **Treatment** |
| 2c | Iron and steel production and foundries | 17.37 | 0 | 87.86 | **105.23** | **(0.35)** |
| 2d | Copper production | 0.01 | 0.15 | - | **0.16** | |
| 2e | Aluminum production | 6.62 | 0 | 150.00 | **156.62** | **(21.24)** |
| 2f | Lead production | 0.45 | - | 0.80 | **1.26** | |
| 2g | Zinc production | 0.00 | 0 | - | **0.00** | |
| 2h | Brass and bronze production | 0.10 | 0 | 2.00 | **2.10** | |
| 2l | Thermal wire reclamation and e-waste burning | 12.40 | 0 | - | **12.40** | |
| | **Total** | **36.95** | **0.15** | **240.67** | **277.77** | **(21.59)** |
| | | | | | **256.18** | |

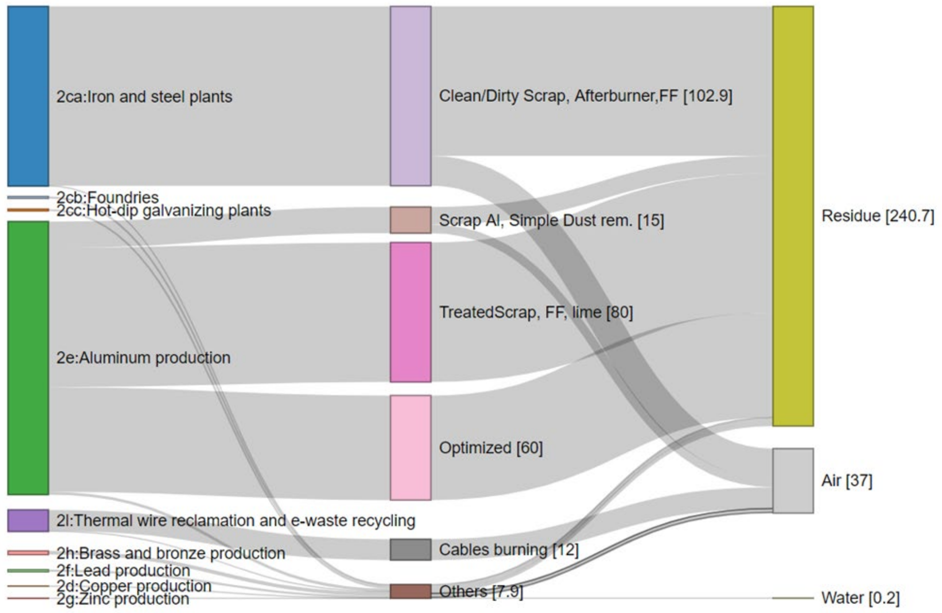


Figure 3-12: Summary of PCDD/F emissions from Source Group 2: Ferrous and Non-Ferrous Metal Production in 2017 [unit: g TEQ/a]

□□□

## Annex 2. Capacity and production of iron and steel products in 2017

**Table 3-39: Capacity and production of iron and steel products in 2017 (in tonnes)**

| | Source | OIE | |
|---|---|---|---|
| **ISIC Code** | **Product** | **Capacity** | **Productivity** |
| 24102.030 | Galvanized Steel Sheets | 1,747,390 | 1,093,149 |
| 24103.010 | Steel pipes | 975,000 | 787,616 |
| 24109.010 | Steel rods | 974,072 | 458,854 |
| 24109.020 | Deformed steel bars | 4,176,808 | 2,154,476 |
| 24109.050 | Steel wire rods | 1,434,979 | 834,337 |
| 24109.060 | Steel wires | 889,092 | 448,883 |
| 24109.070 | High tension steel wires | 374,916 | 258,854 |
| 24109.080 | Cold-rolled steel | 1,791,632 | 1,139,712 |
| 24109.090 | Hot-rolled steel | 695,528 | 339,800 |

*Data source: OIE 2019* [18]

## 3.3 Source Group 3: Heat and Power Generation

The UNEP Toolkit categorizes emission sources within this group into 5 categories:

- Fossil fuel power plants
- Biomass power plants
- Landfill, biogas combustion
- Household heating and cooking with biomass
- Household heating and cooking with fossil fuels

Activities within these source categories took place in Thailand in 2017.

Data used for heat and power generation are based on the following national statistics data:

- Ministry of Energy (MoEN) "Thailand Table of Energy Balance 2017" [38][39] (hereafter called "MoEN's energy balance statistics")
- Data from an MoEN funded project in 2015 "Project to study, analyze and compile databases for factories and business that supply and consume thermal energy" [40][6] ("MoEN thermal energy survey data")
- Online Energy Regulatory Commission (ERC)'s power producer database[7] ("ERC SPP/VSPP database")
- Ministry of Industry (M-Industry) factory registration database ("M-Industry factory database")
- M-Industry industrial waste transfer manifest ("M-Industry waste transfer manifest")

The MoEN's energy balance statistics provide information on the amount of energy consumed by each economic sector. Unfortunately, these data do not provide information on the types of end-uses (boilers, kilns and furnaces, engines, etc.). Information gained from MoEN thermal energy survey data is used to estimate the proportion of each fuel type consumed by each sector for each end-use (see Table 3-53). Only the portions of fuels used for heat and power generation are included for the estimations of dioxin/furans released from this source group.

Fuel consumptions in MoEN energy balance statistics are available both in physical unit (tonne) and in kilotonnes of oil equivalent unit (ktoe). MoEN applies different conversion factors for different fuel types and these factors are available within the MoEN's data table to enable data tracing. MoEN aggregates and compiles data from every fuel source

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[6] data retrieved from http://map.thaifuel.com/, last accessed August 16, 2019

[7] ERC SPP/VSPP database (in Thai), http://www.erc.or.th/ERCSPP/default.aspx?x=0&muid=23&prid=41, last accessed August 18, 2019

produced and consumed in Thailand and has made these data available to the public for decades. These conversion factors, therefore, are assumed to be the most appropriate for Thailand and no attempt was made to cross check these factors.

The emission factors given in UNEP Toolkit are based on TJ fuel burned. A conversion factor of 41.868 TJ/ktoe [41] is used to convert MoEN's ktoe values into TJ activity rates.

**Table 3-40: Overview of types and amounts of fuels consumed for heat and power generation by different sectors in Thailand in 2017 (in TJ)**

| Fuel Type | Power Plants | Industry | Households | Others* |
|---|---|---|---|---|
| **Bituminous** | 160,899 | 13,842 | | |
| **Briquettes & other coal** | 31,359 | 97,029 | | |
| **Lignite** | 164,876 | 7,118 | | |
| **MSW** | 1,507 | 2,638 | | |
| **High speed diesel** | 1,591 | 117,096 | | 11,489 |
| **Fuel Oil** | 1,089 | 31,192 | | 105 |
| **Landfill gas** | 10,886 | 22,563 | | |
| **LPG** | | 13,347 | 73,227 | 31,862 |
| **Methane** | 1,087,061 | | | |
| **Natural Gas** | | 60,658 | | |
| **Agricultural Waste** | 192,383 | 82,786 | 42,287 | |
| **Bagasse** | 100,232 | 144,093 | | |
| **Charcoal** | | | 77,874 | |
| **Fuel Wood** | | 8,629 | 93,491 | |
| **Paddy Husk** | 29,391 | 13,791 | 8,918 | |

**Other sectors (*) include agricultural, commercial, construction and mining**

*Data Source: Summarized from MoEN's energy balance statistics*

An overview of relevant fuels consumed in Thailand for heat and power generation (in TJ, after applying consumption factors to account for the amounts used in engines and kilns, etc.) is shown in Table 3-40. (see Table 3-53 and Table 3-54 for the assigned consumption factors)

Burning fuels for heat and power generation also take place in the industry sector, and the UNEP Toolkit also provides separate emission factors for some of these industrial activities (such as pulp and paper industry in Source Group 7). Since the available consumption data do not allow for segregation of fuels used by each industry, all activities related to heat and power generations are investigated within this source group and are not taken into account again in other source groups (SG3) to avoid double counting. This approach is considered more logical when considering also the fact that key energy-intensive industries tend to adopt new business models that consider heat and power generation a separate business entity (with separate factory license) that provides heat and power service to the core factory, surrounding communities, as well as feeding to power grids.

For household heating and cooking with biomass, the estimation of PCDD/F emissions into residues are based on the amount of ashes generated. The MoEN's energy consumption dataset provides data for 4 solid biomass fuels consumed by households: traditional fuel woods, charcoal, paddy husks, and agricultural waste. Again, except for the paddy husks, the aggregated nature of the data makes it difficult to estimate the amount of ashes generated from these biomasses. For the purpose of this inventory study, the ash content for each biomass for household cooking were derived from median values from various proximate analysis of relevant biomasses taken from [42]–[45]. The assumed values are as follows:

| Biomass Type | Ash content (% by weight biomass) |
|---|---|
| Paddy Husk | 14.1% |
| Agricultural Waste | 3.5% |
| Charcoal | 2.9% |
| Fuel Wood-Traditional | 2.3% |

### 3.3.1 Fossil fuel power plants

Relevant activities

The UNEP Toolkit specifies 6 classes of fossil fuel power plants based on the fuel type used, as follows:

- Fossil fuel/waste co-fired power boilers
- Coal fired power boilers
- Peat fired power boilers
- Heavy fuel fired power boilers
- Oil shale fired power plants
- Light fuel oil/natural gas fired power boilers

Peats and Oil shales are not available in Thailand. Hence, emissions from these sources are not included in this study.

Power plants included in this source category are limited to those that are optimized to generate power output at industrial/commercial scale. This assumption implies consistent fuel inputs and year-round, well-maintained power generation system.

### Relevant regulations

According to MNRE's notifications, all power plants are designated pollution sources that are subjected to emission controls [46][47]. The relevant emission limits were published in 2004 by the MNRE [48] and the M-Industry [49]. These limits, however, do not include the release of dioxin and furans to the atmosphere.

All factories with boilers generating steam more than 10 tonnes per hour are subjected to the M-Industry's periodic air and water emission report requirements [25]. Again, these generic emission reports do not cover the release of dioxin/furans. Nevertheless, in 2005 M-Industry published an air emission limit for dioxin/furans of 0.5 ng I-TEQ/$m^3$ for boilers and furnaces that use processed used oil or synthetic oil as fuels [22]. The M-Industry also enforces a standard to control the quality of the processed used oil and the synthetic oil that are allowed for fuel oil substitutions [50]. Among the associated technical requirements, this standard limits the amount of total halogens at 4,000 ppm.

### Emission factors

An overview of the UNEP Toolkit emission factors is shown in Table 3-41. Although emissions of PCDD/F from combustions of fossil fuels to produce heat and power depend also on the size and type of technology, due to the lack of reliable information, the UNEP Toolkit does not account for these factors. These data also are not available to the inventory team; hence no attempt was made to estimate 'type–specific' emission.

The emission factors for fossil fuel/waste co-fired power boilers consider only the uses of waste co-fired with other solid fossil fuels, excluding dedicated systems with intentions to dispose of wastes such as the burning of municipal solid wastes for energy (WTE), which are investigated under Source Group 1 (waste incineration). Fuels to be considered as 'co-combustion' should contain less than 33% of waste.

The emission factors for the coal-fired power boilers in the UNEP Toolkit refer to those for hard coals or anthracites. The Toolkit does not provide emission factors for the types of coals typically used in Thailand (bituminous, lignite) but allows for the use of the provided emission factors in case of lacking information at the national level, with a reminder that the actual emission factor can differ, depending on combustion conditions, quality of the fuels, as well as power plant technology.

The emission factors for light fuel oil/natural gas fired power boilers were derived from boilers for heat and/or power production but can be transferred to the combustion in gas turbines or in combined heat-power (CHP) power plants, which typically are the cases for power plants in the Thai industrial sector.

During 2009-2012, the PCD commissioned a series of studies to determine the levels of PCDD/F emission from fossil fuels and biomass power plants and boilers in Thailand [51]–[54]. PCDD/F emissions from 17 flue gas stacks were evaluated. Seven of these stack data were from coal-fired and fuel oil fired power boilers. The resulting emission factors derived from these data are summarized in Table 3-41 alongside the UNEP default values.

(See information in the Annex for more detail)

There is no data available for PCDD/F emissions into residues from fossil fuel-fired boilers in Thailand. Thus EF for these sources are derived from the UNEP default emission factors.

As mentioned above, the UNEP EFs for coal fired power plants was derived from anthracite data, assuming 10% average ash production rate. With an average PCDD/F concentration of 4 ng TEQ/kg ash, the UNEP estimated an emission factor of 0.4µg TEQ/t (coal input) or approximately 14µg TEQ/TJ for coal fired boilers.

Since energy contents for coals typically used in Thailand are different from anthracite [55], the mass of fuel used is much higher leading to a relatively larger amount of ash per unit energy output. Using the default emission factor for residues from coal fired power plant could lead to an underestimation of the release. Therefore, for PCDD/F in residues from coal fired boilers the emission factor per unit mass (4µg TEQ/t ash) is used instead of the default per unit energy value.

According to the Electricity Generating Authority of Thailand (EGAT), the amounts of ashes generated from their Mae Moh lignite power plants vary between 6.9 to 35.0% for their 4 to 7 plants, and 11.0 to 36.0% for their 8 to 13 plants in operations[8], with an average around 25%[9].

**Table 3-41: PCDD/F emission factors for relevant fossil fuel power plants**

| | **Fossil fuel power plants** | | | **Emission Factors*<br>(µg TEQ/TJ fossil fuel burned)** | |
|---|---|---|---|---|---|
| | Classification | | Air (UNEP) | Air (PCD) | Residue (UNEP) |
| 1 | Fossil fuel/waste co-fired power boilers | | 35 [0.4-118] | No data | No data |
| 2 | Coal fired power boilers | | | | |
| | | Bituminous | 10 [3-100] | 4.3 [3.1-13.8][1] | 4 µg/t (ash) |
| | | Lignite | No data | 6.2 | 4 µg/t (ash) |
| 4 | Heavy fuel fired power boilers | | 2.5 [1-4] | 1.3 [1.1-1.5][2] | No data |
| 6 | Light fuel oil/natural gas fired power boilers | | 0.5 [0.5-1.5] | No data | No data |

Note : *: median [Range], [1]: n=4, [2]: n=2

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[8] http://maemoh.egat.com/index.php/tec [online] last accessed September 16, 2019

[9] http://maemoh.egat.com/index.php/sarattt?id=89 [online] last accessed September 16, 2019

## Activity rates

Based on MoEN's energy balance statistics, heat and power plants in Thailand combusted the following amount of fossil fuels in 2017:

| | | |
|---|---|---|
| Coal co-fired with waste | 49,000 | TJ* |
| Waste co-fired with coal | 4,140 | TJ* |
| Bituminous | 161,000 | TJ |
| Coal briquettes | 108,000 | TJ |
| Lignite | 172,000 | TJ |
| Fuel oil | 27,000 | TJ |
| High speed diesel | 130,000 | TJ |
| LPG | 13,300 | TJ |
| Methane | 1,090,000 | TJ |
| Natural gas | 60,700 | TJ |

(Note *: Assumed wastes are mixed at 10% rate, and only mixed with coal)

M-Industry allows for the uses of combustible non-hazardous industrial wastes as fuels for boilers and kilns. Such waste treatments are classified into 3 classes; treatment codes 041, 042, 043, based on the characteristics of the waste summarized as follows:

| | |
|---|---|
| 041 | Use as fuel substitution: Non-hazardous wastes with lower heating value (LHV) above 2,800 kCal/kg |
| 042 | Fuel blending: Non-hazardous wastes with LHV below 2,800 kCal/kg |
| 043 | Burn for energy recovery |

Factories using "synthetic fuel oils" derived from these wastes must comply with M-Industry's emission standards which include the PCDD/F air emission limit of 0.5 ng I-TEQ/$m^3$ [22]. Fuels to be sold as "synthetic fuel oils" must meet M-Industry's minimum quality standard [50] which includes, among the 12 quality items, gross heat of combustion exceeding 9,500 kCal/kg and total halogen content below 4,000 ppm.

A search for industrial wastes with treatment codes 041, 042, and 043 revealed a combined registered amount of over 1.5 million tonnes in 2017. More than 90% of waste under treatment code 043 was biomass (wood wastes). This waste stream is treated in the next source category – biomass power plants. Wastes under treatment code 041 and 042 are very diverse but a screening for the top 90% contributors yields more reliable information. This is reasonable considering the fact that minor inconsistent wastes are less likely to be accepted by boiler/kiln operators.

Assuming 2,800 kCal/kg and 1,400 kCal/kg of energy can be recovered from waste codes 041 and 042, respectively, the total amount of energy recovered as 'fuel' from non-hazardous wastes can be estimated as follows:

| Treatment Code | Liquid | Solid | |
|---:|---:|---:|---|
| 041 | 200 | 500 | TJ |
| 042 | 1,000 | 1,000 | TJ |
| **Total** | **1,200** | **1,500** | **TJ** |
| **Allocated to boilers** | **600** | **1,300** | **TJ** |
| **Allocated to kilns** | **600** | **200** | **TJ** |

Assuming the recovered fuels were co-fired with fossil fuels at 10% rate, the total amounts of fossil fuels energy consumed by power plants are:

| | | |
|---:|---:|---|
| Waste derived Synthetic Fuel Oil | 600 | TJ |
| Fuel Oil | 5,400 | TJ |
| Industrial Solid Waste | 1,300 | TJ |
| Coal | 11,700 | TJ |

## Releases of dioxins and furans

The estimated PCDD/F emissions from fossil fuel-fired power plants in Thailand in 2017 are summarized in Table 3-42. Except for the emissions from bituminous and fuel oils into air, which were calculated using emission factors derived from the PCD studies, all other calculations were based on the UNEP Toolkit default emission factors as described above. It can be seen that the emission into residues (fly ash) is about 4 times the emission into air. The reason for this is the relatively high ash contents of lignite. Nevertheless, readers should be reminded that this estimation is based on dioxin concentration in fly ashes from anthracite power plants.

**Table 3-42: Estimated PCDD/F emissions from fossil fuel power plants in 2017**

| | **Fossil fuel power plants**<br>Classification | **Activity Rate**<br>(TJ)[1)] | **Ash**<br>(tonne) | **Emission (g TEQ/a)**<br>Air | <br>Residue | <br>**Subtotal** |
|---|---|---:|---:|---:|---:|---:|
| **1** | **Fossil fuel/waste co-fired power boilers** | **60,400** | **n.a.** | **2.116** | **-** | **2.116** |
| **2** | **Coal fired power boilers** | **441,000** | **5,180,000** | **2.225** | **20.705** | **22.930** |
| | Coal | 269,000 | 1,030,000 | 1.161* | 4.120 | 5.281 |
| | Lignite | 172,000 | 4,150,000 | 1.064* | 16.585 | 17.649 |
| **4** | **Heavy fuel fired power boilers** | **157,000** | **n.a.** | **0.206*** | **-** | **0.206** |
| **6** | **Light fuel oil/natural gas fired power boilers** | **1,160,000** | **n.a.** | **0.581** | **-** | **0.581** |
| | Liquefied Petroleum Gas | 13,300 | n.a. | 0.007 | - | 0.007 |
| | Methane and Natural Gas | 1,150,000 | n.a. | 0.574 | - | 0.574 |
| | **Total Fossil Fuel Power Plant** | | | **5.127** | **20.705** | **25.832** |

1): numbers rounded to 3 significant figures for legibility.

* Calculated using EF derived from site specific data (see Table 3-41.)

## Uncertainty

**Uncertainty from Activity rates:**

- Confidence level for methane, natural gas and lignite consumptions is high due to the availability of end-use data.
- Although the confidence level for the overall energy consumption is relatively high, due to the lack of national data on the proportions of

fuels used to feed boilers and for other activities (such as kilns), the level of confidence for activity rates are medium. There are uncertainties associated with utilization factors used to allocate fuels to all relevant activities. Nevertheless, the utilization factors employed were derived from information gained from a MoEN database [40]. The level of confidence for these factors is considered medium.

- Since there is no data at the national level for fuel uses in fossil fuel/waste co-fired power boilers, the activity rates for this source category were derived from the amount of industrial wastes reused as fuels (from M-Industry waste transfer manifest) and the assumed mixing ratio. The confidence level for this source category is medium to low.

**Uncertainty from Emission Factors:**

- Confidence level for the emissions from coal-fired power boilers into air is high due to the availability of country-specific emission factors for similar plants.
- Confidence level for the emissions from coal-fired power boilers into residues is medium for bituminous and low for lignite due in part to the lack of data for emissions from lignite power plants into residues and in part to difference in pre-combustion cleaning and combustion technologies.

### 3.3.2 Biomass power plants

Relevant activities

The UNEP Toolkit specifies 4 classes of biomass power plants based on the types and cleanliness of biomass used, as follows:

- Mixed biomass fired power boilers
- Clean wood fired power boilers
- Straw fired boilers
- Boilers fired with bagasse, rice husks etc.

Although the use of rice straw as an alternative source for energy is continuously promoted, there is no straw-fired boiler registered in both MoEN and M-Industry databases.

The UNEP Toolkit defines "mixed biomass" as wood waste not contaminated by paints or coatings that is frequently used in wood industries. Wood waste contaminated by paints or coatings should be considered in category 1f. Clean wood is defined as high-quality fuel derived from log wood, wood chips, or pellets, which allows for optimized combustion conditions. Both classes are referred to as "waste wood" or "wood residues" in the context of our datasets.

Both mixed biomass and clean wood fired power boilers exist in Thailand, but the existing database does not allow for the differentiation between the two sources. However, when considering also the data sources for the assigned default emission factors, it may be more appropriate to assign mixed biomass as clean wood biomass for Thailand. The default emission factors for mixed wood fired boilers were derived from straw fired boilers while those for Class 2 boilers were derived from wood. Therefore, no attempt was made to further differentiate the sources and the end-uses for fuel labeled in MoEN's energy balance statistics as 'Fuel wood'.

Feedstocks for boilers fired with "bagasse, rice husk, etc." include not only paddy husk and bagasse but also agricultural waste. These feedstocks were also consumed in activities other than boilers. Therefore, similar to the case of fossil fuels, utilization factors (shown in Table 3-54) are applied.

## Emission factors

An overview of UNEP Toolkit emission factors for biomass fired power plants is shown in Table 3-43.

The UNEP Toolkit emission factors for clean wood fired boilers (Class 2) are based on woods with heating values of 12–15 MJ/kg which are close to 15.99 MJ/kg, the standard values for Thai fuel woods [56].

The UNEP emission factors into air for boilers fired with "bagasse, rice husk, etc." are derived from straw fired boilers from a Danish investigation in 2002 [57] because there was no other emission data available for this source.

The PCD dioxin/furan emission studies during 2009-2012 covered 3 bagasse fired power plants, 5 paddy husk fired power plants, and 2 mixed waste wood/agricultural residues fired power plants [51]–[54]. (See information in the annex for more detail.)

Due to the diverse nature of the feedstock, emission data from mixed waste fired power plants were too varied to represent emission factor for this source. Besides, there is no data on mixed waste consumption and mixed-waste fired power plants available. Therefore these data were removed from the PCD's emission dataset.

The combined fuel consumption for the 5 paddy husk power plants was about 58,000 TJ, which is higher than the amount consumed in 2017, and is hence considered good coverage for this source category.

On the other hand, the combined fuel consumption for the 3 bagasse power plants studied by the PCD was only 9,000 TJ, less than 4% of the amount of bagasse fired in 2017. Nevertheless, the observed emission factors varied in a narrow range. Given the fact that the Toolkit factor was derived from straw fired power plants and the value was given as the first expert estimate, the emission factor derived from these 3 bagasse power plants is considered more appropriate.

The derived emission factors into air for these biomass fired boilers are summarized alongside the UNEP's values in Table 3-43. (See information in the annex for more detail).

Although the PCD studies investigated both feedstocks and fly ashes in great depth, no information is available for the concentration of PCDD/F in fly ashes.

The UNEP Toolkit emission factor into residue (fly ash) for bagasse fired boilers was derived from a bagasse fired power plant in Mauritius in 2007 [58]. This value is considered appropriate for bagasse fire power plants in Thailand.

**Table 3-43: PCDD/F emission factors for biomass power plants**

| | **Biomass power plants** | | **Emission Factors (µg TEQ/TJ biomass burned)** | |
|---|---|---|---|---|
| | Classification | Air (UNEP) | Air (PCD)* | Residue (UNEP) |
| 1 | Mixed biomass fired power boilers | 500 | No data | No data |
| 2 | Clean wood fired power boilers | 50 | No data | 15 |
| 3 | Straw fired boilers | 50 | No data | 70 |
| 4 | Boilers fired with bagasse, rice husk etc. | | | |
| | Bagasse | 50 | 10.3[7.0-28.7][1] | 50 |
| | Rice Husks | 50 | 31.5[0.1-40.3][2] | 50 |

*: Median [Range], [1]: n=3, [2]: n=5

## Activity rates

Based on MoEN's energy balance statistics, heat and power plants in Thailand consumed the following amount of biomass derived energy in 2017:

| | | |
|---|---|---|
| Agricultural waste | 275,000 | TJ |
| Bagasse | 244,000 | TJ |
| Paddy husk | 43,200 | TJ |
| Fuel wood | 8,630 | TJ |

According to the M-Industry waste transfer manifest, there were about one million tonnes of waste registered with treatment code 043; about 97% of these were wood based. Assuming these wastes had an average energy value of 2,600 kCal/kg (typical value for waste woods, saw dust, etc. [56]), industrial wastes coded 043 are estimated to contribute an additional 10,700 TJ of biomass burned in 2017.

## Releases of dioxins and furans

The estimated PCDD/F emissions from biomass-fired power plants in Thailand in 2017 are summarized in Table 3-44.

Except for emission into air from bagasse and paddy husk fired power plants that were estimated using country specific emission data, all other emissions were estimated using the UNEP Toolkit default emission factors.

As in the case of fossil fuel fired boilers, emissions into residues are higher than those into air. Due to lack of information about PCDD/F in residues from paddy husk, bagasse, and agricultural waste fired boilers, the uncertainty from these portions could be high. Nonetheless, these estimates point out the importance of residues (both fly ash and bottom ash) that should be investigated in more details.

**Table 3-44: Estimated PCDD/F emissions from Biomass power plants in 2017**

| | **Biomass power plants**<br>Classification | **Activity Rate**<br>(TJ)1) | **Emission (g TEQ/a)**<br>Air | <br>Residue | <br>**Subtotal** |
|---|---|---|---|---|---|
| **2** | **Clean wood fired power boilers** | **19,300** | **0.97** | **0.29** | **1.26** |
| | Fuel wood | 8,630 | 0.431 | 0.129 | 0.561 |
| | Industrial Waste | 10,700 | 0.536 | 0.161 | 0.697 |
| 3 | Straw fired boilers | **No data** | **-** | **-** | **-** |
| **4** | **Boilers fired with bagasse, rice husk etc.** | **562,000** | **17.63** | **28.13** | **45.76** |
| | Agricultural Waste | 275,000 | 13.758 | 13.758 | 25.517 |
| | Bagasse | 244,000 | 2.513* | 12.216 | 14.729 |
| | Paddy Husk | 43,200 | 1.359* | 2.159 | 3.518 |
| | **Total Biomass power plants** | **582,000** | **18.60** | **28.42** | **47.02** |

1): numbers rounded to 3 significant figures for legibility.

* Calculated using EF derived from site specific data (see Table 3-43.)

## Uncertainty

**Uncertainty from activity rates:**

- The level of confidence for the reported activity rates is high due to the fact that they were derived from national data. However, other biomass variations beyond those classified in national dataset may exist.
- The available data do not allow for differentiation between mixed biomass fired and clean wood fired power boilers. This report assigns all wood to Class 2 (clean wood) due to more appropriate emission factors.
- There could be wood waste from wood processing and wood working plants. However, data from M-Industry waste transfer manifest do not reflect any waste from these factories. The reason for this missing data is unknown. However, considering the fact that the majority of the waste woods were captured both in the M-Industry waste transfer manifest (mainly from paper industry) and in the MoEN's energy balance statistics, the confidence level for this activity rate is high.
- Straw fired boilers may exist but data are missing at the national level. In fact, straw briquettes are becoming common. However, these briquettes also contain binders which may or may not be accounted for by the Toolkit's EF.

**Uncertainty from emission factors:**

- Confidence level for emissions from bagasse and paddy husk power plants into air is high due to the use of local emission data with relatively high coverage.
- For the emissions into residues, the estimates were based on UNEP

Toolkit emission factors which were estimated with low confidence due to scarcity of data.

### 3.3.3 Landfill biogas combustion

Relevant activity

Landfill gas and biogas combustion refers to the combustion of biogas resulting from anaerobic digestion of organic matters. Emissions from these sources are associated with gas-fired boilers, gas motors/turbines and flaring. These activities exist in Thailand, typically in the forms of renewable energy generations from organic wastes, wastewater treatment plants and landfill gas.

Emission factors

Emissions into air are anticipated as the only vector for these emission sources. Since landfill gas and biogas burn virtually residue-free, the UNEP Toolkit does not expect any release to land, water, or residues.
No information is available for the emissions of PCDD/F from biogas power plants in Thailand. The estimations from these sources; therefore, rely solely on the UNEP Toolkit default emission factor.
This UNEP Toolkit default emission factor, shown in Table 3-45, is based on TJ of gas burned, and covers both emission from engines and gas flares.

**Table 3-45: PCDD/F emission factors for Landfill biogas combustion**

| | **Landfill biogas combustion** | **Emission Factors (µg TEQ/TJ gas burned)** | |
|---|---|---|---|
| | Classification | Air | Water |
| 1 | Biogas-/landfill gas fired boilers, motors/turbines and flaring | 8 | No data |

Activity rates

Thailand is an agricultural country. There are abundant agricultural wastes to be converted to biogas. There can be as many as 1,700 biogas plants in the country [59]. Most of these plants produce biogas from animal manures, organic wastes, and wastewater from food and bio-based products processing plants. Among these plants, starch production plants produced the highest amount of biogas, followed by ethanol production plants, and livestock manure, respectively.

Based on MoEN’s energy balance statistics, Thailand consumed about 33,500 TJ of biogas in 2017. About 33% (10,900 TJ) was used in gas engine to generate electricity and the remaining 67% (22,600 TJ) was used in manufacturing sector. There is no information related to the sources of these biogases in this dataset.

A search within the M-Industry factory database for factories established before 2017 with keywords “biogas” (in Thai and English) yielded 259 factories, in 44 provinces. The majorities (131) of the licensees were firms under TSIC[10] code 20111 (production of industrial gases other than natural gases), 80 factories were under TSIC 35101 (electric power generation and transmission), and the rest (48) were firms in food or fertilizer businesses.

A search in ERC SPP/VSPP database yielded 161 biogas power plants that supplied about 8,800 TJ of electricity to power grid in 2017. In this database, power plants that use landfill biogas were registered under waste-derived power plants. This power plant category also includes waste-to-energy incineration (WTE) which should be considered under MSW incinerations (Source Group 1a.) A search for waste-derived power plants with gas engines yielded 12 power plants that supplied about 1,100 TJ of electricity to power grid in 2017.

Releases of dioxins and furans

The estimated releases of PCDD/F from landfill gas and biogas combustions in Thailand in 2017 are summarized in Table 3-46

**Table 3-46: Estimated PCDD/F emissions from landfill biogas combustion in 2017**

| | Landfill biogas combustion | Activity Rate (TJ)[1)] | Emission to Air (g TEQ/a) |
|---|---|---|---|
| **1** | **Biogas-/landfill gas fired boilers, motors/turbines and flaring** | **33,500** | **0.268** |
| | Biogas combustion in power plants | 10,900 | 0.087 |
| | Biogas combustion in manufacturing sector | 22,600 | 0.181 |

1): numbers rounded to 3 significant figures for legibility.

Uncertainty

The confidence level for the activity rates is high.
Since emissions depend on the existence of PCDD/F precursors in the gas, the UNEP Toolkit assigns confidence level for emission factor to medium. The majority of biogas accounted for in this report is from digestion of agricultural residues and wastewater treatment. Emissions from burning biogas from these sources may be lower than those from burning landfill biogas.

### 3.3.4 Household heating and cooking with biomass

Relevant activity

The UNEP Toolkit classifies emission from 6 different types of stove based on the type and cleanliness of biomass used as follows:

- Contaminated wood/biomass fired stoves
- Virgin wood/biomass fired stoves
- Straw fired stoves
- Charcoal fired stoves
- Open-fire (3-stone) stoves (virgin wood)
- Simple stoves (virgin wood)

As a hot and humid country, Thailand generally does not need space

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[10] Thailand Standard Industrial Classification (TSIC) 2009

heating. Fireplaces and/or residential heating fire stoves are very rare; hence, considered irrelevant for this report.

## Emission factors

There is no information regarding PCDD/F emissions from biomass fired cooking stoves in Thailand. This study relies on the UNEP Toolkit default values as summarized in Table 3-47. The emission factors for the releases into air are based on the amount of fuel burned (in TJ) while the releases into residues are per tonne of ashes generated.

Contaminated wood (Class 1) is defined as contaminated biomass such as wood waste, painted wood, etc.

Virgin wood/biomass fired stoves (Class 2) refer to stoves firing in well controlled combustion conditions (such as modern stoves using consistent feedstocks, e.g., wood chips or pellets.)

Simple stoves (Class 6) refer to simple cooking stoves with limited combustion control and with a duct for the evacuation of flue gases.

**Table 3-47: PCDD/F emission factors for household heating and cooking with biomass**

| | Household heating and cooking with Biomass Classification | Emission Factor to Air (µg TEQ/TJ) | Concentration in Ash (µg TEQ/t ash) |
|---|---|---|---|
| 1 | Contaminated wood/biomass fired stoves | 1,500 | 1,000 |
| 2 | Virgin wood/biomass fired stoves | 100 | 10 |
| 3 | Straw fired stoves | 450 | 30 |
| 4 | Charcoal fired stoves | 100 | 0.1 |
| 5 | Open-fire (3-stone) stoves (virgin wood) | 20 | 0.1 |
| 6 | Simple stoves (virgin wood) | 100 | 0.1 |

## Activity rates

MoEN reported household consumption of the following amount of biomass in 2017:

| | | |
|---|---|---|
| Fuel Wood | 93,500 | TJ |
| Charcoal | 77,900 | TJ |
| Agricultural Waste | 42,300 | TJ |
| Paddy Husk | 8,920 | TJ |

These figures are assumed to also cover all relevant consumptions by family-run food and prepared meal businesses. In households, including restaurants, traditional markets and street food vendors, etc., the uses of biomasses are mainly for cooking. There is no information on the amount of contaminated (treated or painted) woods available or burnt for this purpose. However, burning of contaminated hard woods for cooking are considered rare for following reasons:

- Due to strict government controls (virtually a ban) on new loggings of forest products, used woods, particularly native species, are considered precious materials that can command higher prices than new woods.
- The strong smell from burning contaminated woods may degrade

the food flavor; hence contradicts the purpose of cooking.

- There has been no PCP production plant in Thailand. The substance has been banned in Thailand since the early 1990s. Based on the inventory team's interview with the Royal Forest Department officers, there was no report of any widespread use of this substance for wood preservation in Thailand prior to the ban.

The uses of residues from wooden shipping pallets, on the other hand, may be relevant, particularly if the pallets were treated with methyl bromides (MB). MB is an approved chemical for wooden pallets treatment under International Standards for Phytosanitary Measures (ISPM). Although many developed countries, US, Canada and Europe, had completely phased-out MB, shipments from other developing countries can still contain MB. Nevertheless, since these woods are contaminated with bromine, not chlorine, this source is considered beyond the scope of this report.

The use of straw for cooking exists in Thailand but is not widespread, and there is no national statistics for straw consumption. The purpose of using straw for cooking, in many cases, is not only to provide heat but also to render special characteristics to the food. This practice usually takes place in special occasion such as parties, festivals, etc. or in specialized restaurants.

Similarly, open-fire 3-stone (Class 5) stoves can be anticipated to exist in various rural areas in Thailand. Again, no national statistics exist for the amount of biomass consumed in this sector. However, since the emissions factors for both virgin wood/biomass fired stoves (Class 2) and simple stoves (Class 6) are higher, the inventory team, therefore, made no attempt to allocate certain portion of biomass to these Class-5 stoves.

The uses of biomass cooking stoves in Thailand are generally without exhaust ducts. Traditionally, Thai houses have separate cooking and living areas. Cooking areas, though simple, are usually designed to be as open as possible to prevent not only smoke but also the pungent smell of Thai spices from entering living space. Traditional Thai stoves (known as "Ung-lo") are portable stoves with two compartments and natural draft combustion. Ung-lo stoves can be used with charcoal and biomass. Recently, more efficient wood stoves; using appropriately placed exhaust duct to control draft and provide more complete combustion, are becoming available for applications that requires long cooking time.

Dioxins/furans generated from burning biomass can be transferred to ashes. The amount of ashes depends largely on the type of biomass. For the purpose of this inventory, the ash content for each biomass group is derived from median values from proximate analysis of relevant biomasses [42]–[45]. The estimated amounts of ashes are summarized as follows:

**Table 3-48: Estimated amount of ashes generated from biomass cooking stoves in 2017**

| | Amount burned (tonne) | Ash content | Ash generated (tonne) |
|---|---:|---:|---:|
| Paddy Husk | 624,000 | 14.1% | 87,800 |
| Agricultural Waste | 3,360,000 | 3.5% | 119,000 |
| Charcoal | 2,720,000 | 2.9% | 78,900 |
| Fuel Wood | 5,900,000 | 2.3% | 134,000 |

## Releases of dioxins and furans

The estimated PCDD/F emissions from household cooking with biomass are summarized in Table 3-49.

Overall, emissions into air were dominant while emissions to residues contributed about 10% of total emissions from this source. Nevertheless, like in the case of biomass fired boilers, emissions into residues are becoming significant for biomass fired stoves. Note, however, that residues in this case could easily be discarded to nearby land.

**Table 3-49: Estimated PCDD/F emissions from household heating and cooking with biomass in 2017**

| | Household heating and cooking with Biomass | Biomass burned (TJ) | Ash generated (tonne) | Emission (g TEQ/a) | | |
|---|---|---:|---:|---:|---:|---:|
| | | | | Air | Residue | **Subtotal** |
| **2** | **Virgin wood/biomass fired stoves** | **51,200** | **207,000** | **5.120** | **2.071** | **7.191** |
| | Paddy Husk | 8,920 | 87,800 | 0.892 | 0.878 | 1.770 |
| | Agricultural Waste | 42,300 | 119,000 | 4.229 | 1.193 | 5.421 |
| 3 | **Straw fired stoves** | **No data** | | | | |
| **4** | **Charcoal fired stoves** | **77,900** | **78,900** | **7.787** | **0.008** | **7.795** |
| **5** | **Open-fire (3-stone) stoves (virgin wood)** | **No data** | | | | |
| **6** | **Simple stoves (virgin wood)** | **93,500** | **134,000** | **9.349** | **0.013** | **9.363** |
| | Fuel Wood | 93,500 | 134,000 | 9.349 | 0.013 | 9.363 |
| | **Total Household heating and cooking with Biomass** | **223,000** | **420,000** | **22.26** | **2.09** | **24.35** |

## Uncertainty

Confidence level for the activity rates is high while that for emission factors is medium to low. Emission factors in the UNEP Toolkit are mainly derived from stoves for household heating. Combustion characteristics, especially the burning temperature, of these stoves are different from cooking stoves.

Wood-fired cooking stoves are evolving toward a more energy efficient design. The type of biomass and the form of biomass used are also changing. Pellets and loose (straw) briquettes are gaining attraction. This new development points to a better control of combustion but, at the same time, may also contribute to more ash if, in addition to biomass, binders are involved.

### 3.3.5 Household heating and cooking with fossil fuels

Relevant activities

The Toolkit identifies emissions from 6 classes of stoves based on fuel types used as follows:

- High chlorine coal/waste/biomass co-fired stoves
- Coal/waste/biomass co-fired stoves
- Coal fired stoves
- Peat fired stoves
- Oil fired stoves
- Natural gas or LPG fired stoves

Like in the case of biomass fired stoves, space heating is not necessary for Thai climates. When taking account also the availability and the relative ease of access to the fuel, only LPG fired cooking stoves are considered relevant for Thailand.

Emission Factors

There is no data for the emission of PCDD/F from cooking stoves using Thai LPGs. The default value from the UNEP Toolkit, shown in Table 3-50, is used.

**Table 3-50: PCDD/F emission factors for household heating and cooking with fossil fuels**

| | **Household heating and cooking with fossil fuels** Classification | **Emission Factor into Air** (µg TEQ/TJ) |
|---|---|---|
| 6 | Natural gas or LPG fired stoves | 1.5 |

Activity rates

Based on MoEN’s energy balance statistics, in 2017 household and commercial sectors consumed 2,776 and 1,207 million liters of LPG, respectively. Using MoEN’s conversion factor of 0.63014 ktoe per million liters and IEA’s conversion factor of 41.868 TJ per ktoe, these values equal 73,227 TJ and 31,862 TJ, for household and commercial sectors respectively.

Releases of dioxins and furans

The estimated emissions of PCDD/F from household heating and cooking with fossil fuels are summarized in Table 3-51.

**Table 3-51: Estimated PCDD/F emissions from household heating and cooking with fossil fuels in 2017**

| | **Domestic heating - Fossil fuels** | **Fossil fuel burned (TJ)** | **Emission to Air (g TEQ/a)** |
|---|---|---|---|
| 6 | **Natural gas or LPG fired stoves** | **105,000** | **0.158** |
| | Household | 73,200 | 0.110 |
| | Commercial | 31,900 | 0.048 |
| | **Total Domestic heating with Fossil fuels** | **105,000** | **0.16** |

Uncertainty

Since LPG is tightly regulated throughout the supply-chain, the uncertainty associated with LPG consumptions is considered low. Uncertainty associated with this source category is, therefore, considered low due to high level of confidence for the UNEP’s emission factor and the activity rate.

### 3.3.6 Summary

The overall emissions of PCDD/F from heat and power generation in Thailand are summarized in Table 3-52 and visually displayed in Figure 3-13. For this source group, the emissions into residues are of the same order as emissions into air. Particularly, residues from fossil and biomass power plants a large portion of the total emissions. Since the fates of these residues are largely unknown at the time of this report, they deserve more in-depth investigations in the upcoming action plan.

**Table 3-52: Summary of estimated emissions of PCDD/F from Source Group 3 – heat and power generation in 2017**

| | **Heat and Power Generation** | | | **Emission (g TEQ/a)** |
|---|---|---|---|---|
| | Source category | Air | Residue | **Subtotal** |
| 3a | Fossil fuel power plants | 5.13 | 20.71 | **25.83** |
| 3b | Biomass power plants | 18.60 | 28.42 | **47.02** |
| 3c | Landfill biogas combustion | 0.27 | 0 | **0.27** |
| 3d | Household heating and cooking with biomass | 22.26 | 2.09 | **24.35** |
| 3e | Domestic heating with fossil fuels | 0.16 | 0 | **0.16** |
| | **Total Heat and Power Generation** | **46.41** | **51.22** | **97.63** |

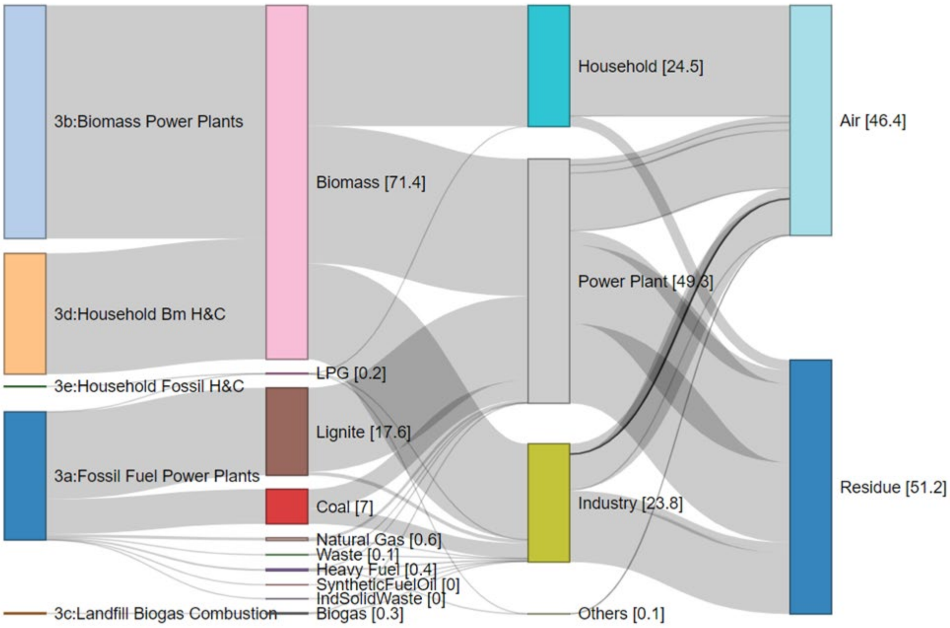

**Figure 3-13: Summary of PCDD/F emissions from heat and power generation in 2017 [unit: g TEQ/a]**

While biomass has been widely regarded as a green energy source with low carbon footprint, relatively high PCDD/F emission contribution from biomass (73%) deserves national attention. Biomass is a major part of Thailand’s renewable energy portfolio. Diverting unused biomass residues from agricultural fields to power plants also help curb biomass open burning problems. However, attention should also be paid to ensure the risks from unintended PCDD/F generations/emissions are under controlled. Particularly, research and development into new power plant/combustion technology with low PCDD/F generation should be promoted. Moreover, due to high PCDD/F emissions into residues coupled with potentially high amount of residue generation from biomass power plants, technology for ultimate destruction of PCDD/F will be needed.

The high emission from the use of biomass for household cooking is also important from the risk proximity and gender point of views. Again, measures should be put in place to ensure public awareness and the availability and accessibility of efficient, low PCDD/F generation stoves.

□□□

## Annex 3. Supporting information for Source Group 3

**Table 3-53: Estimated proportions of fuel consumed in industry sector for different end-use applications**

| Fuel type | Application | Consumption (ktoe/a) | (%) |
|---|---|---|---|
| **Biogas** | BOILER | 116 | 85.0 |
| **Biogas** | ENGINE | 11 | 7.7 |
| **Biogas** | OVEN | 9 | 6.6 |
| **Biomass** | BOILER | 3,473 | 90.4 |
| **Biomass** | KILN | 291 | 7.6 |
| **Biomass** | OVEN | 43 | 1.1 |
| **Coal** | BOILER | 4,383 | 57.8 |
| **Coal** | KILN | 3,193 | 42.1 |
| **Coal** | OVEN | 9 | 0.1 |
| **Diesel** | BOILER | 12,479 | 81.4 |
| **Diesel** | OVEN | 1,807 | 11.8 |
| **Diesel** | FURNACE | 525 | 3.4 |
| **Diesel** | ENGINE | 150 | 1.0 |
| **Diesel** | KILN | 147 | 1.0 |
| **Diesel** | INCINERATOR | 136 | 0.9 |
| **Diesel** | PRODUCTION | 79 | 0.5 |
| **Natural Gas** | BOILER | 1,672 | 40.1 |
| **Natural Gas** | KILN | 1,543 | 37.0 |
| **Natural Gas** | FURNACE | 509 | 12.2 |
| **Natural Gas** | OVEN | 255 | 6.1 |
| **Natural Gas** | PRODUCTION | 156 | 3.8 |
| **LPG** | BOILER | 203 | 42.1 |
| **LPG** | OVEN | 129 | 26.8 |
| **LPG** | FURNACE | 57 | 11.8 |
| **LPG** | KILN | 32 | 6.5 |
| **LPG** | STOVE | 32 | 6.5 |
| **LPG** | INCINERATOR | 17 | 3.6 |
| **LPG** | PRODUCTION | 13 | 2.7 |

**Table 3-54: Utilization factors assigned for each fuel type, business sector, and end-uses**

| Fuel type | Sector | Heat & Power | Kiln and ovens | Engine |
|---|---|---|---|---|
| **Municipal Solid Waste** | All | 1 | 0 | 0 |
| **Bituminous** | Industry | 0.58 | 0.42 | 0 |
| **Briquettes & Other Coal** | Industry | 0.5 | 0.5 | 0 |
| **Lignite** | Industry | 1 | 0 | 0 |
| **High speed diesel** | Agricultural | 0.1 | 0 | 0.9 |
| **High speed diesel** | Industry | 0.8 | 0 | 0.2 |
| **High speed diesel** | Construction | 0.1 | 0.1 | 0.8 |
| **High speed diesel** | Mining | 0.1 | 0 | 0.9 |
| **Fuel Oil** | Agriculture | 1 | 0 | 0 |
| **Fuel Oil** | Industry | 1 | 0 | 0 |
| **Fuel Oil** | Construction | 0.1 | 0 | 0.9 |
| **Fuel Oil** | Mining | 0.1 | 0 | 0.9 |
| **Natural Gas** | Industry | 0.4 | 0 | 0 |
| **LPG** | Industry | 0.42 | 0.58 | 0 |
| **Liquid gasoline (Unleaded Gasoline, Gasohol E10, E20, E85, Ron 91, 95, Kerosene)** | Industry | 0 | 0 | 1 |
| **Biomass (Paddy Husk, Bagasse, Agricultural Waste, Fuel Wood)** | Industry | 0.9 | 0.1 | 0 |
| **Landfill gas** | Industry | 0.85 | 0.08 | 0.07 |
| **Biomass, Charcoal, & LPG** | Household & Commercial | 1 | 0 | 0 |

### Table 3-55: Results from PCD studies of PCDD/F emissions from bituminous fired boilers in Thailand during 2010-2012

| Year | Company ID | Fuel Type | Boiler Age (Year) | PCDD/F Measured (ng TEQ/m$^3$) | Excess O$_2$ (%) | PCDD/F at 11% O$_2$ (ng TEQ/m$^3$) | PCDD/F at 7% O$_2$ (ng TEQ/m$^3$) | Air Flow (m$^3$/hr) | Net Release (ng/hr) | Fuel Consumption (TJ/hr) | Emission Factor (µg TEQ/TJ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2009** | C-1 | Sub Bituminous | 2 | 0.0073 | 5.8 | 0.0048 | 0.0067 | 195,050 | 1,426 | 0.2780 | 5.1 |
| **2010** | C-2 | Sub Bituminous | 5 | 0.0333 | 7.4 | 0.0244 | 0.0343 | 54,718 | 1,823 | 0.1318 | 13.8 |
| **2010** | C-3 | Sub Bituminous | 15 | 0.0068 | 9.5 | 0.0059 | 0.0083 | 380,742 | 2,592 | 0.8241 | 3.1 |
| **2012** | C-4 | Sub Bituminous | 4 | 0.0066 | 7.0 | 0.0047 | 0.0066 | 20,361 | 134 | 0.0385 | 3.5 |
| | | | | | | | | | | min | 3.1 |
| | | | | | | | | | | max | 13.8 |
| | | | | | | | | | | median | 4.3 |

### Table 3-56: Results from PCD studies of PCDD/F emissions from lignite fired boilers in Thailand during 2010-2012

| Year | Company ID | Fuel Type | Boiler Age (Year) | PCDD/F Measured (ng TEQ/m$^3$) | Excess O$_2$ (%) | PCDD/F at 11% O$_2$ (ng TEQ/m$^3$) | PCDD/F at 7% O$_2$ (ng TEQ/m$^3$) | Air Flow (m$^3$/hr) | Net Release (ng/hr) | Fuel Consumption (TJ/hr) | Emission Factor (µg TEQ/TJ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2009** | L-1 | Lignite | 25 | 0.0130 | 4.9 | 0.0080 | 0.0113 | 1,242,976 | 16,168 | 2.6136 | 6.2 |

### Table 3-57: Results from PCD studies of PCDD/F emissions from fuel oil fired boilers in Thailand during 2010-2012

| Year | Company ID | Fuel Type | Boiler Age (Year) | PCDD/F Measured (ng TEQ/m$^3$) | Excess O$_2$ (%) | PCDD/F at 11% O$_2$ (ng TEQ/m$^3$) | PCDD/F at 7% O$_2$ (ng TEQ/m$^3$) | Air Flow (m$^3$/hr) | Net Release (ng/hr) | Fuel Consumption (TJ/hr) | Emission Factor (µg TEQ/TJ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | F-1 | Fuel Oil | 7 | 0.0038 | 5.4 | 0.0024 | 0.0034 | 8,911 | 34 | 0.0298 | 1.1 |
| 2012 | F-2 | Fuel Oil | 16 | 0.0160 | 7.0 | 0.0114 | 0.0160 | 12,350 | 198 | 0.1326 | 1.5 |
| | | | | | | | | | | min | 1.1 |
| | | | | | | | | | | max | 1.5 |
| | | | | | | | | | | median | 1.3 |

### Table 3-58: Results from PCD studies of PCDD/F emissions from bagasse fired boilers in Thailand during 2010-2012

| Year | Company ID | Fuel Type | Boiler Age (Year) | PCDD/F Measured (ng TEQ/m$^3$) | Excess $O_2$ (%) | PCDD/F at 11% $O_2$ (ng TEQ/m$^3$) | PCDD/F at 7% $O_2$ (ng TEQ/m$^3$) | Air Flow (m$^3$/hr) | Net Release (ng/hr) | Fuel Consumption (TJ/hr) | Emission Factor (µg TEQ/TJ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2009** | BM-1 | Bagasse | 5 | 0.0378 | 3.4 | 0.0214 | 0.0300 | 67,403 | 2,546 | 0.2475 | 10.3 |
| **2009** | BM-2 | Bagasse | 18 | 0.0647 | 9.3 | 0.0552 | 0.0775 | 136,649 | 8,838 | 0.3081 | 28.7 |
| **2011** | BM-3 | Bagasse | 20 | 0.0165 | 10.0 | 0.0150 | 0.0210 | 241,966 | 3,985 | 0.5685 | 7.0 |
| | | | | | | | | | | min | 7.0 |
| | | | | | | | | | | max | 28.7 |
| | | | | | | | | | | median | 10.3 |

### Table 3-59: Results from PCD studies of PCDD/F emissions from paddy husk fired boilers in Thailand during 2010-2012

| Year | Company ID | Fuel Type | Boiler Age (Year) | PCDD/F Measured (ng TEQ/m$^3$) | Excess $O_2$ (%) | PCDD/F at 11% $O_2$ (ng TEQ/m$^3$) | PCDD/F at 7% $O_2$ (ng TEQ/m$^3$) | Air Flow (m$^3$/hr) | Net Release (ng/hr) | Fuel Consumption (TJ/hr) | Emission Factor (µg TEQ/TJ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2009** | BM-6 | Paddy Husk | 4 | 0.0530 | 7.8 | 0.0400 | 0.0562 | 167,891 | 8,892 | 0.2826 | 31.5 |
| **2009** | BM-7 | Paddy Husk | 24 | 0.0174 | 11.1 | 0.0176 | 0.0247 | 80,560 | 1,403 | 0.0348 | 40.3 |
| **2011** | BM-8 | Paddy Husk | 5 | 0.0705 | 10.3 | 0.0660 | 0.0927 | 57,000 | 4,017 | 0.1320 | 30.4 |
| **2012** | BM-9 | Paddy Husk | 4 | 1.3674 | 7.0 | 0.9739 | 1.3674 | 81,542 | 111,500 | 2.8800 | 38.7 |
| **2012** | BM-10 | Paddy Husk | 6 | 0.0204 | 7.0 | 0.0145 | 0.0204 | 20,361 | 415 | 3.8880 | 0.1 |
| | | | | | | | | | | min | 0.1 |
| | | | | | | | | | | max | 40.3 |
| | | | | | | | | | | median | 31.5 |

## 3.4 Source Group 4: Mineral Products

This source group concerns emissions from high-temperature processes in the mineral industry. The UNEP Toolkit classifies this source group into 7 categories depending on production process, namely:

- Cement production (4a)
- Lime production (4b)
- Brick production (4c)
- Glass production (4d)
- Ceramics production (4e)
- Asphalt mixing (4f)
- Oil shale pyrolysis (4g)

Data for assessing activity rates within this source group are taken from the following sources:

- DIW Factory Registration Dataset [online data on DIW web portal[11], last retrieved February 2019]
- M-Industry's Industrial waste transfer manifest ("M-Industry waste transfer manifest")
- EIA reports from Office of Natural Resources and Environmental Policy and Planning (ONEP) [online data on ONEP web portal[12], last retrieved September 2019]
- Office of Industrial Economics (OIE) background data for the derivation of OIE industrial indices (as of 29 May 2019) [18], ("OIE statistics data")
- Interviews with key stakeholders
- Business association yearbooks and website

Thailand has one relatively poor- to medium-quality oil shale deposit at Mae Sot Basin [60].The potential oil shale has been assessed in 2008 [61]. The study concluded that the cost for electricity generated from an oil shale power plant would be twice higher than electricity from other sources [62]. To our best knowledge, there is no commercial oil shale plant in Thailand. Emission from oil shale production is, therefore, considered irrelevant to Thailand and is not included in this report.

### 3.4.1 Cement production

Cement industry forms a foundation for national infrastructure development. The growth of the industry mirrors national GDP growth.

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[11] http://www2.diw.go.th/factory/tumbol.asp

[12] http://eia.onep.go.th/index.php

According to the Thai Cement Manufacturers Association (TCMA)[13], Thai cement industry is currently operated by 7 companies with 12 plants producing 50.3 million tonnes of cement clinker per year from 32 cement kilns.

Cement plants are located around Saraburi province, and one each in Lampang, Nakhon Sawan, Phetchaburi and Nakhon Si Thammarat provinces. According to DIW Factory database, cement plants contributed to about 42.6 billion bahts of capital investment and about 2,700 employments.

### Emission factors

UNEP classifies emissions from cement productions into 4 classes namely;

Class 1: shaft kilns
Class 2: old wet kilns with electrostatic precipitator (ESP) operated above 300°C
Class 3: wet kilns with ESP or fabric filter (FF) operated at temperature between 200 to 300°C
Class 4: wet kilns with ESP or FF operated at temperature below 200°C and all types of dry kilns with preheater/pre-calciner and dust collector operated at temperature below 200°C

An overview of UNEP emission factors for cement production is shown in Table 3-60.

**Table 3-60: PCDD/F emission factors for cement production**

| 4a | Cement kilns Classification<br>Classification | Air<br>(µg TEQ/t cement) |
|---|---|---|
| 1 | Shaft kilns | 5 |
| 2 | Old wet kilns, ESP temperature >300°C | 5 |
| 3 | Wet kilns, ESP/FF temperature 200 to 300°C | 0.6 |
| 4 | Wet kilns, ESP/FF temperature <200°C and all types of dry kilns with preheater/pre-calciner, T<200°C | 0.05 |

### Activity rates

Based on OIE statistics data [18], Thailand produced 43,029,611 tonnes of cement clinkers (TSIC 23941) in 2017.

Cement plants are designated pollution source that must be controlled for air emission under MNRE notification B.E. 2549 [63]. The pollutant types and air emission level are limited by DIW air emission standard for cement plants B.E. 2549 [64]. Cement plants using waste as an energy or material source are also subjected to MNRE's dioxin emission control of 0.5 ng I-TEQ/$m^3$ [65]. It should be noted that all stack air emission standards in Thailand are based on dry air with air volume calculated at 760 mmHg, 25°C and 7% excess oxygen.

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[13] http://thaicma.or.th/cms/scale-of-cement-industry/scale-of-cement-industry/#

All cement plants must conduct EIA study and follow the specified measures to monitor and mitigate environmental impacts [24]. In addition to dust and typical air pollutants (heavy metal, SOX, NOX, etc.), dioxin is also included in most cement plants' approved action plans[14]. Almost all cement plants use waste as a supplementary energy source. An investigation into EIA monitoring reports from three major cement companies (multiple plants, using various kinds of waste) found typical stack concentrations below 0.05 ng I-TEQ/$m^3$ (7% $O_2$). Unfortunately, despite the wealth of measurement data, country-specific emission factor for cement kilns could not be derived due to missing corresponding clinker production data.

Based on an interview with a major cement producer, all cement kilns in Thailand are dry kilns operated with waste heat recovery system which brought exhaust gas temperature to below 200°C.

Based on the technology used and the published dioxin emission reports, all cement productions in Thailand are considered Class 4.

Releases of dioxins and furans

The estimated emission of from cement kilns in Thailand in 2017 is shown in Table 3-61.

**Table 3-61: Estimated PCDD/F emissions from cement kilns in 2017**

| 4a | Cement kilns Classification | Activity Rate (tonne) | Emission to Air (g TEQ/a) |
|---|---|---|---|
| 1 | Shaft kilns | 0 | 0.000 |
| 2 | Old wet kilns, ESP temperature >300°C | 0 | 0.000 |
| 3 | Wet kilns, ESP/FF temperature 200 to 300°C | 0 | 0.000 |
| 4 | Wet kilns, ESP/FF temperature <200°C and all types of dry kilns with preheater/pre-calciner, T<200°C | 43,000,000 | 2.151 |
|  | **Total Cement kilns** | **43,000,000** | **2.151** |

Uncertainty

Confidence levels are high for both activity rate and emission factors.

### 3.4.2 Lime production

Relevant activity

Lime is an important mineral that find uses in many applications including metals refinery, pulp and paper, construction, food and feed, agriculture and, lately, environmental applications.

According to the Department of Primary Industries and Mines (DPIM), there are currently 29 valid licenses (called "Prathanabat[15]") for lime stone mining in 8 provinces, with total mining area of about 800 ha.

A search in DIW factory database with "lime" related keywords (in Thai)

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[14] A search in ONEP EIA database (http://eia.onep.go.th/index.php) with a keyword "cement production" (in Thai)

[15] "Prathanabat" means a license issued for mining within the area designated therein

yielded 74 factories in 15 provinces with combined investment of about 3,700 million Baht creating about 1,500 jobs. Top 13 highest investment factories, concentrated in Saraburi and 4 surrounding provinces, contribute to about 90% of all investment in this industry. These factories are well-established, with an average age of 15.1 years and employ, on average, 58 persons per plant.

### Emission factors

There is no data associated with PCDD/F measurements from lime kilns in Thailand. Emission factors from the UNEP Toolkit, as shown in Table 3-62, are used to estimate emissions from lime kilns in Thailand.

**Table 3-62: PCDD/F emission factors for lime production**

| 4b | Lime production<br>Classification | Emission Factors<br>(µg TEQ/t lime produced) |
|---|---|---|
| 1 | Cyclone/no dust control, contaminated or poor fuels | 10 |
| 2 | Good dust abatement | 0.07 |

### Activity rates

There is no data at the national level for lime production. According to annual reports from 2 listed public limited companies [66], [67], there are 4 major group of companies in lime business in Thailand with a combined production capacity in 2017 estimated at about 2.4 million tonnes.

In Thailand, lime factories share the same official factory classification type with cement factories. Lime kilns are, therefore, subjected to the same emission controls as those for cement kilns. A search in ONEP EIA database found 25 ongoing projects. Most of the projects registered are under mining category. The search found only 2 relevant projects registered under industry category. Dioxin monitoring is mentioned in a recently approved project that uses industrial waste as substitute materials for lime production. Monitoring data for this factory is not yet available at the time of this report.

Since almost all production volumes are dominated by well-established factories that are subjected to stringent regulations, all activities are assigned to Class 2 (good dust abatement).

### Releases of dioxins and furans

The estimated emission of from lime kilns in Thailand in 2017 is shown Table 3-63.

**Table 3-63: Estimated PCDD/F emissions from lime production in 2017**

| 4b | Lime production<br>Classification | Activity Rate<br>(tonne) | Emission to Air<br>(g TEQ/a) |
|---|---|---|---|
| 1 | Cyclone/no dust control, contaminated or poor fuels | 0 | 0 |
| 2 | Good dust abatement | 2,400,000 | 0.168 |
| | **Total Lime production** | **2,400,000** | **0.168** |

Uncertainty

The confidence level for activity rate is medium due to lack of activity data at national level.
Large users, such as pulp and paper industry, also produce and recycle lime in-house. Emissions from such ‘by-product’ lime productions are not included in this estimation.

### 3.4.3 Brick production

Relevant activity

Clay brick is a traditional building material that has been produced in Thailand since the Tawaravadee (B.E.12-16) Era[16].
Traditionally the brick industry used either fire wood or rise husks to fire bricks. Brick industry used to be the largest user of firewood in Thailand [68]. Without proper flue gas abatement, brick production is one of the seven main sources of outdoor air pollution that needs to be transformed [69].

Clay brick producers in Thailand are mostly SMEs. A search into DIW Factory registration database with Thai “clay bricks” related keywords (excluding irrelevant products such as refractory bricks, concrete blocks, autoclaved aerated concretes, etc.) yielded 407 factories in 49 provinces with an average investment and employment per plant of 1.5 million bahts and 9.3 persons, respectively.

Clay bricks are losing their advantages to cement blocks, autoclaved aerated concrete (AAC, also known as “foam concrete”) [70], and recently pre-casted walls. The rise of energy and labor costs, long production cycle time (about 1 month for traditional kilns), and the need to have large area to dry the green bricks make clay brick production less appealing to investors.

Emission factors

PCDD/F emissions from brick production are mainly associated with quality of fuel used. The UNEP Toolkit classifies brick production into 2 main classes; those using contaminated and non-contaminated fuels, as shown in Table 3-64.
PCDD/Fs from fuel combustions are also transferred to residues and embedded in the resulting bricks. Emission factors into these vectors for kilns with contaminated fuels (Class 1) are derived from artisanal brick kilns using waste or contaminated oil. Emission factors for Class 2 kilns are derived from coal and virgin wood fired brick kilns operated at industrial and artisanal scale.

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[16] https://en.wikipedia.org/wiki/Architecture_of_Thailand

**Table 3-64: PCDD/F emission factors for brick production**

| 4c | Brick production | Emission Factors (µg TEQ/t brick produced) | | |
|---|---|---|---|---|
| | Classification | Air | Product | Residue |
| 1 | No emission abatement in place and using contaminated fuels | 0.2 | 0.06 | 0.02 |
| 2 | No emission abatement in place and using non-contaminated fuels; Emission abatement in place and using any kind of fuel; No emission abatement in place but state of the art process control | 0.02 | 0.006 | 0.002 |

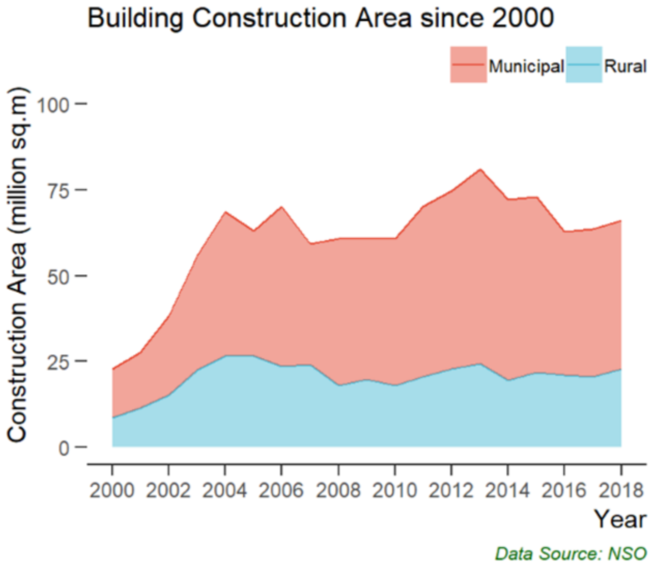

**Figure 3-14: Building construction in Thailand since 2000**

Activity rates

There is no data at the national level for clay brick production in Thailand.

In 2006 inventory assessment, Thailand reported brick production in 2004 at about 4.5 million tonnes. Based on data from the National Statistical Office (NSO), building construction (floor) areas in Thailand in 2017 were about 63 million square meters which was in the same order as in 2004 (see Figure 3-14). However, brick uses in modern constructions were on decline. The rise in labor costs, shortage of skilled labors, relatively low overall costs of alternative materials, quality inconsistency, and the demand for short construction time made brick less appealing to home owners and developers.

The market size for wall materials in Thailand was about 300 million $m^2$/year [70]. The current market share for AAC concrete block is about 10%. Assuming market share for clay bricks in wall materials in 2017 of about 33%, there were 100 million $m^2$ of clay bricks produced. Using an average mass of 100 kg/$m^2$, this area could be converted to 10 million tonnes of clay brick[17].

(Note: OIE database [18] indicated the production of cement block of about 33 million pieces or about 2.7 million square meters which is less than 0.1% of total wall market. This value is considered too low and, therefore, excluded from the estimation.).

Clay brick kilns can be classified into 2 types: stationary kilns (with masonry wall and chimneys) and clamp kilns [71]. Brick kilns are typically fired with biomass, rice husk for clamp kilns, and mixed biomass or fuel woods for stationary kilns. Most kilns are without flue gas abatement.

Due to the total ban of forest logging, processed woods are scarce items. There is no record of commercial supply of contaminated woods in Thailand. All clay brick kilns, therefore, are assigned to Class 2.

Releases of dioxins and furans

The estimated releases of from bricks production in Thailand in 2017 are summarized in Table 3-65.

**Table 3-65: Estimated PCDD/F emissions from brick production in 2017**

| **4c** | **Brick production** Classification | **Activity Rate** (tonne) | Air | Product | **Emission (g TEQ/a)** Residue | Subtotal |
|---|---|---|---|---|---|---|
| 1 | No emission abatement in place and using contaminated fuels | 0 | 0 | | | |
| 2 | No emission abatement in place and using non-contaminated fuels; Emission abatement in place and using any kind of fuel; No emission abatement in place but state of the art process control | 10,000,000 | 0.20 | 0.06 | 0.02 | **0.28** |
| | **Total Brick Production** | **10,000,000** | **0.20** | **0.06** | **0.02** | **0.28** |

Uncertainty

The level of confidence for activity rate is medium due to lack of national data. Comparing with the cement production in 2017 of about 40 million tonnes, the activity rate estimated here could represent the upper range of this activity.

### 3.4.4 Glass production

Relevant activity

With an energy intensity in 2003 of 10.88 GJ/t [72], glass industry is an energy-intensive industry in Thailand. Glass industry in Thailand consists of flat glass and float glass industry, glassware industry, glass container industry, and fiber glass industry [72].

A search in DIW factory database yielded 104 glass factories in 18 provinces. The glass industry provides more than 13,000 jobs and about 52 billion bahts in investment.

Table 3-66 summarizes Thailand’s import and export of glass goods in 2017. Flat glass, glass containers and glassware were the 3 main export products.

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[17] Dry weight without mortar

**Table 3-66: Thailand's 2017 glass goods import and export**

| Category | HS Code | Quantity (tonne) | | CIF Value (Million Baht) | |
|---|---|---|---|---|---|
| | | Import | Export | Import | Export |
| Float glass | 7005 | 143,478 | 182,946 | 2,042 | 3,453 |
| Glass fiber | 7019 | 88,412 | 26,377 | 5,825 | 1,969 |
| Glass container | 7010 | 69,144 | 108,463 | 1,629 | 1,679 |
| Glassware | 7013 | 25,099 | 48,259 | 1,262 | 2,906 |
| Cast glass and rolled glass | 7003 | 18,648 | 36,173 | 5,942 | 732 |
| Glass mirrors | 7009 | 14,104 | 33,326 | 2,384 | 2,888 |
| Glass envelopes | 7011 | 412 | 15,514 | 32 | 651 |
| Other | Other | 218,032 | 92,305 | 13,417 | 9,439 |
| Total | | 577,330 | 543,363 | 32,532 | 23,717 |

*Data source: trademap.com*

## Emission factors

The UNEP Toolkit emission factors are associated with the type of fuels, combustion condition, and flue gas control system as shown in Table 3-67

**Table 3-67: PCDD/F emission factors for glass production**

| 4d | Glass production Classification | Emission to Air (µg TEQ/t glass) |
|---|---|---|
| 1 | Cyclone/no dust control, contaminated or poor fuels | 0.2 |
| 2 | Good dust abatement | 0.015 |

## Activity rates

Thai Flat glass industry is dominated by 3 firms that contribute to more than 90% of total investment in this sector. The glassware and glass packaging industries, on the other hand, do not have dominant players, with the top 15 firms contributing to 90% of total investment. All registered plants are required to have dust abatement system in place to meet DIW emission standards.

In 2005, DEDE commenced a research study to evaluate specific energy consumption (SEC) in glass industry and found SEC value of 18.6 GJ/t and 10.4 GJ/t for glassware and flat glass industry, respectively [72]. The proportions of energy types used in this industry were 30% electricity, 34% natural gas, 5% LPG and 31% heavy fuel.

In 2015, the proportion of natural gas in glass industry energy mix has increased to 68% while heavy fuel reduced to 13% [73]. Based on the EIA approved gas pipe distribution projects to feed natural gas to 4 major glass producers, the current natural gas proportion is expected to be higher and the heavy fuel proportion to be lower.

Glass industry is included in the Thai V-ETS carbon trading scheme. At least 3 major glass producers participate in this carbon trading scheme[18].

OIE database indicated in 2017 the combined production of flat glass (TSIC 23101) and glass containers & glassware (TSIC 23102), of

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[18] TGO online data, http://carbonmarket.tgo.or.th/organizations/organizations.pnc, last accessed September 1, 2019

1,817,014 tonnes. There is no data available for production of glass fiber and glass envelopes. These products, therefore, were assumed to provide additional 100,000 tonnes to the total activity rate.

Based on the industry's energy mix data, most of these glasses were produced with clean fuel (Class 2). 10% of total production is allocated to Class 1 for those produced using heavy fuel.

### Releases of dioxins and furans

The estimated emissions from glass production in Thailand in 2017 are summarized in Table 3-68. Although heavy fuel was used in only a small portion in total energy mix, it contributed the major part of PCDD/F emission from this industry.

**Table 3-68: Estimated PCDD/F emissions from glass production in 2017**

| 4e | Glass production<br>Classification | Activity Rate<br>(tonne) | Emission to Air<br>(g TEQ/a) |
|---|---|---|---|
| 1 | Cyclone/no dust control, contaminated or poor fuels | 192,000 | 0.038 |
| 2 | Good dust abatement | 1,730,000 | 0.026 |
| | **Total Glass Production** | **1,922,000** | **0.064** |

### Uncertainty

The confidence levels for the activity rate and technology classification are high due to the availability of productivity data and energy mix data.

## 3.4.5 Ceramics production

### Relevant activity

Ceramic industry (Factory type 055) in Thailand consists of 515 factories in 48 provinces, with total registered capital of 27.8 billion baht and an average employment of 81 persons per factory. Ceramic products can be classified into 4 groups: sanitary ware, tableware, wall and floor tiles and electrical insulator. Sanitary ware and tiles are the most capital intensive. Producers in this sector represent the top 30 companies with combined capital investment of over 80%.

The ceramic industry is known to be energy-intensive. In 2005, DEDE commenced a research study to evaluate specific energy consumption (SEC) in this industry and found SEC values varied from 4 to nearly 40 GJ/t depending on product, as shown in Table 3-69. The proportion of energy types used in this industry were 23% electricity, 74% natural gas, 2% LPG and 1% heavy fuel [72].

**Table 3-69: SEC for ceramic industry (in 2005)**

| Product | SEC (GJ/t) |
|---|---|
| Table ware | 22.35-38.8 |
| Sanitary ware | 13.23 |
| Wall tiles | 5.74 |
| Floor tiles | 4.08 |
| Electrical insulator | 23.14 |

*Source: DEDE 2005* [72]

## Emission factors

Emissions from ceramic industry stem from combustion process. The UNEP Toolkit defines ceramic production process in two classes: those using poor fuels without exhaust control and those with good dust abatement as shown in Table 3-70.

**Table 3-70: PCDD/F emission factors for ceramic production**

| 4e | Ceramics Production | Emission Factors (µg TEQ/t product) |
|---|---|---|
| | Classification | Air |
| 1 | Cyclone/no dust control, contaminated or poor fuels | 0.2 |
| 2 | Good dust abatement | 0.02 |

## Activity rates

OIE database contains productivity data from products under TSIC 23922 (tiles), 23923 (sanitary ware), and 23931 (tableware). Available data were recorded in square meters for tiles, pieces for sanitary ware, and tonne for tableware. Since the UNEP emission factors are based on tonne of products, conversion factors are needed.

Conversion factors are estimated by an average weight of Top 10 best-selling products on Amazon.com (experiment conducted on April 2019). The resulted activity rates for each product, as recorded and after conversion, are summarized in Table 3-71.
Based on DEDE specific energy consumption (SEC) study, ceramic industry, though energy-intensive, typically use clean fuels [15]. Ceramic industry is included in the Thai V-ETS carbon trading scheme. At least 3 major ceramic producers participate in this carbon trading scheme[19].

The majority (95%) of ceramic production is, therefore, assigned to Class 2 with the rest (5%) assigned to Class 1 to account for the smaller factories distributed in 47 provinces around the country.

**Table 3-71: Overall production of ceramic products in 2017**

| TSIC | Product | Production (2017) | Unit | Conversion (kg/unit) | t/year |
|---|---|---|---|---|---|
| 23922.010 | Floor and wall tiles | 140,608,974 | Sq. meter | 12 | 1,687,308 |
| 23923.020 | Toilet bowls | 3,854,681 | Piece | 100 | 385,468 |
| 23923.030 | Urinals | 244,084 | Piece | 20 | 4,882 |
| 23923.040 | Bathroom sink | 2,285,172 | Piece | 10 | 22,852 |
| 23923.060 | Soap stands & toilet paper holders | 531,734 | Piece | 0.2 | 106 |
| 23931.010 | Table ware | 29,862 | Tonne | 1,000 | 29,862 |
| | | | | Total production | 2,130,478 |

Data source: Production data from OIE database 2017, Conversion factors – from MTEC online experiment

## Releases of dioxins and furans

The estimated emissions of from producing ceramic products are summarized in Table 3-72.

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[19] TGO online data, http://carbonmarket.tgo.or.th/organizations/organizations.pnc, last accessed September 1, 2019

**Table 3-72: Estimated PCDD/F emissions from ceramic production in 2017**

| **4e** | **Ceramic Production**<br>Classification | **Activity Rate**<br>(tonne) | **Emission to Air**<br>(g TEQ/a) |
|---|---|---:|---:|
| 1 | Cyclone/no dust control, contaminated or poor fuels | 100,000 | 0.020 |
| 2 | Good dust abatement | 2,150,000 | 0.043 |
|  | **Total Ceramic Production** | **2,250,000** | **0.063** |

#### Change since previous inventory

Previous 2004 inventory assessment reported activity rate of 850,000 tonnes, releasing 0.17 g I-TEQ/a of into air. All ceramic productions were assigned Class 1 based on the types of fuel used, and to some extent, the installation of exhaust abatement.

For this inventory study, activity rate has increased about 250% but estimated emission into air decreased by about 63%. This change is attributed to the use of cleaner fuels and improved end-of-pipe dust abatement.

#### Uncertainty

The level of confidence for activity rate is medium to high. Though national data are available, conversion factors are used to estimate the mass of the ceramic products. These estimates are checked against import/export volume (see Table 3-77) and found to be consistent.

OIE data may not cover all ceramic products. Judging from amount of import/export, this estimate should cover the majority (>80%) of ceramic products produced in Thailand in 2017.

### 3.4.6 Asphalt mixing

#### Relevant activity

Thailand asphaltic concrete industry (Factory type 50(1) and 50(4)) consist of 560 registered factories in 76 provinces with total registered capital of 15.7 billion baht and average employment of 10.5 persons per factory. The provinces of Surat Thani, Chiang Mai and Nakhon Sawan are the top 3 provinces with the most number of asphaltic concrete producers.

#### Emission factors

The UNEP Toolkit classifies asphalt mixing process into 2 classes based on the installation of gas cleaning system as shown in Table 3-73

**Table 3-73: PCDD/F emission factors for asphalt mixing**

| **4f** | **Asphalt mixing** | **Emission Factors (µg TEQ/t asphalt mix)** |  |
|---|---|---:|---:|
|  | Classification | Air | Residue |
| 1 | Mixing plant with no gas cleaning | 0.07 | No data |
| 2 | Mixing plant with fabric filter, wet scrubber | 0.007 | 0.06 |

#### Activity rates

OIE database indicates production of asphaltic concrete (TSIC 23999) of 1,309 million liters in 2017. Using a unit weight of 2.24 kg per liter, this asphaltic concrete volume was converted to 2,930,000 tonnes.

Releases of dioxins and furans

The estimated emissions from asphalt mixings are summarized in Table 3-74

**Table 3-74: Estimated PCDD/F emissions from asphalt mixing in 2017**

| **4f** | **Asphalt mixing**<br>Classification | **Activity Rate**<br>(tonne) | **Emission to Air**<br>(g TEQ/a) |
|---|---|---|---|
| 1 | Mixing plant with no gas cleaning | 2,930,000 | 0.205 |
| 2 | Mixing plant with fabric filter, wet scrubber | 0 | 0.00 |
| | **Total Asphalt mixing** | **2,930,000** | **0.205** |

Change since previous inventory

Previous inventory for baseline year 2004 reported activity rate of 655,737 tonnes, releasing 0.046 g TEQ/a of PCDD/F into air. All asphaltic concrete was assigned Class 1, the same as this study.

### 3.4.7 Summary

The overall emissions of PCDD/F from production of mineral products in Thailand are summarized in Table 3-75.

**Table 3-75: Summary of the estimated PCDD/F emissions from production of mineral products in 2017**

| | **Production of Mineral Products**<br>Sub category | Air | Product | **Emission (g TEQ/a)**<br>Residue | **Subtotal** |
|---|---|---|---|---|---|
| a | Cement production | 2.151 | 0 | 0 | **2.15** |
| b | Lime production | 0.168 | 0 | 0 | **0.17** |
| c | Brick production | 0.20 | 0.06 | 0.02 | **0.28** |
| d | Glass production | 0.064 | 0 | 0 | **0.06** |
| e | Ceramics production | 0.063 | 0 | 0 | **0.06** |
| f | Asphalt mixing | 0.205 | 0 | 0.000 | **0.21** |
| | **Total Production of Mineral Products** | **2.85** | **0.06** | **0.02** | **2.93** |

□□□

## Annex 4. Supporting information for Source Group 4

### Table 3-76: Import/Export of glass and glassware products in 2017 (tonne)

| HS Code | Description | Export | Import |
|---|---|---|---|
| 7005 | Float glass and surface ground or polished glass, in sheets, … | 182,946 | 143,478 |
| 7010 | Carboys, bottles, flasks, jars, pots, phials, ampoules and other containers, of glass, … | 108,463 | 69,144 |
| 7013 | Glassware of a kind used for table, kitchen, toilet, office, indoor decoration or similar purposes | 48,259 | 25,099 |
| 7003 | Cast glass and rolled glass, in sheets or profiles | 36,173 | 18,648 |
| 7009 | Glass mirrors, whether or not framed, including rear-view mirrors. | 33,326 | 14,104 |
| 7001 | Cullet and other waste and scrap of glass; glass in the mass. | 31,254 | 40,584 |
| 7019 | Glass fibers (including glass wool) and articles thereof | 26,377 | 88,412 |
| 7006 | Glass of heading 70.03, 70.04 or 70.05, bent, edge-worked, engraved, drilled, enameled or otherwise worked | 18,905 | 8,388 |
| 7016 | Paving blocks, slabs, bricks, squares, tiles and other articles of pressed or molded glass, | 18,660 | 10,864 |
| 7007 | Safety glass, consisting of toughened (tempered) or laminated glass. | 16,767 | 124,362 |
| 7011 | Glass envelopes (including bulbs and tubes), open, and glass parts thereof, without fittings, for electric lamps, cathode-ray tubes or the like. | 15,514 | 412 |
| Others | Others | 6,719 | 33,834 |
|  | Total | 543,363 | 577,330 |

*Data Source: Thai Customs*

### Table 3-77: Import/Export of ceramic products in 2017 (tonne)

| HS Code | Description | Export | Import |
|---|---|---|---|
| 6910 | Ceramic sinks, washbasins, washbasin pedestals, baths, … | 86,539 | 21,307 |
| 6912 | Tableware and kitchenware, other household articles and toilet articles, other than of porcelain or china. - of ceramics other than porcelain or china | 40,370 | 7,028 |
| 6905 | Roofing tiles | 39,433 | 1,566 |
| 6902 | Refractory bricks, blocks, tiles | 35,395 | 46,691 |
| 6904 | Ceramic building bricks, flooring blocks | 19,073 | 203 |
| 6911 | Tableware, kitchenware - of porcelain or china | 16,007 | 8,730 |
| Others | Others | 20,460 | 20,098 |
|  | Total | 257,277 | 105,623 |

*Data Source: Thai Customs*

## 3.5 Source Group 5: Transport

The estimations of dioxins/furans released from “transport” cover both on-road and off-road motor vehicles but not air transport. The PCDD/F emissions from motor vehicles are results of incomplete combustions of fuel in engines. The UNEP Toolkit categorizes emission sources within this source group into 4 categories:

- 4-stroke engines (5a)
- 2-stroke engines (5b)
- Diesel engines (5c)
- Heavy oil fired engines (5d)

Data from the following sources are used to estimate activity rates within this source group.

- MoEN’s energy balance statistics 2017 [38][39]
- MoEN Final energy consumption for Agriculture, Commercial, Construction, Manufacture, Mining, Residential and Transportation sectors [74]–[80] (“MoEN Energy Consumption data”)
- Department of Land Transport (DLT) “Number of Vehicle Registered in Thailand”.[35] (“DLT Vehicle Registered data”)
- DLT “Number of Registered Vehicle by Fuel Used”.[81] (“DLT Fuel data”)

Information on annual average mileage for vehicles and vehicles de-registrations are not available. Further, there is no information available for PCDD/F emissions from motor vehicles in Thailand. The estimation of the emissions from transport sectors in this report; therefore, relies solely on emission factors given in the UNEP Toolkit 2013.

An overview of the amount of fuels consumed by different sectors in Thailand in 2017 is shown in Table 3-78. High amount of diesel and fuel oil were reported not only for transport sector but also industry and agriculture. The end-uses in these sectors could be for purposes other than engines (for boilers, kilns and furnaces, etc.). Except for fuels consumed by industrial sector, information related to end-uses of these fuels is not available. To estimate the portion of the fuel used in engines, following utilization factors are assumed.

| Fuel Type | Industry | Agriculture | Construction | Mining |
|---|---|---|---|---|
| **Diesel** | 0.2 | 0.9 | 0.8 | 0.9 |
| **Fuel Oil** | 0 | 0 | 0.9 | 0.9 |

The UNEP emission factors for this source group are based on tonnes of fuel burned in engines while values in MoEN datasets are available either in ktoe or million liters. Conversion factors extracted from International Energy Agency’s conversion factors [82] are used to convert volume to mass as followed:

| Fuel Type | Density kg/$m^3$ |
|---|---|
| **LPG** | 522.2 |
| **Gasoline (incl. Gasohol)** | 740.7 |
| **Diesel** | 843.9 |
| **Fuel Oil** | 925.1 |

The corresponded masses for each fuel type are presented alongside the volume data in Table 3-78.

**Table 3-78: Overview of fuel consumptions in different sectors in Thailand in 2017**
(Unit: Million Liters (kt))

| Fuel Type | Road & Rail | Waterway | Industry | Agriculture | C&M | Total |
|---|---|---|---|---|---|---|
| Diesel | 15,765 | 222 | 4,056 | 3,048 | 136 | 23,227 |
| | (13,304) | (187) | (3,423) | (2,572) | (115) | (19,601) |
| Fuel Oil | 0 | 1,239 | 792 | 0 | 27 | 2,058 |
| | | (1,146) | (733) | | (25) | (1,904) |
| Gasohol E10 | 8,162 | 0 | 0 | 0 | 0 | 8,162 |
| | (6,046) | | | | | (6,046) |
| Gasohol E20 | 1,903 | 0 | 0 | 0 | 0 | 1,903 |
| | (1,410) | | | | | (1,410) |
| Gasohol E85 | 383 | 0 | 0 | 0 | 0 | 383 |
| | (284) | | | | | (284) |
| ULG | 114 | 0 | 0 | 0 | 0 | 114 |
| RON 87 & RON 91 | (84) | | | | | (84) |
| ULG RON 95 | 896 | 0 | 0 | 0 | 0 | 896 |
| | (664) | | | | | (664) |
| LPG | 2,442 | 0 | 0 | 0 | 0 | 2,442 |
| | (1,275) | | | | | (1,275) |

C&M=Construction and Mining, ULG=Unleaded Gasoline, RON=Research Octane Number

*Data source: Modified from MoEN Energy Balance data* [39]

### 3.5.1 4-stroke engines

Emission factors

The UNEP Toolkit 2013 classifies 4-stroke engines based on types of fuels and the installation of catalytic converter for exhaust abatement, as summarized in Table 3-79.

"Leaded fuel" refers to gasoline with lead content more than 0.013 g/L. Halogenated compound such as ethylene dibromide (EDB) and 1,2-dichloroethane (DCA) [83][84] had been added to leaded fuels to prevent lead deposits from fouling the engine. The lead-halogen scavenger reaction, which takes place in the engine, is believed to be the main reason for high PCDD/F emissions from engines burning leaded fuel.

"Unleaded gasoline without catalyst" refers to vehicles using regular unleaded gasoline with no catalytic converter installed.

"Unleaded gasoline with catalyst" covers vehicles with catalytic converter; fueled with regular gasoline, or ethanol-gasoline mix with ethanol content less than 50% or LPG. Vehicles within this class should meet Euro 2 emission standard or better.

"Ethanol with catalyst" refers to vehicles with catalytic converter fueled with ethanol-gasoline mixture, with ethanol content greater than 50%.

**Table 3-79: PCDD/F emission factors for 4-stroke engines**

| 5a | 4-Stroke engines<br>Classification | Emission Factors to Air<br>(µg TEQ/t fuel burned) |
|---|---|---|
| 1 | Leaded fuel | 2.2 |
| 2 | Unleaded gasoline without catalyst | 0.1 |
| 3 | Unleaded gasoline with catalyst | 0.001 |
| 4 | Ethanol with catalyst | 0.0007 |

## Activity rates

Thailand started phasing-down lead content in gasoline since 1984 and completely banned leaded gasoline in 1996. Starting from 2014, gasoline (lean or gasohol) with lead content more than 0.005 g/L have been prohibited [85], [86].

Gasohol first appeared in MoEN energy balance report in 2001. Gasohol consumption grew steadily until it virtually replaced regular gasoline in 2013. In 2017, three gasohol mixtures were available at gas stations: E10, E20, and E85, having ethanol to gasoline volume ratios of 10%, 20%, and 85%, respectively [85].

Starting from 1993, all new passenger cars fueled with gasoline must have catalytic converters installed [87]. Moreover, vehicles equipped with positive ignition engines fueled with gasoline must comply with TISI mandatory exhaust emission control standards [88] [89] which are equivalent to Euro-4 emission standards. Vehicles with better emission performances are also available on the market and are encouraged through a government driven "EcoCar" campaign: an incentive program that provides up to 40% excise tax reduction. At the time of this report, there are 61 models and 127 models[20] available for cars that meet Euro-5 and Euro-6 emission standards, respectively.

Based on DLT Vehicle Registered data, in 2017 there were about 6.8 million valid registrations for gasoline-fueled passenger cars and light trucks, and 63,000 for passenger vans. Passenger cars produced before 1993 may not be equipped with catalytic converters. Based on DLT data, the number of gasoline fueled vehicles without catalytic converters are estimated to be around 450,000 units. The amount of fuel consumed by these vehicles is unknown. Nevertheless, considering the fact that these vehicles may not be able to use gasohol without modification, all lean gasolines consumed by 4-stroke engines are allocated to these cars.

## Releases of dioxins and furans

The estimated activity rates and PCDD/F emissions from 4-stroke engines in 2017 are summarized in Table 3-80. About 9.2 million tonnes of gasolines were consumed in 4-stroke engines causing about 26 mg TEQ

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[20] http://www.car.go.th/ (last access: August 2019)

of PCDD/F released into air

**Table 3-80: Estimated emission of PCDD/F from 4-stroke engines in 2017**

| 5a | 4-stroke engines<br>Classification | Activity Rate<br>(tonne)[1)] | Emission to air<br>(g TEQ/a) |
|---|---|---|---|
| 1 | Leaded fuel | 0 | 0.000 |
| 2 | Unleaded gasoline without catalyst | 170,000<br>(0-0.62M) | 0.017<br>(0-0.062) |
| 3 | Unleaded gasoline with catalyst | 8,735,000<br>(7.96-9.0M) | 0.009<br>(0.008-0.009) |
|  | Gasoline | 7,460,000 | 0.007 |
|  | LPG | 1,275,000 | 0.001 |
| 4 | Ethanol with catalyst | 284,000 | 0.000 |
|  | **Total 4-stroke engines** | **9,189,000** | **0.026**<br>**(0.009-0.07)** |

1): numbers rounded to 3 significant figures for legibility.

Uncertainty

The level of confidence is high for activity rate due to the availability of national data on fuel consumptions and medium for activity classification due to the lack of attributed data and, hence, assumptions have been made.

**Worst-case scenario:** If the old cars (about 6.6% of all gasoline vehicles) consumed the same amount of fuels (per car) as new cars (620,000 t/a), the estimated emission from old cars would be quadrupled to 0.062 g TEQ/a; bringing the overall emissions from 4-stroke engines to 0.07 g TEQ/a.

**Best-case scenario**: If most of the old cars were somehow modified to meet new emission standards (as required for renewing car registrations), there would be no car in Class 2. All gasoline fuels would be consumed by Class 3 vehicles. The overall emissions in this case would be 0.01 g TEQ/a.

### 3.5.2 2-stroke engines

Emission factors

UNEP toolkit classified emission from 2-stroke engines into 2 classes: emissions caused by leaded and unleaded fuels, as shown in Table 3-81.

**Table 3-81: PCDD/F emission factors for 2-stroke engines**

| 5b | 2-stroke engines<br>Classification | Emission Factors into Air<br>(µg TEQ/t fuel burned) |
|---|---|---|
| 1 | Leaded fuel | 3.5 |
| 2 | Unleaded fuel | 2.5 |

Activity rates

According to DLT motor vehicles registration data, there were about 20.6 million motorcycles and about 22,000 motor-tricycles or tuk-tuks in Thailand in 2017. Most (92%) registered tuk-tuks in Thailand run on LPGs, whereas almost all motorcycles run on gasoline. There is no data available for the types of engines for these vehicles. Nevertheless, due to tight noise and exhaust emission standards, it can be anticipated that most motorcycles used in 2017 were likely equipped with 4-stroke engines.

On the other hand, due to its relative light weight, high revolution speed, and low cost, 2-stroke engines can find popular uses in portable applications such as grass string trimmers, leaf blowers, chain saws, motorized knapsack sprayers, etc. Unfortunately, neither information on the number of 2-stroke engines put on market nor the amount of fuel burnt by these engines in 2017 is available.

Therefore, for the purpose of this report, fuels burnt by 2-stroke engines are assumed to be mainly from regular gasoline (90% of ULG 87 & 91 and 50% of ULG 95).

## Releases of dioxins and furans

The estimated PCDD/F emissions from 2-stroke engines in 2017 are summarized in Table 3-82.

**Table 3-82: Estimated emission of PCDD/F from 2-stroke engines in 2017**

| 5b | 2-stroke engines | Activity Rate (tonne)1) | Emission to Air (g TEQ/a) |
|---|---|---|---|
| 1 | Leaded fuel | 0 | 0.000 |
| 2 | Unleaded fuel | 204,000<br>(0.076-0.5M) | 0.51<br>(0.19-1.25) |
| | **Total 2-stroke engines** | 204,000<br>(0.076-0.5M) | **0.51**<br>**(0.19-1.25)** |

1): numbers rounded to 3 significant figures for legibility.

## Uncertainty

The level of confidence for activity rate is medium due to the lack engine-related data and, hence, assumptions have been made.

**Worst-case scenario:** Assuming that there were about 1 million portable 2-stroke appliances in-use in 2017, each consumed on average 1 liter (1 full tank) per day. This increased the annual consumption of unleaded fuel to 0.5 million tonnes, leading to an emission of 1.25 g TEQ/a.

**Best-case scenario:** If assuming that 2-stroke engines could only be fueled with regular gasolines and 2-stroke engines consumed all of RON 87 and 91, and 10% of RON 95 (76,000 tonnes total), the overall emission is 0.19 g TEQ/a.

### 3.5.3 Diesel engines

Emission factors

The UNEP Toolkit classifies diesel engines into 2 classes: those fueled with regular diesel and those fueled with biodiesel. The term “biodiesel” refers to diesel with 20% or more biofuel.

**Table 3-83: PCDD/F emission factors for diesel engines**

| 5c | Diesel engines<br>Classification | Emission Factors into Air<br>(μg TEQ/t fuel burned) |
|---|---|---|
| 1 | Regular diesel | 0.1 |
| 2 | Biodiesel | 0.07 |

Activity rates

Based on MoEN’s Energy Balance statistics, Thailand consumed about 19.6 million tonnes of diesel fuels in 2017. According to the Department of Energy Business (DOEB) diesel fuel standard [90], all diesel fuels permitted for Thai market in 2017 were biodiesel, with 6.5-7% (by volume) methyl ester of fatty acids derived from biofuel.

Diesel fuels are also used in activities other than running engines. Information on the compositions of energy used in industrial sector is available, allowing an estimation of the proportion of diesel fuels used in diesel engine (discussed in source group 3a). End-uses information is not available for other sectors. Therefore, to estimate the total amount of diesel fuel used in diesel engines, the following utilization factors is assumed.

**Table 3-84: Estimated amount of diesel fuel consumed by diesel engines in Thailand in 2017**

| Year 2017 | Road & Rail | Waterway | Industry | Agriculture | C&M | Total |
|---|---|---|---|---|---|---|
| Total diesel consumed | 13,304 | 187 | 3,423 | 2,572 | 115 | 19,601 |
| Fraction allocated to engine | 1.0 | 1.0 | 0.2 | 0.9 | 0.8 | 0.85 |
| Total diesel used in engines | 13,304 | 187 | 685 | 2,315 | 93 | 16,584 |

C&M=Construction and Mining, Unit: kt

Releases of dioxins and furans

The estimated PCDD/F emissions from diesel engines in Thailand in 2017 are shown in Table 3-85.

**Table 3-85: Estimated emission of PCDD/F from diesel engines in 2017**

| 5c | Diesel engines<br>Classification | Activity Rate<br>(tonne) | Emission to Air<br>(g TEQ/a) |
|---|---|---|---|
| 1 | Regular Diesel | 16,584,000<br>(13.5-19.6M) | 1.66<br>(1.35-1.96) |
| 2 | Biodiesel | 0 | 0.0 |
| | **Total diesel engines** | **16,584,000**<br>(13.5-19.6M) | **1.66**<br>(1.35-1.96) |

Uncertainty

The level of confidence for activity rate is medium to high due to the availability of national data on fuel consumptions but lack of end-uses data to allocate fuels to diesel engines and, hence, assumptions have been made.

**Worst-case scenario:** If all diesel fuels put on market in 2017 were used in engines, the estimated emission would increase by 0.3 g TEQ/a.

**Best-case scenario:** If all diesel engines were already accounted for in transport sector; assuming other sectors sourced fuels from gas stations, the estimated emission would decrease by 0.31 g TEQ/a.

### 3.5.4 Heavy oil fired engines

Emission factors

There is only class of heavy fuel oil (HFO) fired engines in the UNEP Toolkit as shown below.

**Table 3-86: PCDD/F emission factors for heavy oil fired engines**

| 5d | Heavy oil fired engines<br>Classification | Emission Factors into Air<br>(µg TEQ/t fuel burned) |
|---|---|---|
| 1 | All types | 2 |

Activity rate

Based on MoEN Energy Balance statistics; apart from transportation, fuel oils were used in power plants, constructions and mining. Again, except for energy consumed in industrial sector, end-uses information for fuel oils is not available and estimations have to be made. For the purpose of this report, the following utilization factors are assumed.

| 2017 | Waterway | Industry | C&M | Total |
|---|---|---|---|---|
| Total Fuel oils consumed | 1,146 | 733 | 25 | 1,904 |
| Fraction used in engine | 1.0 | 0 | 0.88 | 0.61 |
| Total Fuel Oil Engines | 1,146 | 0 | 22 | 1,169 |

C&M = Construction and Mining, Unit: kt

Releases of dioxins and furans

The estimated PCDD/F emissions from heavy oil fired engines in Thailand in 2017 are summarized in Table 3-87.

**Table 3-87: Estimated emission of PCDD/F from heavy oil fired engines in 2017**

| 5d | Heavy oil fired engines<br>Classification | Activity Rate<br>(tonne) | Emission to Air<br>(g TEQ/a) |
|---|---|---|---|
| 1 | All Type | 1,169,000<br>(1.15-1.9M) | 2.34<br>(2.30-3.81) |

Uncertainty

The level of confidence for activity rate is medium to high due to the availability of national data on fuel consumptions but lack of end-uses data to allocate fuels to diesel engines and, hence, assumptions have been made.

**Worst-case scenario:** If all fuel oils reported for non-transport sectors were used to feed engines, the estimated emission would increase by 1.5 g TEQ/a; bringing total emission to 3.81 g TEQ/a

**Best-case scenario:** If fuel oil consumed in non-transport sectors were for purposes other than to feed engines, the estimated emission would decrease by 0.04 g TEQ/a; bringing total emission to 2.30 g TEQ/a.

### 3.5.5 Summary

The total emission of dioxins and furans from combustion engines in Thailand in 2017 is summarized in Table 3-88. About half of the emissions were from heavy oil fired engines, particularly engines for waterway transport vessels.

**Table 3-88: Summary of the estimated PCDD/F emissions from Source Group 5 - transport engines in 2017**

| | **Transport**<br>Source category | **Activity Rate**<br>(tonne) | **Emission to Air**<br>(g TEQ/a) |
|---|---|---|---|
| a | 4-stroke engines | 9,189,000 | 0.026 |
| b | 2-stroke engines | 204,000 | 0.51 |
| c | Diesel engines | 16,584,000 | 1.66 |
| d | Heavy oil fired engines | 1,169,000 | 2.34 |
| | **Total Source Category 5** | | **4.53** |

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## 3.6 Source Group 6: Open Burning Processes

Open burning processes cover combustion under ill-defined conditions. This source group can be classified into 2 categories depending on the nature of burning, namely:

- Biomass burning, which usually involves burning of biomass over large area of land, and
- Waste burning and accidental fires, in which various materials are burned in sub-optimal conditions.

Data for assessing activity rates within this source group are taken from the following sources:

- Office of Agricultural Economics (OAE) "Agricultural Statistics of Thailand 2018" [91]
- Office of the Cane and Sugar Board (OCSB) "Thailand Cane Production Annual Report 2016/2017" [92]
- Food and Agriculture Organization of the United Nations (FAO) "FAOSTAT-Burning - Crop Residues" [93]
- Royal Forest Department "Forest Statistics Data 2017" [94]
- Department of National Parks, Wildlife and Plant Conservation (DNP), Ministry of Natural Resources and Environment (MNRE), "Forest fire statistics in 9 Northern Provinces in B.E. 2541-2561" [95]
- DNP "Forest Burnt in Protected Areas in 2013 – 2017" [96]
- Geo-Informatics and Space Technology Development Agency (Public Organization) – GISTDA "Satellite Monitoring of Forest Fires and Smoke: Summary Report 2017 (in Thai)" [97]
- Pollution Control Department (PCD), MNRE, "Thailand Municipal Waste Management Sites 2017" [5]

### 3.6.1 Biomass burning

Relevant activities and emission factors

Thailand is an agricultural country. About 47% of Thailand's 323.5 million rai (49.7 Mha) land area are farm holdings [98].

With an upward trend to speed up field clearing to prepare fields for the next cultivation rounds, biomass burning has become a popular practice for farmers. Open burning has caused serious air pollution problems especially during the dry season. However, measurement data related to the emission of PCDD/F from biomass burning in Thailand are still very rare and country-specific emission factors from this source are not yet available. Therefore, the estimation of emissions from this source category is based on the default factors (per tonne dry mass of material burned) provided in the UNEP Toolkit as shown in Table 3-89.

Two approaches were taken to estimate the amount of biomass burned from agricultural field burning in Thailand in 2017: one based on country-specific survey data (BM model [99]), the other based on FAO “Burning - Crop Residues” data [93], which provides information on the type and the amount of biomass burned.

The BM model estimates the amount of biomass burned ($M_B$) from 3 model parameters as follows: biomass fuel load (BL) – the amount of residues available, biomass subjected to open burning (FB) – the fraction of biomass that could be burned, and combustion factor (CF) – the fraction of biomass actually burned by fire.

$$M_B = BL \times FB \times CF \qquad (1)$$

$$BL = RD \times A \qquad (2)$$

$$BL = N \times D \qquad (3)$$

Biomass fuel load (BL) can be estimated from residue density (RD) in t/ha and harvested area (A) as shown in Equation (2) or from residue to crop ratio (N) and dry matter to crop residue ratio (D) as shown in Equation (3).

The amount of biomass burned in FAOSTAT was derived from harvested area with default model parameters (FB and CF) given in the IPCC 2006 guideline[21].

**Table 3-89: PCDD/F emission factors for biomass burning**

| | **Open Burning Processes** | **Emission Factors (µg TEQ/t material burned)** | |
|---|---|---|---|
| | Classification | **Air** | **Land** |
| 1 | Agricultural residue burning in the field of cereal and other crops stubble, impacted, poor burning conditions | 30 | 10 |
| 2 | Agricultural residue burning in the field of cereal and other crops stubble, not impacted | 0.5 | 0.05 |
| 3 | Sugarcane burning | 4 | 0.05 |
| 4 | Forest fires | 1 | 0.15 |
| 5 | Grassland and savannah fires | 0.5 | 0.15 |

## Activity rates

**Paddy Rice Fields**

During the 2015/2016 cultivate season, Cheewaphongphan *et al.* [100] conducted a nation-wide survey to investigate potential of rice straws as a renewable energy source in Thailand. The authors reported residue density (RD) between 4.18 and 8.02 t/ha, with an average value of 5.81 t/ha (dried weight); which is about 30% higher than the Toolkit guideline value.

Studies found fraction of residues subjected to open burning (FB) are declining; from 0.49 in 2009 [101] to 0.23 in 2017 [100], as a result of stricter regulations as well as a new economic opportunity from renewable energy development. Particularly, based on 3,900

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[21] http://www.fao.org/faostat/en/#data/GI/metadata

questionnaire survey results, Cheewaphongphan *et al.,* [99] reported FB of 29.7% for irrigated fields and 21.4% for rain-fed fields. The higher FB for irrigated fields was attributed to the need to clear-up the fields for the second cultivation round.

Cheewaphongphan *et al* [102] conducted questionnaire survey of 1,000 Thai framers and field experimentation in 2013 and reported the fraction of biomass combusted by fire or combustion factor (CF) of 0.18 for stubble and 0.69 for straw, with an average value of 0.34 for the whole country [99]. The reason for low CF was attributed to high moisture content in the stubble.

In 2017, total paddy rice harvested area was 65.4 million rai (11.15 Mha); 22.0 million irrigated and 43.4 million rain-fed fields. The overall, including major and second, rice paddy outputs from irrigated and rain-fed fields were 13.33 and 18.23 million tonnes (15% moisture), respectively [91].

Based on the above described country-specific model parameters, Thai paddy rice farmers generated about 64.8 Mt residues, of which 14.9 Mt were prone to open burning, and about 4.8Mt were burned in 2017. All these residues are assigned to Class 1 (impacted) due to the low CF.

**Maize:**

Based on the Office of Agricultural Economics (OAE) statistic data [91], in 2017 Thailand’s maize production was around 4.8 million tonnes. Maize plantations occupied 6.5 million rai (1.04 Mha), in which about 69% were in uplands and highlands in the northern provinces. Most (96%) of maize farms are rain-fed. Some maize are illegally planted in sloping lands or in reserved forestland [103].

Open burning is a serious concern in the northern part of Thailand. In 2018, Arunrat [104] studied maize farmers in northern Thailand and found that 41% of farmers burned their residues in the fields. Kanokkanjana [105] measured the amount of biomass load in an experimental corn field in a north-eastern province in 2011 and found a load of 526±91 g/m$^2$. This value is close to the value provided by IPCC [106]. The reported combustion factor was 85%±13%, which is also within the range of IPCC default value of 0.8.

The average production yields for maize planted in the northern region and north-eastern region are about the same [107]–[109]. The average amount of biomass subjected to open burning in the northern region can be assumed to be of the same order as that reported for the north-eastern region.

From these figures, the amount of maize residues burned in 2017 is estimated at about 2.28 million tonnes. Although CF value for maize burning indicates efficient burning, the uses of chlorinated herbicides/pesticides cannot be ruled out and the open burning of maize, therefore, is assigned to Class 1.

**Sugar cane:**

Based on Office of the Cane and Sugar Board (OCSB) annual report [92], Thailand harvested about 10.99 million rai (1.76 Mha) of sugar cane in 2016/2017, feeding about 92.95 million tonnes of cane to sugar mills. Sugar mills in Thailand operate over a limited duration called “Sugar-crushing season”, typically from November to April. During the harvest season a large portion of farmers choose to burn off most of the residues to save costs, ease the cutting and speed up the manual harvesting. To a lesser extent, farmers using machine- or green-harvesting method may resort to fire to burn off residues to prevent accidental fires from neighboring fields and to prepare soil for the next plantations [110].

In 2012, Sornpoon *et al.* [110] conducted a field survey covering 13 different sugarcane farms to evaluate residue density (RD), biomass fuel load (BL) and combustion factor (CF) for sugarcane open burning. The reported value for residue density (RD) was 0.79 kg/m$^2$ (7.9 t/ha, dry mass), about 20% higher than the IPCC guideline default value [111]. The authors attributed this difference to the variety of crop cultivars, climatic conditions, number of ratoon crops, and farming system.

The reported fractions of sugarcane residue to crop ratio (N) range from 0.24 to 0.47 with an average value for the whole country of 0.37. The burned materials were typically quite wet, with average moisture contents for stalks, fresh leaves, dry leaves, and ground leaves of 72.1%, 75.7%, 12.3% and 9.8% respectively. The authors reported different CF values for pre- and post-harvest burnings, with values for post-harvest burning (0.83) being about 30% higher than the pre-harvest burning (0.64). Unfortunately, unlike pre-harvest burning which can be detected at the mills, the extents of the post-harvest burning are largely unknown. It should be noted, however, that the IPCC guideline default value for the combustion value for sugarcane also does not cover post-harvest burning. The reported combustion factor value of 0.64 for pre-harvest burning is about 20% lower than IPCC guideline default value.

According to OCSB, for the 2016/2017 season, Thailand harvested about 10.99 million rai (1.76 Mha) and yielded about 92.95 Mt of sugarcane. Based on the residue density of 7.9 t/ha, the amount of sugarcane residues available would be 13.9Mt, of which 64.2% [92] (8.9Mt) were burned. Using the combustion factor of 0.64, the estimated amount of sugarcane burned in 2017 was estimated at 5.7 million tonnes. Sugarcane burning is also assigned to Class 1 based on the reported high moisture content in the fuel.

**Forest fires:**

Based on 2017 Forest Statistic Data [94], forest covers about 31.6% of the 323.5 million rai (49.7 Mha) of Thailand's land area. Forest densities ranged from 15% in the north-eastern region to 52.5% in the northern region. In 2017, there were 4,650 forest fire incidents that burned about 75,419 rai (11,603 ha) of forest area. Forest fires usually occur during the dry season, with 9 northern provinces being the most affected area, accounting for about 70% of total forest fires.

Most of the forest fires in Thailand are classified as surface fires [112], while information provided for the amount of biomass fuel consumed in open fires in the UNEP Toolkit (Table II.6.4, page 96) for tropical forests are mostly derived from slash and burn fires.

The Forest Fire Control Division (FFCD) studied the amount of biomass available for 2017 fires [113] for the three most abundant forest classes in Thailand: deciduous dipterocarp forest (DDF), mixed deciduous forest (MDF), and dry evergreen forest (DEF). The reported amounts of biomass fuel were 5.1 t/ha, 4.6 t/ha and 7.1 t/ha from DDF, MDF, and DEF respectively. The main contributors, ranging from highest to lowest density were leaves, ground level residues, twigs, and grasses, respectively.

Junpen *et al.* [114] studied forest fires in Chiang Mai during 2005 to 2009 and reported amount of fuel in MDF and DDF of 3.65 t/ha (2.14 t/ha from fine fuel and 1.50 t/ha from dry matters) and 3.71 t/ha (2.18 t/ha from fine fuel and 1.53 t/ha from dry matters), respectively. The authors also reported burning efficiency values of 0.78 (0.98 for fine fuel and 0.49 for dry matters) for both MDF and DDF.

Based on official forest fires report that indicated 75,419 rai (12,067 ha) was burned in 2017, the average available biomass of 5 t/ha, and the burning efficiency of 0.78, the amount of biomass burned is estimated to be around 47,000 tonnes.

Forest fires in Thailand are mostly surface fires. Many of these fires can fit into Class 5 (Grassland and savannah fires). However, the official fires report does not allow meaningful differentiation between Class 4 and Class 5. All forest fires in this study, therefore, are assigned to Class 4.

### FAO "Burning - Crop Residues" data

Data for the amount of biomass burned are freely available on UN FAOSTAT website[22], making it convenient for parties to keep track and update their emission estimates. Information available on a common

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[22] http://www.fao.org/faostat/en/#home, last accessed August 2019

portal also makes it possible to provide consistent estimates across different conventions (such as GHG emission). Based on FAOSTAT metadata, FAO estimates for crop residues burning were derived from the harvested area data supplied by country statistics offices, and the derived activity data are based on IPCC guidelines. Particularly, the amount of biomass burned is estimated from the reported harvest area using mean default crop values of mass of fuel available for combustion (MB) and combustion factor (CF) provided in IPCC 2006 [111]. FAO forest biomass burning is based on burned areas from MODIS MCD64A1 Collection 6 [115] and fuel biomass consumption values from IPCC guidance 2006 [111].

For Thailand, data for the baseline year 2017 were available for crops but not for forest biomass burning, which was available only up to 2016. Nevertheless, FFCD reported the burned area in 2017 was about 86% lower than 2016. Similarly, GISTDA, which also used satellite data to monitor forest fires, reported burned area in 2017 of about 83% lower than 2016 [97]. Therefore, to estimate the amount of forest biomass burning for 2017, the values provided for 2016 was used with an average reduction factor of 0.85.

**Table 3-90: Comparing activity data for biomass burnings based on FAOSTAT and BM Model**

| Source | Biomass | FAOSTAT | | BM Model | |
|---|---|---|---|---|---|
| | | ton | t/ha | ton | t/ha |
| Agricultural residues | Paddy rice | 5,838,156 | 0.55 | 4,751,764 | 0.45 |
| | Maize | 1,106,281 | 1.0 | 1,921,950 | 1.83 |
| | Wheat | 489.52 | 0.4 | No data | |
| Sugarcane | Sugarcane | 889,374.7 | 0.65 | 5,704,230 | 3.25 |
| Forest fires | Humid | 15,726,603 | 53.6 | 47,061 | 3.9 |
| | other | 6,944,304 | 53.7 | | |

Table 3-90 compares the estimated amount of biomass burned in 2017 obtained from FAOSTAT and from BM modelled with country-specific data and model parameters. For agricultural residues, results from the two approaches are comparable. On the other hand, results for sugarcane and forest fires are quite far apart.

The reasons for high value in FAOSTAT forest fires estimates could be because of the high values for default factors and the discrepancy between the areas assigned as ‘Forest’. The total amount of biomass burned per ha for FAOSTAT was about 53 t/ha whereas that from country-specific model parameter was 3.9 t/ha. The total area burned reported in FAOSTAT was 497,407 ha which is quite different from the 12,067 ha reported by FFCD, which considered only forests within FFCD jurisdiction.

On the other hand, an apparent factor for sugarcane burning in FAOSTAT of 0.65 t/ha was far below the IPCC default value of 5.2 t/ha (6.5

t/ha*0.8). The reason for this discrepancy is unknown.

### Releases of dioxins and furans

The estimated releases of PCDD/F from biomass open burning process calculated based on FAOSTAT data and country-specific BM model parameters are shown in Table 3-91 and Table 3-92, respectively. As expected, emission into air is significant but the relatively high emission into land also deserves attentions.

Coincidentally, the overall emissions estimated from the two approaches differ only 7%.

Emission estimated for forest fires in BM model may be underestimated. However, when using forest fire area from FAOSTAT and applying country-specific biomass burned rate of 3.9 t/ha, the emission from forest fires increases from 0.05 to 2.2 g TEQ/a, contributing to a variation in overall emission of about 0.7% (Table 3-93). Therefore, this scenario is used to represent emissions from open burning of biomass in Thailand in 2017.

**Table 3-91: Estimated PCDD/F emissions from biomass open burning process in 2017 (based on data from FAOSTAT)**

| **6a** | **Biomass Open Burning** | **Source** | **Activity Rate** | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|---|
| | Classification | | (tonne)[1)] | Air | Land | Subtotal |
| 1 | Agricultural residue burning, impacted, poor burning conditions | Rice, paddy | 5,840,000 | 175.14 | 58.38 | **233.52** |
| | | Maize | 1,110,000 | 33.19 | 11.06 | **44.25** |
| | | Wheat | 490 | 0.01 | 0.00 | **0.01** |
| 2 | Agricultural residue burning in the field of cereal and other crops stubble, not impacted | | 0 | 0 | 0 | **0** |
| 3 | Sugarcane burning | Sugar cane | 889,000 | 3.56 | 0.04 | **3.6** |
| 4 | Forest fires | Humid tropical forest | 18,500,000 | 18.50 | 2.78 | **21.28** |
| | | Other forest | 8,170,000 | 8.17 | 1.23 | **9.4** |
| 5 | Grassland and savannah fires | | 0 | 0 | 0 | **0** |
| | | | **Total Biomass Open Burning Processes** | **238.58** | **73.49** | **312.06** |

1): numbers rounded to 3 significant figures for legibility.

**Table 3-92: Estimated PCDD/F emissions from Biomass open burning process in 2017 (based on Country specific model parameters)**

| 6a | Biomass Open Burning Classification | Source | Activity Rate (tonne)[1)] | Emission (g TEQ/a) Air | Land | Subtotal |
|---|---|---|---|---|---|---|
| 1 | Agricultural residue burning, impacted, poor burning conditions | Rice, paddy | 4,750,000 | 142.55 | 47.52 | **190.07** |
| | | Maize | 1,920,000 | 57.66 | 19.22 | **76.88** |
| 2 | Agricultural residue burning in the field of cereal and other crops stubble, not impacted | | 0 | 0 | 0 | **0** |
| 3 | Sugarcane burning | Sugar cane | 5,700,000 | 22.82 | 0.29 | **23.10** |
| 4 | Forest fires | Humid tropical forest | 47,100 | 0.05 | 0.01 | **0.05** |
| 5 | Grassland and savannah fires | | 0 | 0 | 0 | **0** |
| | | | **Total Biomass Open Burning Processes** | **223.08** | **67.03** | **290.10** |

1): numbers rounded to 3 significant figures for legibility.

**Table 3-93: Estimated PCDD/F emissions from biomass open burning process in 2017 (based on Country specific model parameters and FAOSTAT data for forest fires areas)**

| 6a | Biomass Open Burning Classification | Source | Activity Rate (tonne)[1)] | Emission (g TEQ/a) Air | Land | Subtotal |
|---|---|---|---|---|---|---|
| 1 | Agricultural residue burning, impacted, poor burning conditions | Rice, paddy | 4,750,000 | 142.55 | 47.52 | **190.07** |
| | | Maize | 1,920,000 | 57.66 | 19.22 | **76.88** |
| 2 | Agricultural residue burning in the field of cereal and other crops stubble, not impacted | | 0 | 0 | 0 | **0** |
| 3 | Sugarcane burning | Sugar cane | 5,700,000 | 22.82 | 0.29 | **23.10** |
| 4 | Forest fires | Humid tropical forest | 47,100 | 0.05 | 0.01 | **0.05** |
| | | Other forest | 1,890,000 | 1.89 | 0.28 | **2.17** |
| 5 | Grassland and savannah fires | | 0 | 0 | 0 | **0** |
| | | | **Total Biomass Open Burning Processes** | **224.97** | **67.31** | **292.28** |

1): numbers rounded to 3 significant figures for legibility.

## Uncertainty

Level of confidence for activity rate is higher for values derived from country specific parameters (BM Model) except for forest fires where fires beyond FFCD jurisdiction may not be included and, hence, lead to an underestimation for this particular source.

Level of confidences for emission factor, according to UNEP, are generally high except for agricultural residue burning (impacted) and sugar cane burning where level of confidence is stated to be medium.

Since the emissions estimated for both biomass burning and forest fires are quite high for Thailand and there is also possibility that the PCDD/Fs created by burning are transferred to land, the emissions from these two sources deserve more in-depth investigation.

### 3.6.2 Open burning of waste and accidental fires

Emission factors

Open burning of waste and accidental fires are classified into 6 classes

- Fires at waste dumps (compacted, wet, high organic carbon content)
- Accidental fires in houses, factories
- Open burning of domestic waste
- Accidental fires in vehicles (per vehicle)
- Open burning of wood (construction/demolition)

There is no country specific information about emissions from these sources. The estimations of PCDD/Fs, therefore, relies on the UNEP toolkit default emission factors as shown in Table 3-94.

**Table 3-94: PCDD/F emission factors for open burning of waste and accidental fires**

| **6b** | **Waste burning and accidental fires** | **Emission Factors (µg TEQ/t material burned)** | |
|---|---|---|---|
| | Classification | **Air** | **Land** |
| 1 | Fires at waste dumps (compacted, wet, high organic carbon content) | 300 | 10 |
| 2 | Accidental fires in houses, factories | 400 | 400 |
| 3 | Open burning of domestic waste | 40 | 1 |
| 4 | Accidental fires in vehicles (per vehicle) | 100 | 18 |
| 5 | Open burning of wood (construction/demolition) | 60 | 10 |

Activity rates

**Fires at waste dumps:**
Based on Department of Disaster Prevention and Mitigation (DDPM) fire statistics, there were 1,516 fire incidents reported in 2017 with estimated damage values of about 2,500 million baht. A brief summary of fire incidents reported in 2017 is presented in Table 3-95.

There were 9 fire incidents at waste dumps reported in 2017. A cross-reference search based on the recorded street addresses to the PCD waste disposal data for 2017 [5] indicates that these fires were at seven open dump sites, one waste-to-energy (WTE) site, and one engineered landfill site. The total amount of waste burned at these sites in 2017 is estimated at 120,000 tonnes based on the following assumptions:

- Amount of waste burned at the waste-to-energy site accounted for about 7 days of 2017 waste that was delivered to the site (approximately 3,500 tonnes)
- Amount of waste burned at the engineered landfill and at the 7 open dump sites accounted for about 10% of total waste disposed at these sites in 2017 (approximately 116,500 tonnes)

**Accidental fires in houses, factories:**
Accidental fires in houses and factories accounted for most of the fire incidents reported by DDPM, both from the number of incidents and the damage cost perspectives. However, the existing data do not allow for meaningful estimation of the extent of the fire from PCDD/F emissions

perspective. Data typically found on the records were physical damages, injuries, and estimated damage costs. These data can be misleading if applied beyond their intended purposes. For example, damage costs or the mass of materials burned recorded for antique teak house fires may outweigh incidents associated with chemical waste. The evaluation results would obviously be the opposite from toxic gas emissions perspective.

Without meaningful information about the types (or classes) and the extent of the burned materials, estimations of PCDD/F emissions from fire incidents would be misleading. Therefore, this report does not attempt to estimate PCDD/F emissions from such fires.

**Table 3-95: A summary of fire incidents in 2017**

| Group | No of Incident | No of Fire Truck used | Fire truck per incident | Damage Costs | Cost per incident | No of casualty |
|---|---|---|---|---|---|---|
| Factory (incl. Warehouse) | 106 | 718 | 6.77 | 1,053,200,000 | 9,935,849 | 14 |
| Residential House | 1,058 | 2,907 | 2.75 | 997,323,395 | 942,650 | 89 |
| Commercial Building | 141 | 515 | 3.65 | 238,615,000 | 1,692,305 | 23 |
| Government Building | 96 | 341 | 3.55 | 209,807,200 | 2,185,492 | 4 |
| Agricultural (incl. Storage, Mills) | 48 | 132 | 2.75 | 62,742,870 | 1,307,143 | 1 |
| Landfill Fires | 9 | 117 | 13.00 | 0 | 0 | 0 |

### Accidental vehicle fires:

In 2017, DDPM reported 171 incidents that involved damage to motor vehicles. Of these, 130 were accidental vehicle fires that damaged 234 vehicles, while in the other 41 incidents 118 vehicles were involved as collateral damage.

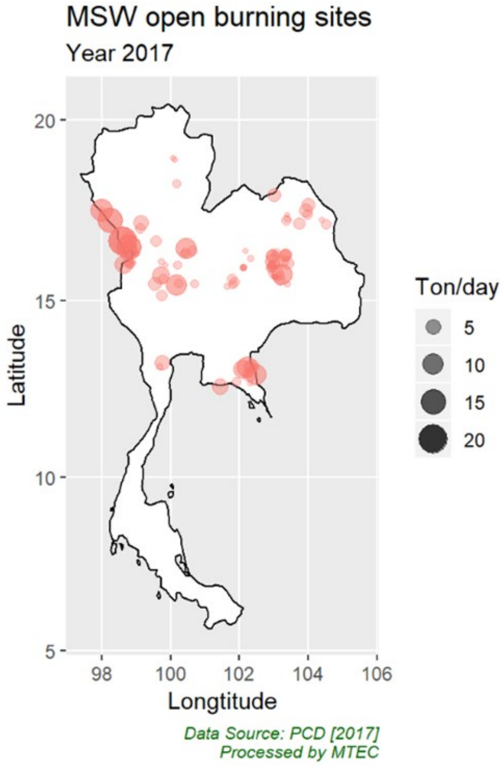
Motor vehicles in DDPM database include motorcycles, tricycles, passenger car, trucks, trailers, tractors, speedboats, yachts, fishing boats, etc. Detail on number of vehicles burned for each category is summarized in Table 3-96. Note that the burnings may not be extensive if vehicles were involved as collaterals in the fires.

**Table 3-96: Accidental vehicle fires in 2017**

| Category | Vehicles | Remark |
|---|---|---|
| Motorcycles | 158 | 4 accidental fires, 154 collaterals |
| Tricycles | 2 | Accidental vehicle fires |
| Passenger cars and light duty trucks | 133 | 89 vehicle fire accidents, 44 collaterals |
| Buses and minivans | 14 | All vehicle fires |
| Trucks and Trailers | 31 | Oil trucks, cement trucks, cargo trucks, back-hoes, trailers, harvesting trucks, etc. (10 collaterals) |
| Water vessels | 14 | Ferries, Speed boats, fishing boats, yachts, tour boats – all accidental fires |

The Toolkit emission factors were derived from limited number of cases, mainly from passenger cars, a subway car and a railway carriage. Considering the differences in the types of vehicles and the nature of the burning as reported in Table 3-96, the Toolkit's emission factors may not be applicable for certain incidents. However, these emission factors were assigned per fire incident, with an intention to provide rough estimates for emissions from this source.

Therefore, all vehicles are counted without differentiation while keeping in mind of limitations of the estimations.



Data Source: PCD [2017]
Processed by MTEC

**Figure 3-15: Distribution of MSW open burning sites in Thailand**

**Open burning of domestic waste:**

Based on PCD Waste Disposal data for 2017 [5], 93 municipalities/LAOs in 15 provinces disposed their wastes by open burning. Cities/LAOs that resorted to open burning were mostly located in the rural or border areas as shown in Figure 3-15. The amount waste burned ranged from 0.5 to 20.3 tonne/day with a median value of 2 tonne/day. The total amount of MSW burned in 2017 was 112,478 tonnes.

Unlike open burning of biomass, open burning of MSW is decreasing as a result of the government Municipal Solid Waste Management Master Plan (2016-2021) [3]. In 2018, the number of open burning sites decreased to 72 with the total amount of MSW burned reduced by 25%

**Open burning of wood (construction/demolition):**

Due to strict government controls (virtually a ban) on new loggings of forests, used woods, particularly native species, are considered precious materials that can demand higher prices than new woods. Open burnings of woods from construction/demolition are considered rare and, therefore, considered irrelevant for this study.

## Releases of dioxins and furans

The estimated PCDD/F emissions from waste burning and accidental fires are presented in Table 3-97.

**Table 3-97: Estimated PCDD/F emissions from waste burning and accidental fires in 2017**

| | **Waste burning and accidental fires** | **Activity** | | | **Emission** |
|---|---|---|---|---|---|
| | | **Rate** | | | **(g TEQ/a)** |
| | Classification | (tonne)[1)] | Air | Land | Subtotal |
| 1 | Fires at waste dumps (compacted, wet, high organic carbon content) | 120,000 | 36.000 | 1.200 | **37.20** |
| 2 | Accidental fires in houses, factories | No data | No data | No data | **No data** |
| 3 | Open burning of domestic waste | 112,000 | 4.497 | 0.112 | **4.61** |
| 4 | Accidental fires in vehicles (per vehicle) | 352* | 0.035 | 0.006 | **0.04** |
| 5 | Open burning of wood (construction/demolition) | 0 | 0.000 | 0.000 | **0.00** |
| | **Total Waste burning and accidental fires** | | **40.532** | **1.319** | **41.85** |

1): numbers rounded to 3 significant figures for legibility.

*: per vehicle activity rate

Uncertainty

This study does not include emissions from accidental house and factory fires due to lack of material related data.

Emissions estimated for dump site fires are given a low level of confidence due to the rough approximation method employed. Emissions associated with vehicle fires are estimated at low confidence. Fires associated with cargo trucks (oil or chemical trucks) have not been accounted for, since emission from this source is specific in nature. Information related to the types and amount of chemicals/materials involved in the fire accidents will help future evaluation of the level of risk and associated impact to surrounding area and the environment.

### 3.6.3 Summary

The overall PCDD/F emissions from open burning processes in 2017 are summarized in Table 3-98 and visually illustrated in Figure 3-16. Biomass open burning contributes most of the releases from this source group. A relatively large portion (21%) of the PCDD/F generated from burning is released into land.

Agriculture is central to the Thai society. Biomass open burning is on the rise due to the need to speed up cultivation and harvesting, coupled with the increase in labor costs. The deposition and possible accumulation of PCDD/Fs and other persistent organic pollutants (such as PAHs) into land and surface water pose not only short-term but also long-term risks to the society that relies on food and feed produced from these lands. Emissions from biomass open burning are, therefore, identified as a major source that needs to be addressed in the upcoming NIP.

It should be noted that emission factors for in-field burning of biomass were derived from steel barrel burning experiments [37]. Field data on the effect of chlorinated pesticides on the emissions are lacking and, therefore, deserve further study to understand the associated risk.

## Table 3-98: Summary of estimated PCDD/F emissions from Open burning processes in 2017

| **6** | | **Open Burning** | **Source** | **Emission (g TEQ/a)** | | |
|---|---|---|---|---|---|---|
| | | Classification | | Air | Land | Subtotal |
| **a** | | **Biomass open burning** | | **224.97** | **67.31** | **292.28** |
| | 1 | Agricultural residue burning, | Rice, paddy | 142.55 | 47.52 | **190.07** |
| | | impacted, poor burning conditions | Maize | 57.66 | 19.22 | **76.88** |
| | 3 | Sugarcane burning | Sugar cane | 22.82 | 0.29 | **23.10** |
| | 4 | Forest fires | Humid tropical forest | 0.05 | 0.01 | **0.05** |
| | | | Other forest | 1.89 | 0.28 | **2.18** |
| **b** | | **Waste burning and accidental fires** | | **40.53** | **1.32** | **41.85** |
| | 1 | Fires at waste dumps (compacted, wet, high Corg content) | | 36.00 | 1.200 | 37.20 |
| | 3 | Open burning of domestic waste | | 4.50 | 0.11 | 4.61 |
| | 4 | Accidental fires in vehicles (per vehicle) | | 0.04 | 0.01 | 0.05 |
| | | | **Total Open Burning** | **265.50** | **68.63** | **334.13** |

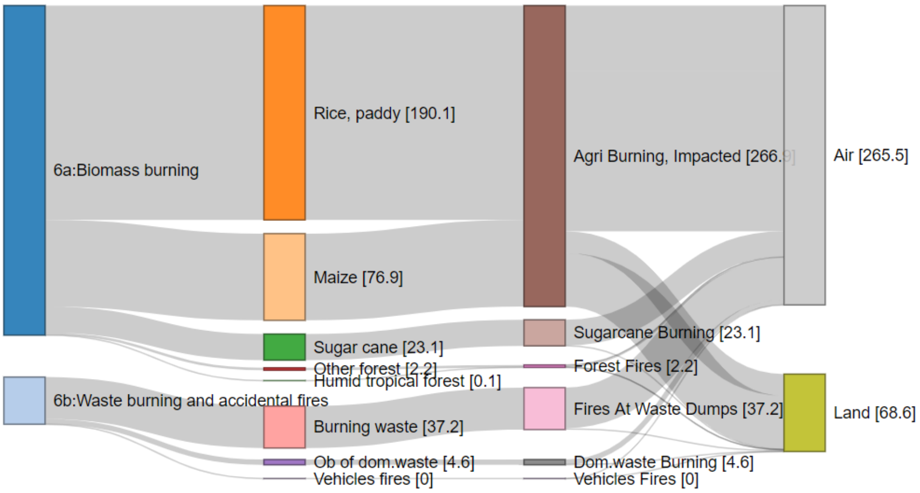


Figure 3-16: Overview of PCDD/F emissions from Source Group 6 – Open Burning Processes [unit: g TEQ/a]

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## 3.7 Source Group 7: Production and Use of Chemicals and Consumer Goods

PCDD/F emissions from production and use of chemicals and consumer goods in this study cover potential formation of PCDD/F during the production and/or uses of following 8 source categories:

- Pulp and paper production (7a)
- Chlorinated inorganic chemicals (7b)
- Chlorinated aliphatic chemicals (7c)
- Chlorinated aromatic chemicals (7d)
- Other chlorinated and non-chlorinated chemicals (7e)
- Petroleum production (7f)
- Textile production (7g)
- Leather refining (7h)

Data for assessing activity rates within this source group are taken from following sources:

- OIE background data for the derivation of OIE industrial indices (as of 29 May 2019) [18]
- PCD "Thailand Municipal Waste Management Sites 2017" [5] PCD municipal waste water treatment dataset [116]
- DIW "Factory Registration Data" (last access February 2019) [19]
- DIW "Industrial Waste Transfer Manifest" [20]
- EIA reports from Office of Natural Resources and Environmental Policy and Planning (ONEP) [online data on ONEP web portal[23], last retrieved October 2019]
- Interview with key stakeholders
- Business association yearbooks, directories, and websites
- MoEN Thailand energy balance data [38]

### 3.7.1 Pulp and paper production

Relevant activities

Pulp and paper is an important industry that supports the development in other industries [117]. The industry directly contributes to more than 11,600 jobs in 26 provinces [19]. Pulping industry in Thailand is based mostly on eucalyptus trees. The industry therefore also indirectly contributes to jobs creation in eucalyptus plantations and farming.

Pulp and paper mills burn large amounts of fuels (usually biomass) in power boilers to generate heat and power. In 2009, the pulp and paper industry consumed about 8% of the total energy consumed by Thailand's

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[23] http://eia.onep.go.th/index.php

manufacturing sector [118]. As described in Source Group 3, depending on fuel types and operating conditions, power boilers can emit a significant amount of PCDD/F to air. Ashes from burning contaminated fuels may also contain significant amounts of PCDD/F [37].

Most pulps in Thailand are produced via chemical pulping, also known as the “Kraft process”. Pulping process that employs elemental chlorine ($Cl_2$) to dissolve lignin can generate PCDD/F [37]. If not properly managed, these unintentionally produced dioxins can be released to the environment via water, sludge, and product.

Pulping mills with daily capacities above 50 tonnes are subjected to EIA reporting under MNRE’s EIA regulation [24]. Air emission from pulp and paper mills are controlled by MNRE’s air emission standards [26] while air emissions from boilers using energy sources other than LPGs, natural gases, or electricity are subjected to additional visible (smoke) emission controls by MNRE notification B.E. 2549 (2005) [119] and by DIW air emission limits [120].

Releases of waste water from factories are generally controlled by the newly revised M-Industry notification on industrial waste water B.E. 2560 (2017) [121]. This notification prescribes limits on 16 key wastewater quality parameters[24]. For wastewater released from pulp and paper mills, the limits set for 5 parameters -- namely color, TDS, BOD, COD, and Total Kjeldahl Nitrogen (TKN) -- are different from those released from typical factories and are described by DIW notification concerning waste water discharges from pulp and paper factories B.E. 2561 (2018) [122].

The UNEP Toolkit 2013 considers the releases of PCDD/F from two main sources: on-site boilers and pulp and paper production processes.

**Boilers:**

Emission factors

Releases from on-site boilers depend on the type of fuels being used. Fuels contaminated with salt and/or elemental chlorine (e.g., from sludge) can generate high amounts of dioxins. The Toolkit prescribes releases from three important fuels: salt-laden wood, sludge and/or biomass/bark, and black liquor. It takes into account both the release to air and to residues, as summarized in Table 3-99.

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[24] 1.pH, 2.Temperature, 3.Color, 4.Total Dissolved Solids (TDS), 5.Total Suspended Solids, 6.BOD, 7.COD, 8.Sulfide, 9.Cyanides 10.Oil and Greases, 11.Formaldehyde, 12.Phenols, 13.Free Chlorine, 14.Pesticides, 15.TKN (Total Kjeldahl Nitrogen), 16. Heavy metals

**Table 3-99: UNEP's PCDD/F emission factors for boilers in the pulp and paper industry**

| | **Source Category**<br>Classification | **Air**<br>(µg TEQ/ADt) | **Residue**<br>(µg TEQ/t ash) |
|---|---|---|---|
| 1 | Recovery boilers fueled with black liquor | 0.03 | No data |
| 2 | Power boilers fueled with sludge and/or biomass/bark | 0.5 | 5 |
| 3 | Power boilers fueled with salt-laden wood | 13 | 228 |

Note: ADt = Air dry tonne

## Activity rates

Based on DIW factory registration database, there were 13 pulping mills in 9 provinces [19], with 8 mills[25] considered major producers. These mills produced about 1.23 million tonnes of pulps to feed the paper industry in 2017 [123]. The rest of the mills were smaller firms mostly producing pulps for the production of mulberry or other specialty paper. There is no record on the production rates from these smaller mills.

There are two sources of data for the estimation of activity rates at the national level, TPPIA [123] and OIE [18]. TPPIA data are based on information gathered from its members, while OIE data are based on periodic survey of manufacturers. TPPIA data are available only up to the year 2015 (with forecasted volumes up to the year 2020). OIE data are updated every month but do not cover newspapers, sanitary paper, and recovered paper.

Data from the two datasets exhibit similar time trends, with OIE production volumes being about 20% to 30% lower than TPPIA. (See detail production volume for the years 2010 to 2015 in Table 3-129 (Annex)). The reason for the lower reported values in OIE dataset is attributed to potentially fewer number of data points, which would make the OIE estimations sensitive to any missing/unreported values (due to the low number of firms in the industry).

For the purpose of this report, TPPIA forecast data as shown in Table 3-100 are used for PCDD/F estimation.

**Table 3-100: TPPIA forecasted production volumes for pulp and paper products for 2017**

| **Product** | **Forecast production volumes for 2017** |
|---|---|
| Pulp | 1,231,000 |
| Kraft Paper | 3,233,000 |
| Paperboard | 481,000 |
| Writing Paper | 1,257,000 |
| Newsprint | 125,000 |

*Data source: TPPIA* [123]

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[25] 4 non-integrated and 4 integrated pulps and papers mills

**Recovery boilers fueled with black liquor:**

Based on information from key stakeholder interviews and from firms' EIA monitoring reports, all pulping mills have recovery boilers to recover inorganic chemicals and energy (from dissolved organic materials). Since this process helps save chemicals and generate extra energy, enough to sustain the production process [124], firms have the incentive to keep this process as efficient as possible.

MoEN reported burning of 12,581 GJ of black liquor and residual gas in power plants in 2017 [39]. Although the pulp and paper industry is the major source for this black liquor, there is no supporting information to positively associate this energy source to the pulp and paper industry.

Since the Toolkit prescribes emission factors on air-dried tonnage (ADt) basis, activity rates associated with black liquor fired recovery boilers are estimated using TPPIA's productivity report (1.23 million ADt).

**Power boilers fueled with sludge and/or biomass/bark:**

Pulps in Thailand are mostly produced from eucalyptus trees. Mills use sludge and wood residues to generate heat and power, mostly via combined heat and power generating system (CHP). The amounts of heat and power generated are enough to sustain their pulping process's heat requirements as well as those of their downstream paper mills. The excess power is sold to power grids under small power producer (SPP) contracts.

Biomass burning for heat and power generation is mainly considered in Source Group 3 (Heat and Power Generation). Since available data do not allow for the segregation of fuels used by each industry type, all activities related to heat and power generations are investigated within Source Group 3 to avoid double counting. This approach is logical when considering the fact that key energy-intensive industries tend to adopt new business models that treat heat and power generation as separate business entities (with separate factory registration) that provide heat and power to the core factories, nearby communities, as well as feeding to power grids. The activity rate for this class is, therefore, set to zero.

**Power boilers fueled with salt-laden wood:**

There is no record of any salt-laden wood available in Thailand. Wood residues from mangrove forests may be contaminated by salt water. However, mangrove logging in Thailand has been forbidden by the National Reserved Forest Act since 1964 [125]. Additionally, all pulp mills are located at considerable distances from the coasts. It is unlikely that salt-contaminated wood was collected and transported to the mills on a commercial basis. The activity rate for this class is, therefore, estimated at zero.

## Pulp and paper production processes:

### Emission factors

Pulping mills require vast amounts of water and chemicals to dissolve lignin from biomass feedstock [124]. The levels of PCDD/F formation depend on the production processes, particularly the extents to which elemental chlorine are involved. The Toolkit specifies emissions for 3 different pulping processes; Kraft process, sulfite process, and thermo-mechanical process (TMP) with varying degree of elemental chlorine involvement.

In addition to releases to water, PCDD/F generated in the pulping processes can be transferred to products (i.e., paper pulps) as well as to sludge. In addition to chemicals intentionally used in the production process, significant amounts of dioxins/furans can be found if the feedstock itself is contaminated with dioxin precursors, particularly pentachlorophenols [37] (PCP, a wood preservative historically used to protect wood from insects and other biological degradation).

Unlike pulping mills, paper-making processes in general use water only to disperse the pulp and to remove the remaining residues. The releases of PCDD/F at this stage are carried-over dioxins embedded within the pulp, which are already counted in the pulping process. Thus, there is no emission factor prescribed for water discharged from paper-making processes.

There are concerns, however, for PCDD/F in recovered paper that may have been produced with old bleaching technologies and/or contaminated with PCDD/F from other sources (e.g., ink). The Toolkit accounts for these by considering PCDD/F that may have been embedded in the products produced with Kraft process, using old and mixed technologies, respectively.

The emission factors for pulp and paper production are summarized in Table 3-101.

**Table 3-101: UNEP's PCDD/F emission factors for Source Category 7a: Pulp and Paper production**

| 7a | Pulp and Paper | Emission Factor (µg TEQ/ADt) | | |
|---|---|---|---|---|
| | **Classification** | **Water** | **Product** | **Residue** |
| 1 | Kraft process, Cl2 gas, non-wood, PCP-contaminated fibers | No data | 30 | No data |
| 2 | Kraft process, old technology (Cl2 ) | 4.5 | 10 | 4.5 |
| 3 | Kraft process, mixed technology | 1.0 | 3 | 1.5 |
| 4 | Sulfite process, old technology | No data | 1 | No data |
| 5 | Kraft process, modern technology (ClO$_2$) | 0.06 | 0.5 | 0.2 |
| 6 | Sulfite process, new technology (ClO$_2$, TCF) | No data | 0.1 | No data |
| 7 | TMP pulp | No data | 1.0 | No data |
| 8 | Recycling paper from contaminated waste paper | No data | 10 | No data |
| 9 | Recycling pulp/paper from modern paper | No data | 3 | No data |

## Activity rates

**Pulp mills:**

In 2017, there were 8 major pulp mills that produced about 1.23 million tonnes (ADt) of pulps to feed the paper industry. Based on information obtained from stakeholder interviews, TPPIA directories, and EIA reports[26], activity rates and the corresponding classes for the pulp industry are as follows:

In terms of Class 1, PCP has been listed as a Category 4 hazardous substance (total ban) under the Hazardous Substances Act since 1995 [126]. According to the Department of Agriculture (DOA), PCP has never been approved for agricultural uses in Thailand. Based on interviews with the Royal Forest Department officers, there has been no report of any widespread use of this substance for wood preservation in Thailand prior to the ban. Similarly, response from the State Railway of Thailand (SRT) also indicates no recollection of PCP use for SRT sleepers or utility poles. Finally, a search for reports on PCP detection in Thailand in scientific literatures did not yield any result. Therefore, the inventory team concluded that there is no evidence of the availability of PCP contaminated biomass feedstock in Thailand and the activity related to Class 1 is estimated at zero.

Most mainstream pulping mills in Thailand are based on Kraft (sulphate) pulping process. There is no mainstream mill that still employs sulfite process or TMP process. This situation is in-line with worldwide trend [15]. The Kraft process employed also similar to that explained in the EU BREF document for the Production of Pulp, Paper and Board [15]. Based on the received information, activities related to Classes 2, 4, 6, and 7 are estimated at zero.

For virgin pulp, only Kraft processes with $Cl_2$ or $ClO_2$ bleaching (Class 3 and Class 5) are considered relevant. The Kraft process uses sodium hydroxide (NaOH) and sodium sulphide ($Na_2S$) to digest ('cook') wood chips, and oxygen or thiosulphate ($Na_2S_2O_3$) to remove lignin (oxygen delignification). The combined virgin pulp production volume in 2017 for all mills was 1.23 million ADt. However, not all pulps were bleached. Pulp for Kraft papers (material for carton box, sack, etc.) do not require bleaching; only pulps designated for writing paper and outer layers of paperboard do.

Pulping mills have mostly moved away from elemental chlorine ($Cl_2$) technology to accommodate the updated wastewater emission limits [121], [122], [127]. At the time of this study, there may be 1-2 firms that may still used mixed $Cl_2$ and $ClO_2$ technology, with combined annual

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[26] Search ONEP EIA database (http://eia.onep.go.th/index.php) with keyword "pulp" (in Thai)

productivity of approximately 247,000 ADt. [128]–[130].

There are two unbleached pulping mills with a combined capacity of about 110,000 ADt/year [123]. The estimated production from these mills in 2017 was about 60,000 ADt. Since there is no bleaching involved in the process, this pulp is considered irrelevant. (The Toolkit provides no PCDD/F emission factor for unbleached pulps.)

Mills with pulp bleaching capability also supply unbleached pulps. The proportion of bleached and unbleached pulps from pulping mills depends on market demand. Unfortunately, the available pulp production data do not allow for disaggregation of these 2 portions.

**Table 3-102: Amounts and types of papers domestically produced in 2017**

| Product | Number of Producers | Production (tonne) | Proportion (%) |
|---|---|---|---|
| Kraft Paper | 17 | 3,130,000 | 61.6 |
| Writing Paper | 9 | 1,120,000 | 22.0 |
| Paperboard | 10 | 464,000 | 9.1 |
| Sanitary Paper | 5 | 126,000 | 2.5 |
| Newsprint Paper | 1 | 125,000 | 2.5 |
| Specialty Paper | 4 | 122,000 | 2.4 |

*Data source: TPPIA* [123]

The amount of unbleached pulp may be roughly estimated from the proportion of Kraft paper in total paper production volume (Table 3-102). This estimation assumes that other paper products are all bleached which may not exactly be the case (for example, paperboard may contain both bleached and unbleached pulps). Nevertheless, Kraft paper also contains high percentage of imported long fibers and recycled pulp. Therefore, for the purpose of this study, the amount of bleached pulps is estimated at 40% of total pulps produced by relevant mills as shown in Table 3-103.

**Table 3-103: Estimated activity rates for domestically produced pulps in 2017**

| Class | Total virgin pulp production(ADt) | Estimated bleached pulp production (ADt)*1) |
|---|---|---|
| Kraft process, mixed technology | 247,000 | 100,000 |
| Kraft process, modern technology ($ClO_2$) | 885,000 | 352,000 |
| | | (*) estimated at 40% of pulps output from relevant mills |

1): numbers rounded to 3 significant figures for legibility.

About 420,000 tonnes of pulps were also imported into the country in 2017, of which about 320,000 tonnes were bleached, as shown in Table 3-104. Depending on the production technology, these bleached pulps may be contaminated with PCDD/Fs. Unfortunately, there is no information related to the technology used to produce these pulps.

For the purpose of estimating possible amount of dioxins/furans embedded in these imported pulps, bleached pulps imported from high-income countries are assumed to have been made from new technology (Class 5) while the rest are assumed to be made from older technology (Class 3). This assumption places 110,000 tonnes and 206,000 tonnes of imported bleached pulps to Class 3 and 5, respectively (see Table 3-104).

**Table 3-104: Import and export of pulps in 2017**

| HS Code | Type | Bleach | Import | Export | Net | Net Class 5* | Net Class 3** |
|---|---|---|---|---|---|---|---|
| 470311 | Long fiber | Unbleached | 105,481 | 0 | 105,481 | - | - |
| 470319 | Short fiber | Unbleached | 3,758 | 101 | 3,657 | - | - |
| 470321 | Long fiber | Bleached | 230,302 | 81 | 230,221 | 195,273 (85%) | 34,949 (15%) |
| 470329 | Short fiber | Bleached | 140,271 | 54,921 | 85,350 | 10,754 (13%) | 74,596 (87%) |
| 4706 | Recovered pulps | - | 45,853 | 52,660 | (6,808) | - | - |
| | | **Total** | **525,665** | **107,763** | **417,902** | **206,027** | **109,545** |

*Data source: Thai Customs, (*) Estimated based on countries of origin, (**) the remainders*

**Recycled fibers:**

In 2015, TPPIA forecasted the demand for recovered paper for 2017 at about 4 million tonnes. About 65% of this would be acquired through local collection, and the rest would be imported. Based on the Thai Customs data, the (net) amount of recovered papers imported to Thailand in 2017 was about 1.4 million tonnes, most of which was unbleached paper (see Table 3-105).

**Table 3-105: Import and export of recovered papers in 2017 (tonne)**

| Product | HS Code | Export | Import | Balance |
|---|---|---|---|---|
| Unbleached paper | 470710 | 791 | 1,109,190 | 1,108,399 |
| Bleached paper | 470720 | 7,038 | 1,426 | -5,612 |
| Newspapers | 470730 | 114 | 158,768 | 158,655 |
| Mixed (unsorted) waste paper | 470790 | 82,114 | 229,524 | 147,410 |

*Data Source: Thai Customs*

Recovered paper is also collected from domestic waste. In 2017, Thailand consumed about 5 million tonnes of paper products (Table 3-106).

**Table 3-106: Mass balance of paper product consumption in 2017 (tonne)**

| Product | Production | Import | Export | Domestic Consumption |
|---|---|---|---|---|
| Kraft Paper | 3,133,551 | 346,763 | 675,212 | 2,805,102 |
| Writing Paper | 1,120,134 | 1,109,048 | 1,112,347 | 1,116,835 |
| Paperboard | 463,890 | 134,936 | 24,819 | 574,007 |
| Specialty Paper | 122,500 | 218,903 | 90,121 | 251,281 |
| Sanitary Paper | 125,740 | 59,298 | 15,163 | 169,875 |
| Newspapers | 125,000 | 58,488 | 55,965 | 127,522 |
| **Total** | **5,090,815** | **1,927,435** | **1,973,628** | **5,044,622** |

*Data Source: Production data from TPPIA,*
*Import and Export volume from Thai Customs (see corresponding HS Codes in Table 3-130 of the Annex)*

Papers can be considered short-life product. Paper products put on market can be anticipated to reach its end-of-life within one year. As the virgin pulp production process changes, the inherent properties of recycled fibers are expected to quickly follow.

PCDD/Fs may be embedded within papers that were produced with old technologies and/or contaminated with PCDD/Fs from other sources. The UNEP Toolkit identifies PCDD/F emissions for two classes of recycled papers: Class 8 for facilities that recycle paper made from Class 1 through Class 4 pulps, and Class 9 for facilities that recycle paper made from Class 5 through Class 7 pulps. Therefore, as with pulp production, only bleached paper and contaminated paper (newsprint paper) are considered.

**Imported recovered papers:**

For imported recovered papers (Table 3-105), only recovered newspapers and mixed (unsorted) waste paper are relevant. Due to relatively high amount of ink and other contaminants, all recovered newspapers are assigned to Class 8 (contaminated waste).

There is no information about the nature of the imported mixed (unsorted) waste paper. For the purpose of estimating possible amount of dioxin emission, all imported unsorted papers are assumed bleached. Waste paper imported from high income countries are assumed to be made from new technology (Classes 5-7) while the rest are assumed to be made from older technology (Classes 1-4). The resulting activity rates and the corresponding class assignments for imported recovered papers are summarized in Table 3-107.

**Domestic recovered papers**

There is no data available at the national level for the amount of bleached paper that was domestically recovered for fiber recycling. The amount of recovered bleached papers available is estimated at about 1.1 million tonnes based on the following assumptions (see Table 3-107 for detail).

- The amount of paper products consumed in Thailand in 2017 is as shown in Table 3-106
- All Kraft paper was unbleached

- All writing paper and paperboard were bleached
- Recovery rate of 65% for all types of domestically consumed paper, except for specialty and sanitary papers, which are not typically recovered for fiber.

There is also insufficient data to allow for the evaluation of the proportion of $Cl_2$ bleached fibers among the total domestic recycled fibers used within the industry. A rough estimate value of 5% was suggested by a stakeholder. This ratio can be considered the lower bound for the PCDD/F estimation from this activity (not shown here).

From Table 3-103, pulp produced with Class 3 and Class 5 technology contributed about 25% and 75% of all bleached pulp produced in Thailand in 2017. If this proportion also held for recovered paper, the recovered bleached papers would have contributed to about 273,000 tonnes of Class 8, and 820,000 tonnes of Class 9 recovered papers. This assumption should represent an upper bound for the PCDD/F emission from this activity.

Note that bleached papers also contain imported long fibers and other constituents. The estimated amount of Classes 3 and 5 pulps (that had PCDD/F carried over) produced in Thailand in 2017 were 100,000 and 352,000 ADt, respectively (see Table 3-103), or about a third of the amount estimated for the aforementioned upper bound values.

For the purpose of assessing the maximum releases, the upper bound values as shown in Table 3-107 are used to estimate the PCDD/F emissions from recovered papers.

**Table 3-107: Estimated amounts of recovered papers available in 2017 and class assignment**

| Type | Net Import & Export of Waste | Recovered from Domestic Waste[1] | Net Recovered Papers | Class 8 | Class 9 |
|---|---|---|---|---|---|
| Unbleached paper | 1,108,399 | 1,823,316 | 2,931,715 | - | - |
| Bleached paper | (5,612) | 1,099,047 | 1,093,435 | 273,359[2] | 820,076[2] |
| Newspapers | 158,655 | 82,890 | 241,544 | 241,544 | - |
| Mixed (unsorted), import | 229,524 | - | 229,524 | 40,944[3] | 188,580[4] |
| Mixed (unsorted), export | (82,114) | - | (82,114) | (20,529)[2] | (61,585)[2] |
| **Total** | **1,408,851** | **3,005,253** | **4,414,104** | **535,318** | **947,071** |

Note:
[1]: Assuming 65% collection rate for all types except for specialty and sanitary papers (not recovered for fiber)
[2]: Assuming 25% Cl2 :75% ClO2 ratio,
[3]: Imported from low to middle-income countries
[4]: Imported from high-income countries

### Releases of dioxins and furans

The estimated PCDD/F emissions from pulp and paper industry in 2017 are summarized in Table 3-108.

**Table 3-108: Estimated annual releases of PCDD/F from Source Category 7a - pulp and paper industry in 2017**

| 7a | Pulp and paper industry | Activity Rate | | | Emission (g I-TEQ/a) | | |
|---|---|---|---|---|---|---|---|
| | Classification | ADt[1] | Air | Water | Product | Residue | Subtotal |
| | **Boilers** | **1,230,000** | **0.037** | **0** | **0** | **-** | **0.04** |
| 1 | Recovery boilers fueled with black liquor | 1,230,000 | 0.037 | 0 | 0 | - | 0.04 |
| | **Pulp & paper production processes** | **2,210,000** | **0** | **0.121** | **9.10** | **0.220** | **9.44** |
| 3 | Kraft process, mixed technology | 100,000 | 0 | 0.100 | 0.300 | 0.150 | 0.55 |
| 3a | Imported pulps, mixed technology | 110,000 | 0 | 0 | 0.330 | 0 | 0.33 |
| 5 | Kraft process, modern technology ($ClO_2$) | 352,000 | 0 | 0.021 | 0.176 | 0.070 | 0.27 |
| 5a | Imported pulps, modern technology ($ClO_2$) | 206,000 | 0 | 0 | 0.103 | 0 | 0.10 |
| 8 | Recycling paper from contaminated waste paper | 535,000 | - | - | 5.350 | - | 5.35 |
| 9 | Recycling pulp/paper from modern paper | 947,000 | - | - | 2.841 | - | 2.84 |
| | **Total Pulp and paper industry** | | **0.04** | **0.12** | **9.10** | **0.22** | **9.48** |

1) numbers rounded to 3 significant figures for legibility.

Uncertainty

The level of confidence for the activity rates is high for boilers, medium for virgin pulps and medium-to-low for paper recycling due to the lack of material-specific data and the several assumptions that have been made.

The level of confidence for class assignment is high. The emission factors were given a medium level of confidence by UNEP due to limited number of reported data and limited geographical coverage.

### 3.7.2 Chlorinated inorganic chemicals

Relevant activities

Based on DIW factory registration data [19], there were 7 factories registered for chlor-alkali (CAK) related chemicals[27] in 4 provinces, with combined investment of about 20.5 billion baht and employment of nearly 1,000 positions. The CAK industry is an established industry in Thailand, with the average age of factory licenses of over 30 years. CAK industry is an important part of the Thai chemical industry, feeding chlorine and caustic soda to a variety of downstream industries including food, antiseptics, plastics, and biodiesel.

CAK plants with productivity above 100 tonne/day must conduct EIA study and monitor their emissions accordingly [24]. Factories that burn wastes in on-site incinerators are also subjected to stringent air emission limits that include the 0.5 ng I-TEQ/m$^3$ (7% excess $O_2$) [9] dioxin standard. A search using relevant keywords (in Thai) in ONEP EIA database found 5 firms that regularly report their monitoring data.

Releases of effluent water from factories are generally controlled by the newly revised M-Industry notification on industrial wastewater B.E. 2560 (2017) [121]. This notification prescribes limits on 16 key wastewater qualities including free chlorine and 12 heavy metals[28].

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[27] Such as Sodium Hydroxides, Hydrochloric acid, Chlorine, etc.

[28] Zn, Cr(VI), Cr(III), As, Cu, Hg, Cd, Ba, Se, Pb, Ni, Mn

## Emission factors

The formation and releases of PCDD/F are associated with the contact of chlorine gas with reactive materials, mostly in the electrolysis process.

There are typically 3 types of electrolysis cells: mercury, diaphragm, and membrane [131]. The contact of chlorine gas occurs mainly at the anode terminals. There is no physical barrier (or separator) for chlorine gas in mercury cells. For the diaphragm cells, diaphragms made of asbestos or non-asbestos materials are used to separate chlorine at the anode and other positive ions (Na+, H+) at the cathode. The operation of membrane cells is similar to diaphragm cells, but with the diaphragms replaced by ion-exchange membranes.

The UNEP Toolkit classifies CAK production into 2 classes based on anode materials: graphite for Class 1 and titanium for Class 2. The CAK processes with titanium electrodes are further classified into 3 subclasses based on the level of control over the process: low-end, mid-range and high-end.

**Table 3-109: PCDD/F emission factors for chlorine/chlor-alkali production**

| | **Chlorine/chlor-alkali production** | **Emission Factor (µg TEQ/ECU*)** | |
|---|---|---|---|
| | Classification | Water | Residue |
| 1 | Chlor-alkali production using graphite anodes | No data | 1000 |
| 2 | Chlor-alkali production using titanium electrodes | | |
| 2a | Low-End Technologies | 17 | 27 |
| 2b | Mid-Range Technologies | 1.7 | 1.7 |
| 2c | High-End Technologies | 0.002 | 0.3 |

Electrochemical unit (ECU) consists of 1 tonne of chlorine and 1.1 tonnes of caustic soda (NaOH)

## Activity rates

In 2017, there were 7 mainstream producers [19] that supplied about 1 million tonnes of caustic soda, mostly for domestic consumption [18]. Most factories were tightly integrated with downstream business (such as epichlorhydrin, ethylene dichloride, etc.). In 2017, the combined NaOH production capacity in Thailand was about 1.29 million tonnes [18].

Based on information from firms' EIA reports and based on interviews with key stakeholders, all CAK plants in Thailand employ the membrane technology. All large firms reported their emissions with respected to the applicable laws. One firm reported dioxin emissions in effluent water. However, due to the highly integrated nature of the production facilities, available information is insufficient to determine contribution from their electrolysis cells.

**Class assignment:**

All CAK processes in Thailand can be assigned to Class 2. The regulatory emission requirements for CAK plants ensure that the permitted CAK processes meet at least Subclass 2b.

According to the Toolkit, Subclass 2c refers to "*processes that are optimized for minimum formation and release of unintentional POPs*" and "*Process residues should be handled in an environmentally sound manner, as described in the guidance on the BAT and BEP*".

Current BATs and BEPs for electrolysis process are focused on mercury cells and carbon graphite electrodes. A search in UNEP Toolkit, UNEP BAT & BEP, EU BREF and EU BAT [132] found no information about the optimized electrolysis process with regard to dioxin formation from membrane cells with titanium electrodes[29].

UNEP BAT & BEP, however, provide generic descriptions for performance standards to be set [133]. For stack air emission, the reference value of 0.1 ng TEQ/Nm$^3$ has become a worldwide norm. However, standard values for PCDD/F releases into water or residues, such as in the CAK case, are rarely found. The followings are relevant standard values for media other than air that are available in the literature:

- A total discharge of PCDD/F in effluent water of 1μg TEQ per tonne oxychlorination capacity, in OSPAR Decision 98/4 [134].
- Japan water effluent standard of 10 pg TEQ/L effluent water from designated facilities, including Kraft pulp bleaching facilities and waste gas cleansing facilities [135].

Apart from dioxin in stack gas emission and ambient air, dioxin in other media is rarely measured nor specified by law in Thailand. Nevertheless, under M-Industry's 2005 waste management notification [10], industrial waste having dioxin above the following limits are classified as hazardous waste that must be properly disposed using M-Industry's approved methods.

| **Medium** | **Relevant pollutant** | **Concentration Limit** |
|---|---|---|
| Solids | Dioxin (2,3,7,8-TCDD) | 10μg/kg |
| Leachates | Dioxin (2,3,7,8-TCDD) | 1μg/L |

*Source: M-Industry 2005*[10]

Since there is no record on the measurement of PCDD/F both in water and in residues, and since there is no measure yet in place to address PCDD/F in media other than stack air emission, all Thai CAK-related activities are allocated to Subclass 2b.

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[29] $RuO_2$+$IrO_2$+$TiO_2$ coated on titanium substrate[131]

### Releases of dioxins and furans

The estimated emissions of PCDD/F from chlorine/chlor-alkali production are summarized in Table 3-110.

PCDD/F from CAK processes are released to water and residues. Waste water from CAK processes is treated before release. Important parameters that are regularly monitored include, among other substances, free chlorine, phenols, and 12 heavy metals. Unfortunately, the limits for these parameters are relatively high when compare to PCDD/F emission level. Due to the absence of standard values prescribed for the effluent water, PCDD/F have not yet been measured and current level of PCDD/F is largely unknown. Actions are needed to rectify this situation.

**Table 3-110: Estimated emissions of PCDD/F from Source Category 7b: chlorine/chlor-alkali production**

| **7b** | **Chlorine/chlor-alkali production** | **Activity Rate** | **Emission (g TEQ/a)** | | |
|---|---|---|---|---|---|
| | **Classification** | **ECU*** | **Water** | **Residue** | **Subtotal** |
| 1 | Chlor-alkali production using graphite anodes | 0 | 0 | 0 | **0** |
| 2 | Chlor-alkali production using titanium electrodes | 909,000 | 1.545 | 1.545 | **3.09** |
| 2a | Low-End Technologies | 0 | 0 | 0 | **0** |
| 2b | Mid-Range Technologies | 909,000 | 1.545 | 1.545 | **3.09** |
| 2c | High-End Technologies | 0 | 0 | 0 | **0** |
| | Total | **909,000**** | **1.55** | **1.55** | **3.09** |

Electrochemical unit (ECU) consists of 1 tonne of chlorine and 1.1 tonnes of caustic soda (NaOH)

*: number rounded to 3 significant figures for legibility.

** Activity Data OIE database

### Uncertainty

The confidence level for the activity rate is high due to the availability of national data. However, the level of confidence for class assignment is medium due to lack of measurement data in relevant media and the unclear classification criteria. The UNEP’s confidence level for emission factors is low due to low data range and limited geographical coverage.

## 3.7.3 Chlorinated aliphatic chemicals

### Relevant activities

Chlorinated aliphatic chemicals to be studied in this section cover the entire PVC resin value chain, which comprises the production of ethylene dichloride (EDC), vinyl chloride monomer (VCM) and polyvinyl chloride (PVC). This industry is a major consumer of elemental chlorine.

A search in DIW factory database found 3 relevant factories with combined capital investment of about 19.1 billion baht. These factories, all located in Rayong Province, contribute to about 400 jobs.

Petrochemical factories with daily capacities exceeding 100 tonnes are required by ONEP to conduct EIA study to evaluate possible environmental impacts, determine and implement prevention measures, and keep monitoring the outcome to ensure appropriate environmental protection [24].

Petrochemical factories that produce or use over 36 tonnes/year of volatile organic compounds (VOCs) are also subjected to MNRE's control for the release of two important VOCs: benzene and 1,3-butadiene [136]. Moreover, there is also PCD daily average ambient air VOC monitoring level for 19 VOCs [137] for relevant stakeholders as action levels to ensure that the national air quality conforms with the National Environment Board (NEB)'s yearly average ambient air VOC standard [138]. EDC and VCM are listed in both of these standards. Finally, facilities that burn waste in on-site incinerators must also comply with dioxin air emission standard of 0.5 ng TEQ/$m^3$ (7% excess $O_2$) [9].

## Emission factors

The PVC resin production chain starts from EDC production. EDC is used to produce VCM, which is then polymerized to produce PVC resins. There are two main EDC production methods: direct chlorination of ethylene using elemental chlorine in the presence of an iron catalyst, and oxychlorination of ethylene using hydrogen chloride (HCl) and air or oxygen in the presence of a copper catalyst.

Since there is no country-specific emission factor for EDC/VCM/PVC process in Thailand, appropriate site-specific data and appropriate default emission factors from 2013 UNEP Toolkit, as summarized in Table 3-111, are used for the estimation of PCDD/F formation and releases.

The whole PVC resin production processes can be an integrated process with EDC, VCM, and PVC production taking place within the same facility, or as separate EDC/VCM and PVC production facilities.

The UNEP Toolkit considers the PCDD/F formation for both scenarios, and from 4 pathways:

- A: Releases from vent and liquid-vent combustors
- B: Releases into spent fixed-bed oxychlorination catalyst
- C: Releases from EDC/VCM and EDC/VCM/PVC production processes and
- D: Releases from PVC-only process

Each pathway is further classified into 3 subclasses based on the level of controls over the process: low-end, mid-range and high-end.

**A: Releases from vent and liquid-vent combustors**

The releases from this pathway are from combustion of vent gas or liquid-vent or from thermal oxidizers. The Toolkit classifies activities in this heading into 3 subclasses based on the stack flue gas control level, as follows:

| Subclass | PCDD/F control levels |
|---|---|
| Class 1 | 5 ng I-TEQ/$Nm^3$ |
| Class 2 | 0.5 ng I-TEQ/$Nm^3$ |
| Class 3 | 0.1 ng I-TEQ/$Nm^3$<br>(with supporting analytical data ) |

### B: Releases in spent fixed-bed oxychlorination catalyst

This pathway is only relevant to the copper catalysts used in fixed-bed oxychlorination, in which there might be residual PCDD/F remaining in the spent catalyst. There is no performance criterion provided for class assignment except for the plant's generic process control for PCDD/F optimization.

### C: Releases from EDC/VCM and EDC/VCM/PVC production processes

The formation and release of PCDD/F to receiving water body are anticipated for plants using oxychlorination; with fluidized-bed chlorination contributing more to solid residues (sludge) than fixed-bed chlorination. The Toolkit classifies activities in each heading into 3 subclasses based on effluent water control level, as follows:

| Subclass | PCDD/F control levels |
|---|---|
| Class 1 | 5 ng TEQ/L |
| Class 2 | 0.5 ng TEQ/L |
| Class 3 | 0.1 ng TEQ/L |
| | (with supporting analytical data ) |

### D: Releases from PVC only process

For plants that produce PVC from VCM sourced from outside, only relevant processes are considered. Similarly, the classifications for this activity are based on the plant's target for PCDD/F control, as follows:

| Subclass | Controlled release to air | Controlled release to water |
|---|---|---|
| Class 1 | 1 ng TEQ/$Nm^3$ | 0.01 ng/L |
| Class 2 | 0.1 ng TEQ/$Nm^3$ | 0.001 ng/L |
| Class 3 | 0.023 ng TEQ/$Nm^3$ | 0.0001 ng/L |
| | (with supporting analytical data ) | (with supporting analytical data ) |

**Table 3-111: PCDD/F emission factors for EDC/VCM/PVC production**

| c | | **Chlorinated Aliphatic Chemicals** | **Emission Factors (µg TEQ/t*)** | | | |
|---|---|---|---|---|---|---|
| | | **Classification** | **Air** | **Water** | **Product** | **Residue** |
| ca | | **EDC/VCM and EDC/VCM/PVC vent and liquid-vent combustors (per tonne VCM)** | | | | |
| | 2 | Mid-Range Technologies | 0.5 | | | |
| | 3 | High-End Technologies | 0.05 | | | |
| cb | | **EDC/VCM and EDC/VCM/PVC spent catalyst from facilities utilizing a fixed-bed oxy-chlorination catalyst (per tonne EDC)** | | | | |
| | 2 | Mid-Range Technologies | | | | 0.85 |
| | 3 | High-End Technologies* | | | | 0.02[2] |
| cc | | **EDC/VCM and EDC/VCM/PVC production processes (per tonne EDC)** | | | | |
| | 2 | Mid-Range Technologies | | | | |
| | 2a | With fixed-bed oxy-chlorination catalyst | | 2.5 | 0.2[1] | 0.2 |
| | 2b | With fluidized-bed oxy-chlorination catalyst | | 2.5 | 0.2[1] | 2 |
| | 3 | High-End Technologies* | | | | |
| | 3a | With fixed-bed oxy-chlorination catalyst | | 0.5 | 0.006[1] | 0.095[2] |
| | 3b | With fluidized-bed oxy-chlorination catalyst | | 0.5 | 0.006[1] | 0.4 |

| c | | Chlorinated Aliphatic Chemicals | Emission Factors (µg TEQ/t*) | | | |
|---|---|---|---|---|---|---|
| | | **Classification** | **Air** | **Water** | **Product** | **Residue** |
| cd | | PVC only (per tonne PVC product) | | | | |
| | 2 | Mid-Range Technologies | 0.1 | 0.003 | No data | 0.06 |
| | 3 | High-End Technologies* | 0.021 | 0.0003 | Not applicable | 0.005[2] |

Note: [*] Releases to residues from facilities with high-end technologies only if solids are NOT incinerated

[1] Modified values in Toolkit spreadsheets to match values prescribed in Toolkit's text

[2]: Only applies if residue is sent to landfill

## Activity rates

In 2017 there were two firms with EDC/VCM/PVC integrated processes with combined capacity of 1.1 million tonnes EDC, 1 million tonnes VCM, and 900,000 tonnes PVC.

Information to be used for estimating emissions from EDC/VCM/PVC production are derived from firms EIA and EHIA monitoring reports, and data obtained from both firms.

### A: Releases from vent and liquid-vent combustors

Based on firms' EIA/EHIA reports, both facilities employ the balanced direct chlorination and fluidized bed oxychlorination process. Both facilities use incinerators to destruct vent gases and contaminated liquids, which subject them to PCD/DIW's waste incinerators' dioxin emission limits of 0.5 ng TEQ/m$^3$ (7% $O_2$). However, both firms indicated their commitments to the European Council of Vinyl Manufacturer (ECVM) emission limits for all relevant vent gases, as follows:

| Parameter | Limits (at 11% $O_2$)1) | Limits (at 7% $O_2$)2) |
|---|---|---|
| VCM | < 5 mg/Nm$^3$ | < 7 mg/Nm$^3$ |
| EDC | < 5 mg/Nm$^3$ | < 7 mg/Nm$^3$ |
| HCl | < 30 mg/Nm$^3$ | < 42 mg/Nm$^3$ |
| Ethylene | < 150 mg/Nm$^3$ | < 210 mg/Nm$^3$ |
| Dioxin | < 0.1 ng TEQ/Nm$^3$ | < 0.14 ng TEQ/Nm$^3$ |

*Source: 1) OSPAR 1996* [139], *2) From calculation*

Most of the measures specified in the firms' EIA reports ("EIA Measures") are consistent with EU's 2017 best available techniques (BAT) for EDC/VCM production [140] and OSPAR BAT for the Vinyl Chloride Industry [139]. Particularly, one facility adopted rapid quenching (EU 2017's BAT number 77) of exhaust gases to prevent the *de novo* formation of PCDD/Fs. Monitoring data extracted from the EIA monitoring reports for both facilities are shown in Table 3-131 (Annex). Except for the analytical results for PCDD/F releases that do not quite meet the 0.1 ng TEQ/Nm$^3$ criteria; all other parameters are well within the EU BAT 2017 recommendations.

However, the calculated emission factors of 0.10 and 0.018 µg/t VCM[30], for facility A and B, respectively, are closer to Toolkit's EF for Class 3 facilities than for Class 2. Therefore, the estimated emission factors for each facility are used to estimate emissions from their vent and liquid-vent combustors.

### B: Releases into spent fixed-bed oxychlorination catalyst

The oxychlorination process used by both facilities is oxygen-based fluidized bed oxychlorination, not the fix-bed. Pathway B is, therefore, considered irrelevant for both facilities. The activity rate for this entry is, thus, estimated at zero.

### C: Releases from EDC/VCM and EDC/VCM/PVC production processes

Wastewater treatment system for both facilities consists of preliminary wastewater pretreatment to strip and recover EDC and HCl at production site followed by series of final treatment at WWTP. Both facilities have water recovery systems installed, with one facility explicitly mentioning a zero liquid discharge policy. Both facilities have quality control protocols to check the quality of their effluent prior to discharge. Parameters routinely monitored are typical M-Industry's effluent water quality items[31] plus EDC and VCM. The monitoring data from both facilities, summarized in Table 3-132 in the Annex to this section, show their WWTP performances are comparable to the EU BAT 2017 environmental performance level associated with BAT (AEPLs) [140].

One facility reported additional data on free chlorine, chloride and copper. Although not include in the EIA measures, this firm also submitted data to the inventory team, showing median dioxin level in effluent water of 0.07 ng TEQ/L. Unfortunately, the other facility does not have monitoring data for dioxin in their effluent water. Nevertheless, due to their resources recovery policy, the liquid discharge from this facility was cut down by about 70%.

Based on the evidence of their implementation of the best available technique for the industry and the dioxin monitoring results from 1 firm, both facilities are assigned to Class 3.

Both firms dispose their wastewater solids by incineration. The emission factor for the release to residue, therefore, set to zero.

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[30] Calculated using median values

[31] pH, Temperature, COD, BOD, Dissolved Solids, Suspended Solids, Grease & Oil, Total Nitrogen, Total Phosphorus

### Releases of dioxins and furans

The estimated PCDD/F emissions from EDC/VCM/PVC production in 2017 are summarized in Table 3-112. Apart from the emission into air that is generally known, emissions into water and residue are less known to relevant stakeholders and, hence, deserve further investigation.

**Table 3-112: Estimated PCDD/F emission from Source 7c - production of chlorinated aliphatic chemicals in 2017**

| **7c** | **Chlorinated Aliphatic Chemicals** | **Activity** | | | **Emission (g TEQ/a)** | | |
|---|---|---|---|---|---|---|---|
| | Classification | (tonne)1) | Air | Water | Product | Residue | Subtotal |
| ca | EDC/VCM and EDC/VCM/PVC vent and liquid-vent combustors (per tonne VCM) | **990,000** | **0.067** | **0** | **0** | **0** | **0.067** |
| 2 | Mid-Range Technologies | 0 | 0 | | | | 0 |
| 3 | High-End Technologies | 990,000 | 0.067[1] | | | | 0.067 |
| cb | EDC/VCM and EDC/VCM/PVC spent catalyst from facilities utilizing a fixed-bed oxychlorination catalyst (per tonne EDC) | **0** | **0** | **0** | **0** | **0** | **0** |
| cc | EDC/VCM and EDC/VCM/PVC production processes (per tonne EDC) | **1,050,000** | **0** | **0.525** | **0.006** | **0** | **0.531** |
| 3 | High-End Technologies | | | | | | 0 |
| 3a | With fixed-bed oxychlorination catalyst | 0 | | 0 | 0 | 0 | 0 |
| 3b | With fluidized-bed oxychlorination catalyst | 1,050,000 | | 0.525 | 0.006 | 0 | 0.531 |
| | **Total Chlorinated Aliphatic Chemicals** | | **0.07** | **0.53** | **0.01** | **0** | **0.60** |

1) number rounded to 3 significant figures for legibility.

Note: [1] calculated using site specific emission factors of 0.1 and 0.02 µg/t VCM for facility A and B, respectively

### Uncertainty

The confidence level for activity rate is high due to the use of primary data gather from all relevant producers. The confidence level for class assignment is high due to the availability of information related to firms' adherence to BAT for the industry.

The confidence level for the emission from EDC/VCM/PVC into receiving water body is moderate to high due to the availability of monitoring data which show concentration within EU BAT 2017's AEPL [140]. The confidence level for the emission into product is low, due to the declared low confidence in UNEP EF and lack of country specific data.

## 3.7.4 Chlorinated aromatic chemicals

### Emission factors and relevant activities

The UNEP Toolkit specifies PCDD/F unintentionally embedded in 11 chlorinated aromatic chemicals and one chlorinated aliphatic chemicals. Based on information from DIW factory registration database, except for chlorinated paraffins (CPs), Thailand does not produce these chemicals. Most of the relevant chemicals have been listed as Category 4 (banned) or Category 3 (requiring prior authorization) hazardous substance under the Hazardous Substances Act B.E. 2535 (1991) and subsequence revisions in 2010 [141], 2008 [142], and 2019 [143].

List of PCDD/F emissions factors along with existing controls for relevant chlorinated aromatic chemicals are summarized in Table 3-113.

As can be seen, many substances were banned as Category 4 hazardous substances more than 10 years ago. These substances are considered irrelevant for this study, and subsequently, their activity rates are set to zero.

**Table 3-113: List of PCDD/F emission factors for source category 7d – chlorinated aromatic chemicals and existing controls in Thailand**

<table>
<tr><th>d</th><th>Chlorinated Aromatic Chemicals</th><th>EF in Product (µg TEQ/t)</th><th>Existing Controls [year]</th></tr>
<tr><td>da</td><td>1,4-Dichlorobenzene (1,4-DCB, p-DCB) (CAS 106-46-7)</td><td>39</td><td>Not listed<br>HS Cat.3 for 1,2-DCB (CAS 95-50-1) [1995]</td></tr>
<tr><td>db</td><td>PCBs</td><td></td><td>HS Cat.4 & already addressed in the first NIP</td></tr>
<tr><td>dc</td><td>PCPs and PCP-Na</td><td></td><td></td></tr>
<tr><td>1</td><td>PCP(CAS 87-86-5)</td><td>634,000</td><td>HS Cat.4</td></tr>
<tr><td>2</td><td>PCP-Na (CAS 131-52-2)</td><td>12,500</td><td>[Agriculture:1995, Industry:2001]</td></tr>
<tr><td>dd</td><td>2,4,5-T and 2,4,6-2,4,6-trichlorophenol</td><td></td><td></td></tr>
<tr><td>1</td><td>2,4,5-T (CAS 93-76-5)</td><td>7,000</td><td>HS Cat.4 [2003]</td></tr>
<tr><td>2</td><td>2,4,6-trichlorophenol(CAS 95-95-4)</td><td>700</td><td>HS Cat.4 [2003]</td></tr>
<tr><td>de</td><td>Chloronitrofen (CNP) (CAS 1836-77-7)</td><td>4,500</td><td>HS Cat.3 [2003]</td></tr>
<tr><td>df</td><td>Pentachloronitrobenzene (PCNB) (CAS 82-68-8)</td><td>2,600</td><td>HS Cat.3 [1995, listed under Quintozene]</td></tr>
<tr><td>dg</td><td>2,4-D and derivatives (CAS 94-75-7, 2702-72-9 2008-39-1, 94-11-1, 1929-73-3, 25168-26-7, 1928-43-4)</td><td>170</td><td>HS Cat.3 (All but 1 substance)
<table>
<tr><th>Substance</th><th>CAS No</th><th>Year</th></tr>
<tr><td>2,4-Dichlorophenoxyacetic acid</td><td>94-75-7</td><td>1995</td></tr>
<tr><td>2,4-D sodium salt</td><td>2702-72-9</td><td>2013</td></tr>
<tr><td>2,4-D-Dimethylammonium</td><td>2008-39-1</td><td>1995</td></tr>
<tr><td>2,4-D-Isopropyl</td><td>94-11-1</td><td>1995</td></tr>
<tr><td>2,4-D-Butotyl</td><td>1929-73-3</td><td>1995</td></tr>
<tr><td>2,4-D-Isoctyl</td><td>25168-26-7</td><td>1995</td></tr>
<tr><td>2,4-D-Ethylhexyl Ester</td><td>1928-43-4</td><td>-</td></tr>
</table></td></tr>
<tr><td>dh</td><td>Chlorinated paraffins</td><td>500</td><td>Not listed</td></tr>
<tr><td>di</td><td>p-Chloranil (CAS 118-75-2)</td><td></td><td>HS Cat.4/3 [2004]– No request for authorization found</td></tr>
<tr><td>dj</td><td>Phthalocyanine dyes and pigments</td><td></td><td></td></tr>
<tr><td>1</td><td>Phthalocyanine copper (CAS 147-14-8)</td><td>70</td><td>Not listed</td></tr>
<tr><td>2</td><td>Phthalocyanine green (CAS 1328-45-6)</td><td>1,400</td><td>Not listed</td></tr>
<tr><td>dk</td><td>Dioxazine dyes and pigments</td><td></td><td></td></tr>
<tr><td>1</td><td>Blue 106 (CAS 6527-70-4)</td><td>35,000</td><td>Not listed</td></tr>
<tr><td>2</td><td>Blue 108 (CAS 1324-58-9)</td><td>100</td><td>Not listed</td></tr>
<tr><td>3</td><td>Violet 23 (CAS 6358-30-1)</td><td>12,000</td><td>Not listed</td></tr>
<tr><td>dl</td><td>Triclosan (CAS 3380-34-5)</td><td>60</td><td>Not listed</td></tr>
</table>

Activity rates

**1,4-Dichlorobenzene (DCB):**
p-DCB is a chemical used in space deodorant products such as room deodorizers, urinal and toilet bowl blocks, and as an insecticide fumigant for moth control [144]. DCB is also used as a raw material for the production of poly(p-phenylene) sulfide (PPS) resins [37].

A search in DOA's registered substances database [145] did not yield any entry related to DCB but a search in Thai Customs database[32] found about 1,450 tonnes of p-dichlorobenzene (HS code 29039100.202) imported from China and Japan.

**Chloronitrofen or 2,4,6-Trichlorophenyl-4-nitrophenylether (CNP):**
CNP is a contact herbicide[146]. It was classified as Category 3 hazardous substance under the DOA in 2003. However, searches in both DOA's registered substances and Thai Customs database (HS Codes: 2909.30.00.002, 3808.93.11.000, 3808.93.19.340) did not yield any entry related to CNP.

**Pentachloronitrobenzene (PCNB) (Quintozene):**
Quintozene is a fungicide [147]. It has been classified as Category 3 hazardous substance under the DOA since 1995. A search in DOA's registered substances found one registered formula with 24% quintozene. DOA reported total import of 27.8 tonnes of quintozene from the US in 2017. Since there is no other information regarding PCDD/F content in this product, the inventory team made a conservative choice to classify this chemical based on median EF value, i.e. Class 2.

**2,4-Dichlorophenoxyacetic Acid (2,4D) and Derivatives:**
2,4-D is a herbicide [148]. This chemical is still active in Thailand. A search in DOA's registered substances found 168 import licenses for fifteen 2,4-D formulations. DOA reported total import of 12,550 tonnes of 2,4-D related chemicals from China, Indian, Poland, Malaysia, and Indonesia, in descending order.

**Chlorinated Paraffins (CPs):**
Chlorinated paraffins are polychlorinated aliphatic chemicals that have been used for a wide range of industrial applications, particularly as plasticizers, metal cutting fluids, and fat liquors.

Based on DIW factory registration database, there were 2 chlorinated paraffins (CP) producers (one in Rayong Province and the other in Samut Prakarn Province). Based on information from stakeholder interview and approximate range of imports of liquefied paraffin used in the manufacture of chlorinated paraffin [HS 27101990] and other medium

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[32] http://www.customs.go.th

oils and preparations [HS 27101989000] the amount of relevant CP in 2017 is estimated at 30,000 tonnes.

Again, since there is no other information regarding PCDD/F content in the product, the inventory team made a conservative choice to classify this chemical based on median EF value, i.e. to Class 2.

**Phthalocyanine dyes and pigments:**

Phthalocyanine (Pc) is a large macrocyclic aromatic organic compound with very low solubility in common solvents [149]. Pc is an important class of colorant, with phthalocyanine copper (CAS no. 147-14-8) as the single largest-volume colorant sold [149].

Phthalocyanine copper is allowed for use in cosmetic products under the MOPH's notification on the list of substances that may be used in cosmetics B.E. 2559 (2016) [150] but forbidden for uses in hair-dyes by MOPH's notification on the list of substances forbidden for uses in cosmetics B.E. 2559 (2016) [151]. No other information about these dyes can be extracted from government database.

According to tariff schedules of several countries (such as US, Canada, Australia, Peru), phthalocyanine pigments have been assigned HS Code 3204.17.10 (synthetic organic pigment in powder form).
The total amounts of pigments imported under 3204.17 heading[33] in 2017 were 8,861 tonnes, of which 3,710 tonnes were registered under HS Code 3204.17.10.
For this preliminary assessment purpose, a rough figure of 1,000 tonnes was allocated to each phthalocyanine pigment.

**Dioxazine dyes and pigments:**

UNEP Toolkit identifies 3 potential PCDD/F contaminated dioxazine dyes; Blue 106, Blue 108 and Violet 23.

Violet 23 (CAS 6358-30-11) has been forbidden for use in cosmetics [151] except for rinse-off application [150].

There was very limited data available about the activity rates for dioxazine pigments. However, searches for HS Code for pigments Blue 106 (6527-70-4), Blue 108 (1324-58-9), and Violet 23 (6358-30-1) found the blue dioxazine pigments registered under the heading "Direct Dye", which has HS Code 3204.14.00 (Direct dyes and preparations based thereon) while Violet 23 or C.I. pigment violet 23 was found in HS Code 3204.17.90.

The import amount for all direct dyes under HS Code 3204.14.00 in 2017 was 1,950 tonnes while import amount for HS Code 3204.17.90 was

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[33] Synthetic organic pigments; preparations based on synthetic organic pigments of a kind used to dye fabrics or produce colorant preparations

5,150 tonnes. These HS codes, unfortunately, also cover many other pigments. It was not possible to extract the import portions for the 3 dioxazine pigments.

Therefore, for this preliminary assessment purpose, a rough figure of 100 tonnes was allocated to each of the 3 dioxazine pigments.

**Triclosan:**

Triclosan is an antibacterial agent that finds uses in many applications, especially in household products such as shampoos, soaps, toothpaste, detergent, cosmetics, etc. Triclosan is an approved biocide for uses in 11 body care and oral care products (with < 0.3% limit) and mouthwash product (with < 0.2% limit).

Online search for HS Code for triclosan found that its suppliers mostly suggest tariff code 2909.50 for this product. In 2017, the total import for this HS Code was 205 tonnes. Therefore, a rough figure of 100 tonnes was allocated to triclosan for this preliminary assessment purpose.

### Releases of dioxins and furans

A preliminary estimation for PCDD/F emissions from chlorinated aromatic chemicals is shown in Table 3-114.

The main contributors for this source category are from PCDD/F unintentionally contaminated in chlorinated paraffins, dioxazine pigments, and 2,4-dichlorophenoxyacetic acid, respectively.

**Table 3-114: Estimated PCDD/F emission from Source Group 7d - chlorinated aromatic chemicals in 2017**

|  | 7d | Chlorinated Aromatic Chemicals | Activity Rate | Emission (g I-TEQ/a) |
|---|---|---|---|---|
|  |  | **Classification** | **(tonne)[1)]** | **Product** |
| da |  | Chlorobenzenes | **1,450** | **0.057** |
|  | 1 | 1,4-Dichlorobenzene | 1,450 | 0.057 |
| db |  | PCBs | 0 | 0 |
| dc |  | PCP and PCP-Na | 0 | 0 |
| dd |  | 2,4,5-T and 2,4,6-2,4,6-trichlorophenol | 0 | 0 |
| de |  | Chloronitrofen (CNP) | 0 | 0 |
| df |  | Pentachloronitrobenzene (PCNB) | **27.8** | **0.072** |
|  | 2 | Mid-Range Technologies | 27.8 | 0.072 |
| dg |  | 2,4-D and derivatives | **12,600** | **2.134** |
|  | 2 | Mid-Range Technologies | 12,600 | 2.134 |
| dh |  | Chlorinated paraffins | **30,000** | **15.000** |
|  | 2 | Mid-Range Technologies | 30,000 | 15.000 |
| di |  | p-Chloranil | 0 | 0 |
| dj |  | Phthalocyanine dyes and pigments | **2,000** | **1.470** |
|  | 1 | Phthalocyanine copper | 1,000 | 0.070 |
|  | 2 | Phthalocyanine green | 1,000 | 1.400 |
| dk |  | Dioxazine dyes and pigments | **300** | **4.710** |
|  | 1 | Blue 106 | 100 | 3.500 |
|  | 2 | Blue 108 | 100 | 0.010 |
|  | 3 | Violet 23 | 100 | 1.200 |
| dl |  | Triclosan | **100** | **0.006** |
|  | 2 | Mid-Range Technologies | 100 | 0.006 |
|  |  | **Total** |  | **23.45** |

1) number rounded to 3 significant figures for legibility.

### Uncertainty

The confidence level for activity rates is high for 2,4-D, PCNB (quintozene), and p-dichlorobenzene due to existing government controls and import statistics; medium for chlorinated paraffins where information from key stakeholders were used instead of national data; and low for phthalocyanine dyes, dioxazine pigments, and triclosan.

The confidence level for class assignment is low due to the lack of information on production technology used for all these imported products.

The confidence level for EFs rated by UNEP is low for CPs and medium for dioxazine pigments and 2,5-D.

## 3.7.5 Other chlorinated and non-chlorinated chemicals

### Emission factors and relevant activities

The UNEP Toolkit specifies PCDD/F released from titanium dioxide ($TiO_2$) and caprolactam productions as summarized in Table 3-115. Only processes that employ chlorine are relevant.

Based on information from DIW factory registration database, Thailand does not have $TiO_2$ production plant but has one plant in Rayong Province that produces caprolactam to feed the nylon industry.

The caprolactam plant is subjected to ONEP's EIA requirements as well as PCD's additional emission requirements for 2 VOC (1,3-butadiene and benzene).

**Table 3-115: PCDD/F emission factors for other chlorinated and non-chlorinated chemicals production**

| 7e | | Other Chlorinated and Non-Chlorinated Chemical | Emission Factor (µg TEQ/t) | | |
|---|---|---|---|---|---|
| | | Classification | Air | Water | Residue |
| ea | | $TiCl_4$ and $TiO_2$ | | | |
| | 1 | Low-End Technologies | No data | 0.2 | 42 |
| | 2 | Mid-Range Technologies | No data | 0.001 | 8 |
| eb | | Caprolactam | | | |
| | 1 | Caprolactam | 0.00035 | 0.5 | No data |

## Activity rates and releases of dioxins and furans

**$TiCl_4$ and $TiO_2$:**

In 2017, Thailand imported about 2,500 tonnes of $TiO_2$ [HS 2823.00.00] mainly from China, Germany, Japan, and Republic of Korea, respectively. There is no $TiCl_4$ or $TiO_2$ production plant in Thailand. Therefore, only PCDD/F contaminated in imported products are considered relevant. However, there is no EF for PCDD/F in these products. The PCDD/F release for this heading is, thus, set to zero.

**Caprolactam:**

There is one caprolactam production factory in Thailand, with an annual capacity of 130,000 tonnes. Based on the firm's EIA monitoring report [152], their process started from imported cyclohexanone with no $Cl_2$ or HCl involved in the process. In 2018, the firm was approved to produce about 75% of the required cyclohexanone feedstock. The approved cyclohexanone process is based on oxidation of cyclohexane using cobalt catalysts. In 2017, the firm discharged about 1.2 million liter of effluent water to receptors.

Since the approved process is based on reaction of cyclohexanone with ammonia and liquid oleum (fuming sulfuric acid), there is no $Cl_2$ or HCl involved in the process. The PCDD/F release for caprolactum is, thus, set to zero.

The estimated PCDD/F Emission from Source 7e is summarized in Table 3-116.

**Table 3-116: Estimated 2017 PCDD/F emission from Source Category 7e - other chlorinated and non-chlorinated chemicals**

| | 7e | **Other Chlorinated and Non-Chlorinated Chemical** Classification | **Activity Rate** (tonne) | **Emission (g TEQ/a)** Air | Water | Residue |
|---|---|---|---|---|---|---|
| **ea** | | **$TiCl_4$ and $TiO_2$** | **0** | **-** | **0** | **0** |
| | 1 | Low-End Technologies | 0 | - | 0 | 0 |
| | 2 | Mid-Range Technologies | 0 | - | 0 | 0 |
| **eb** | | **Caprolactam** | **0** | **0** | **0** | **-** |
| | 1 | Caprolactam | 0 | 0 | 0 | - |
| | | **Total** | | **0** | **0** | **0** |

### 3.7.6 Petroleum refining

#### Relevant activities

According to the Department of Energy Business (DOEB), Ministry of Energy, there are currently 6 petroleum refinery firms in Thailand, with combined capacity of 1.18 million barrel (190 million L) per day [153].

Based on DIW factory registration database, there are 12 refinery licenses (Factory Type 49) in 4 provinces, with combined investment of 136.5 billion Baht. These refineries produce petroleum products, mostly for domestic consumption. The amounts of petroleum products produced in Thailand in 2017 are presented in Table 3-117.

**Table 3-117: Amounts of petroleum products produced in Thailand in 2017**

| Petroleum Products | Amount Produced (Million Liter)[1] | Petroleum Fraction | Density (kg/L)[2] | Mass produced (Million tonnes) |
|---|---|---|---|---|
| Liquefied Petroleum Gas | 11,215 | 1.00 | 0.52 | 5.85 |
| Unleaded Gasoline RON 91 | 1,604 | 1.00 | 0.74 | 1.19 |
| Unleaded Gasoline RON 95 | 522 | 1.00 | 0.74 | 0.39 |
| Gasohol E10 RON 91 | 3,882 | 0.90 | 0.74 | 2.59 |
| Gasohol E10 RON 95 | 4,446 | 0.90 | 0.74 | 2.96 |
| Gasohol E 20 RON 95 | 1,794 | 0.80 | 0.74 | 1.06 |
| Gasohol E 85 | 381 | 0.15 | 0.74 | 0.04 |
| Jet fuel | 7,434 | 1.00 | 0.72 | 5.33 |
| Kerosene | 1,970 | 1.00 | 0.80 | 1.58 |
| High Speed Diesel | 28,302 | 1.00 | 0.84 | 23.88 |
| Fuel oil | 5,878 | 1.00 | 0.93 | 5.44 |
| **Total** | **67,428** | | | **50.32** |

RON = Research Octane Number
*Data sources: [1] Department of Alternative Energy Development and Efficiency (DEDE)* [154] *,*
*[2] IEA Energy Statistics Manual* [82]

#### Emission factors

PCDD/F emissions from burning fossil fuels are already addressed in Source Group 3 and 5. Emissions to be addressed in this section are related to potential sources that have not been addressed, particularly coking units, catalytic reforming units and flares.

There is no PCDD/F data from petroleum refineries in Thailand. The emission estimates for this source category relies on UNEP-defined EFs as summarized in Table 3-118.

The emissions are mainly from two sources: flares and production processes. EFs for flares accounted for PCDD/F from burnings of blow-down and waste gases in routine operations while EFs for production processes include emissions from 3 sources:

- Catalytic reforming units where there are potential releases of PCDD/F from catalyst regeneration processes. The UNEP EF into air is prescribed on tonne oil basis while EF into residue is based on tonne of sludge from separator of catalytic reforming unit
- Coking units with a focus on PCDD/F emissions from coking process that uses heat to thermally crack heavy hydrocarbons
- Refinery-wide wastewater treatment. This heading accounted for PCDD/F in final wastewater effluent from the refinery.

**Table 3-118: PCDD/F emission factors for petroleum refining**

| | **Petroleum refining** | | | **Emission Factors (µg TEQ/unit)** |
|---|---|---|---|---|
| | Classification | Air | Water | Residue |
| 1 | Flares (per TJ fuel burned) | 0.25[1] | 0 | No data |
| 2 | Production processes (per tonne oil) | | | |
| a | Catalytic reforming unit | 0.02[3] | 0 | 14[2] |
| b | Coking unit | 0.4[3] | 0 | No data |
| c | Refinery-wide wastewater treatment | No data | 5[4] | No data |

[1]: Per TJ fuel burned, [2]: Per tonne residue, [3]: per tonne oil, [4]: pg TEQ/Liter

## Activity rates

**Flares:**

Based on data from the Global Gas Flaring Reduction Partnership (GGFR) [34], Thailand burned about 372 million $m^3$ of flare gases in 2017, which amounted to 13,300 TJ if assuming that these are producer gases.

**Table 3-119: Estimated amounts of flare gas from petroleum refining**

| **Year** | **Flare Gas ($Mm^3$)[1]** | **ktoe[2]** | **TJ** |
|---|---|---|---|
| 2013 | 429 | 366 | 15,337 |
| 2014 | 395 | 337 | 14,122 |
| 2015 | 427 | 365 | 15,266 |
| 2016 | 403 | 344 | 14,408 |
| 2017 | 372 | 318 | 13,300 |

[1]: Data from GGFR, [2] Assumed burning producer gas

**Catalytic reforming units:**

The Petroleum Institute of Thailand (PTIT) reported combined production of reformate/platformate of 4 major refineries at 4,041,000 tonnes in 2017 [155]. Based on firms' EIA assessment reports, two other refineries also have catalytic reforming units, but there is no information on the amounts

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[34] Global Gas Flaring Reduction Partnership, https://www.worldbank.org/en/programs/gasflaringreduction#7, last access September 1, 2019

of oil used in these reforming units. To compensate for the possible missing values, a conservative estimate of 4,100,000 tonnes is assumed.

Sludge from catalytic reforming units could not be separated from waste from other sources. An estimated amount of 100 tonnes is made based on the amount of spent catalysts reported in firms' EIA assessment reports.

**Coking units:**

Based on information from firms' EIA assessment reports and MoEN's energy balance statistics, there was no coke produced from Thai petroleum refineries in 2017.

**Refinery wide wastewater treatment:**

Based on information from all 6 refineries' EIA reports, the combined amount of effluent water was about 8.2 million $m^3$/year.

#### Releases of dioxins and furans

The estimated emissions of PCDD/F from petroleum refining in 2017 are shown in Table 3-120.

**Table 3-120: Estimated 2017 emissions of PCDD/F from Source Category 7f - petroleum refining**

| **7f** | **Petroleum refining** | **Activity Rate** | | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|---|
| | Classification | | Air | Water | Residue | Subtotal |
| 1 | Flares (per TJ fuel burned) | 13,300 TJ[1] | **0.003** | | | **0.003** |
| | Production processes (per tonne oil) | | **0.082** | | **0.001** | **0.083** |
| 1 | Catalytic reforming unit | 4,100,000 tonnes oil[2] | 0.082 | | | 0.082 |
| | Catalytic reforming unit | 100 tonnes spent catalyst[2] | | | 0.001 | 0.001 |
| 2 | Coking unit | 0[2] | 0 | | | |
| 3 | Refinery-wide wastewater treatment | 8,200 million liters[2] | | 0.041 | | **0.041** |
| | Total Petroleum refining | | **0.085** | **0.041** | **0.001** | **0.127** |

Data Source

[1]: Global Gas Flaring Reduction Partnership (GGFR)),

[2]: EIA reports from 6 relevant petroleum refineries

### 3.7.7 Textile production

#### Relevant activities

The textile and apparel industry in Thailand encompasses the entire textile value chain, from fibers in the upstream, to the finished clothing products in the downstream. With more than 1,150 registered factories in 42 provinces, the textile industry contributes to more than 113,000 jobs and about 96 billion baht in investment [19].

Thai textile industry is an established industry. Average textile factories have been in business for over 24 years. Although most of the factories are SMEs, the top 150 firms' combined capitals contribute to about 80% of all investment in this industry. Samut Prakarn, Samut Sakorn, Nakhon Pathom are the top 3 provinces with highest number of activities, both from investment and employment perspectives. According to the Thai

Textile Institute (THTI) [156], Thailand's synthetic fiber production ranks 9th and 5th globally for polyester and acrylic fibers, respectively.

Textile production processes can be a potential source of PCDD/Fs. If fibers or materials used for finishing are contaminated, PCDD/F can be transferred to wastewater, sludge, and textile product.

## Emission factors

Although Thailand is a hub for textile products, this study finds no data related to PCDD/F in textile production processes or products in Thailand.

Moreover, due to limited data, UNEP also had difficulty deriving EFs for textile production for the Toolkit and only was able to provide EF for PCDD/F in products, as shown in Table 3-121.

The Toolkit classifies textile production plants into 3 classes based on the type of 'technology' employed by the plants with an emphasis on 'BAT technology' which is defined as "*textile technology that does not involve either formation of PCDD/PCDF or transfer from another vector*".

**Table 3-121: PCDD/F emission factors for textile production**

| 7g | Textile plants (per tonne textile) Classification | Concentration in Product (µg TEQ/t) |
|---|---|---|
| 1 | Low-End Technologies | 100 |
| 2 | Mid-Range, non-BAT Technologies | 0.1 |
| 3 | High-End, BAT Technologies | Not applicable |

## Activity rates

There are several data sources for productivity of Thailand's textile industry. Unfortunately, sources that recorded data on weight (in ton) basis are limited. The inventory team found OIE database and import-export statistics as the only sources that provide physical-based information. However, some of the relevant headings were recorded in pieces which make it difficult to determine their weight in a consistent manner. Therefore, the scope of this study is limited to fibers and fabrics where products' weights can be estimated.

Based on OIE data [18], in 2017 Thailand produced about 86,000 tonnes of cotton yarn, 125 million meters of cotton-based fabrics and 452 million meters of polyester-based fabrics. The estimated amounts of textile produced (in tonne) in 2017 are given in the Table 3-122, with the total amount estimated at about 512,000 tonnes.

According to Thai Customs import-export statistics (Table 3-123), Thailand imported about 776,000 tonnes and exported 1.13 million tonnes of relevant yarns and fabric products in 2017. When taking into account the amount of locally produced fibers and fabrics, the net amount of products remaining in the country (and consequently transformed into parts of other products) was about 155,000 tonnes. This figure appears to be an underestimation considering the fact that the synthetic fibers output in 2017 reported was lower than reported productivity of just one factory.

According THTI [156], in 2016 Thailand was ranked 9th and 5th largest producer for global polyester and acrylic fibers, respectively. THTI estimated synthetic fiber output in 2016 at approximately 900,000 tonnes. Taking the THTI estimated synthetic fiber productivity into account, assuming the same output for 2017, the net balance for 2017 sums up to approximately 890,000 tonnes.

**Table 3-122: Estimated amount (tonne) of textile produced in 2017**

| TSIC | product | production[1] | unit | Amount* (tonne) |
|---|---|---|---|---|
| 13112 | Cotton yarn | 86,079 | t | 86,079 |
| 13113 | Synthetic fibers | 161,995 | t | 161,995 |
| 13121 | Fabric (Cotton) | 125,416,352 | m | 57,340 |
| 13122 | Fabric (Polyesters & Others) | 451,861,209 | m | 206,591 |
|  | Total |  |  | 512,005 |

(*): Assumed Width= 72” and average density of 250 $g/m^2$
*[1] Data from OIE*

**Table 3-123: Estimated mass balance of relevant textile products in 2017 (tonne)**

| HS Codes | Product | Import[1] | Produced[2] | Export[1] | Net |
|---|---|---|---|---|---|
| 5201~5206 | Cotton yarns | 300,475 | 86,079 | 53,036 | 333,518 |
| 5207~5212 | Cotton Fabrics | 30,994 | 57,340 | 45,739 | 42,595 |
| 5401~5406, 5501~5511 | Man-made filaments | 257,780 | 161,995* | 804,741 | -384,966 |
|  |  |  | (900,000[3]) |  | (353,039) |
| 5407~5408, 5512~5516 | Woven fabrics of artificial filament | 122,432 | 168,196* | 85,434 | 205,194 |
| 56~58 | Others | 64,090 | 38,395* | 143,548 | -41,063 |
|  | **Total** | **775,771** | **512,005** | **1,132,498** | **155,278** |
|  |  |  | **(1,043,419)** |  | **(893,283)** |

*: Estimated based on average density of 250 g/m2, and excluding amount recorded in pieces unit
Numbers in parenthesis represent alternative scenario
*Data sources: [1] Thai Customs, [2] OIE, [3] THTI estimates*

**Classification:**
UNEP Toolkit classifies textile industry based on technology used in production with respected to BAT/BEP. To minimize dioxin in products, the BAT is to eliminate the uses of dioxin-contaminated chemicals in the production chains. Particularly, the Toolkit and BAT/BEP guideline identify two high-risk organochlorine chemicals; PCP and chloranils (CAS No 118-75-2). These chemicals were banned in Thailand 15-20 years ago (see Source Category 7d). Additionally, other mentioned organochlorines such as lindane and chloronitrofen (CNP, CAS No. 2836-77-7) were also banned or restricted with no record of any request for registration.

Textile products are expected by global customers to meet global environment and chemical Safety (ECS) requirements. Most export-oriented firms in Thailand declare that their products comply with most relevant regulations, such as EU REACH requirements on substances restriction (Annex XVII) and communication of substances of very high concerns (SVHC). PCP and several other C.I. Direct pigments are among the listed substances.

ECS requirements, particularly REACH, have become the new norm for global products' supply chains for almost 10 years. It can be anticipated that firms who can continue to supply products to global markets have put in place some control measures to address substances within these global ECS lists. A Search on EU RAPEX[35] alert for POPs-related non-compliance products (such as PCP or SCCPs) from Thailand did not yield any result, which further confirms this observation.

Since there is no data at the national level for the ratio of firms with and without BAT technology in place in Thailand, a rough ratio of 80:20 is assumed for both natural and synthetic fibers.

Moreover, although relevant chemicals (PCP and chloranils) are not expected to be available in general market, contaminated products (particularly cotton fabrics and yarns) may still be imported. For preliminary assessment purpose, the amount of relevant products produced with low-end technologies was estimated at 1% of the total activity rate.

### Releases of dioxins and furans

The estimated emissions of PCDD/F from textile production in 2017 are shown in Table 3-124.

It should be noted that this result should be interpreted with caution because, due to lack of EFs as mentioned above, it does not yet account for potential PCDD/F formations and releases to other vectors.

**Table 3-124: Estimated 2017 emissions of PCDD/F from Source Category 7g - Textile production**

| 7g | Textile Products Classification | Activity Rate (tonne)[1)] | Emission (g TEQ/a) Product |
|---|---|---|---|
| 1 | Low-End Technologies | 9,000 | 0.900 |
| 2 | Mid-Range, non-BAT Technologies | 171,000 | 0.017 |
| 3 | High-End, BAT Technologies | 720,000 | 0 |
|  | **Total Textile Products** | **900,000** | **0.917** |

1): numbers rounded to 3 significant figures for legibility.

### Uncertainty

The level of confidence for activity rate is low due to lack of appropriate data at the national level and exclusion of activities that were recorded in different units.

Due to the low level of confidence for the emission factors assigned for all classes and due to the lack of information on factory classification, the information provided in Table 3-124 should be regarded as rough

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[35] https://ec.europa.eu/consumers/consumers_safety/safety_products/rapex/alerts/?event=main.search&lng=en

estimates.

**Worst-case scenario:**

If assuming that no textile factory in Thailand meets Class 3 specification (i.e., no factory can declare free of direct or indirect PCDD/F involvement), the emissions would be increased by 0.072 g, contributing to about 8% increase in overall emissions from this source category.

### 3.7.8 Leather refining

Relevant activities and emission factors

Thailand's leather and tannery industry is relatively small compared to the other industries studied in this source group. There are only 194 registered factories with combined investment of 7.8 billion baht and employment of about 7,200 positions [19]. Only 3 firms are not SMEs[36].

Chemicals used for tanning and finishing as well as incidental chemicals, such as organochlorine biocides in raw hides, have been identified as potential source of PCDD/F in the leather industry. PCDD/F can be anticipated to be released into air (via burnings of residues), wastewater and products. However, due to the lack of measurement data, UNEP Toolkit can only derive EF for PCDD/F carried over within products, as shown in Table 3-125, with a note for parties to note the quantities, method of treatment, fate of wastewater, wastewater sludge, and other solid wastes.

Particularly, UNEP classifies emissions from leather production into 2 classes: tanning with low-end and mid-range technologies. Except for the reference to BAT & BEP guideline, no other criteria are given to allow objective classification.

According to UNEP, BAT & BEP for leather industry includes good management practices, knowledge about raw materials and chemicals and, subsequently, eliminating the use of dioxin-contaminated chemicals in the production chains. It is also imperative to avoid burning of leather products and process residues to prevent PCDD/F formation.

Particularly, the Toolkit and BAT/BEP guideline identify two high-risk organochlorine chemicals; PCP and chloranils (CAS No 118-75-2). These chemicals were banned in Thailand 15-20 years ago (see Source Category 7d). Additionally, other mentioned organochlorines such as lindane and chloronitrofen (CNP, CAS No. 2836-77-7) were also banned or restricted with no record of any request for registration.

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[36] As defined by SME Promotion Act B.E. 2543 (2000): <200 employees and < 200 million baht of permanent assets.

### Table 3-125: PCDD/F emission factors for leather production

| 7h | Leather plants<br>Classification | Concentration in Product<br>(µg TEQ/t) |
|---|---|---:|
| 1 | Low-End Technologies | 1,000 |
| 2 | Mid-Range Technologies | 10 |

## Activity rates

According to information from Thai Tanning Industry Association (TTIA)[37], most (90%) of the tanneries in Thailand are based on bovine hides and skins. 80% of raw bovine hides used by the industry are imported. In 2017, the net amount of raw bovine hides imported was about 94,000 tonnes. So, the amount of bovine skins involved in the tanning activity is estimated at about 117,000 tonnes. The industry also imported about 70,000 tonnes of swine skins and negligible amount of sheep and lamps skins in 2017. Based on these data, the amount of relevant tannery products in 2017 is estimated at about 190,000 tonnes (see Table 3-126).

Since there is no PCP and chloranils allowed in the market, all refined leather produced in Thailand are allocated to Class 2.

For PCDD/F that could be embedded as contaminant in imported tanned hides, there’s no information available to enable products’ classification. Therefore, the inventory team opts to use country of origin as a preliminary indicator. Products imported from least developing countries or countries known to have produced or used PCP in the past [157] are allocated to Class 1, which totaled to about 1,000 tonnes for the year 2017.

### Table 3-126: Estimated mass balance of raw and tanned hides in 2017

| Product | HS Code | Detail | Import (t)[1] | Estimated local production (t)[2] | Export (t)[1] | Net (t) |
|---|---|---:|---:|---:|---:|---:|
| Raw Hides | 4101 | Bovine skins | 95,773 | 24,000 | 2,437 | 117,336 |
| | 4103 | Swine and reptile skins | 70,234 | 10,000 | 50 | 80,184 |
| | | **Total Raw hides** | **166,007** | **34,000** | **2,487** | **197,520** |
| Tanned Hides | 4104 | Bovine skins | 38,313 | 117,336 | 23,915 | 131,734 |
| | 4106 | Swine and reptile skins | 315 | 80,184 | 21,790 | 58,709 |
| | | **Total Tanned products** | **38,628** | **197,520** | **45,705** | **190,443** |

*Data sources: [1] trademap.com, [2] Estimated based on OIE data and information from TTIA*

## Releases of dioxins and furans

The estimated emissions of PCDD/F from leather production in 2017 are shown in Table 3-127.

It should be noted that this result does not include potential PCDD/F formations and releases in other vectors. High PCDD/F releases into other media, particularly wastewater, sludge, and air (from burning of process residues) can be anticipated and parties should note the quantities, method of treatment, fate of wastewater, wastewater sludge, and other solid

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[37] https://thaitanning.org/?lang=en, last accessed October 8, 2019

wastes from this industry. Unfortunately, such information is not available at this time.

**Table 3-127: Estimated emissions of PCDD/F from Source Category 7h-leather refining in 2017**

| **7h** | **Leather Plants**<br>Classification | **Activity Rate**<br>(tonne) | **Emission (g TEQ/a)**<br>Product |
|---|---|---|---|
| 1 | Low-End Technologies | 1,000 | 1.00 |
| 2 | Mid-Range, non-BAT Technologies | 190,000 | 1.90 |
| | **Total Leather Plants** | **191,000** | **2.90** |

Uncertainty

The confidence level for activity rates is medium to low due to lack of data at national level.

The confidence level for classification is low due to the lack of information related to the uses and, subsequently, the releases of PCDD/F-relevant chemicals for this industry. It is also not possible to estimate the extents of contamination of dioxin precursors in raw hides (biocides) and in dyes and pigments.

The confidence level for EFs rated by UNEP is low due to scarcity and lack of representativeness of data.

### 3.7.9 Summary

Thailand’s total PCDD/F emission profiles from Source Group 7 (Production and Use of Chemicals and Consumer Goods) during the year 2017 are summarized in Table 3-128 and Figure 3-17, where the emissions to product, water, and residue account for 90%, 5.6% and 4.4% of the total emission, respectively.

The main source for PCDD/F in products were from dioxin contamination in chlorinated chemicals, particularly, chlorinated paraffins and dioxazine pigments, and residuals in paper recovered from contaminated paper waste.

Relatively low values for PCDD/F emission into water and residue should be interpreted with caution. These values do not yet include releases from potential sources, such as textile and leather plants, due to absent of representative EFs. Therefore, releases from these potential sources should be confirmed via measurement data. Particularly, data related to quantities, method of treatment, fate of wastewater, wastewater sludge and other solid wastes should be recorded and analyzed.

**Table 3-128: Summary of 2017 estimated PCDD/F emission from Source Group 7: production and use of chemicals and consumer goods**

| 7 | Chemicals and Consumer Goods | Emission (g TEQ/a) | | | | | |
|---|---|---|---|---|---|---|---|
| | Source category | Air | Water | Land | Product | Residue | Subtotal |
| a | Pulp and paper mills | 0.04 | 0.12 | – | 9.10 | 0.22 | **9.48** |
| b | Chlorinated Inorganic Chemicals | 0.00 | 1.55 | – | 0.00 | 1.55 | **3.10** |
| c | Chlorinated Aliphatic Chemicals | 0.07 | 0.53 | – | 0.01 | – | **0.60** |
| d | Chlorinated Aromatic Chemicals | – | – | – | 23.45 | – | **23.45** |
| e | Other Chlorinated and Non-Chlorinated Chemical | – | 0 | – | – | 0 | **0** |
| f | Petroleum refining | 0.09 | 0.04 | – | 0 | 0.00 | **0.13** |
| g | Textile plants | – | – | – | 0.93 | – | **0.93** |
| h | Leather plants | – | – | – | 2.90 | – | **2.90** |
| | **Total Chemicals and Consumer Goods** | **0.19** | **2.23** | **–** | **36.37** | **1.76** | **40.56** |

Note: “–” indicates “No Data” according the Toolkit (no EF available)

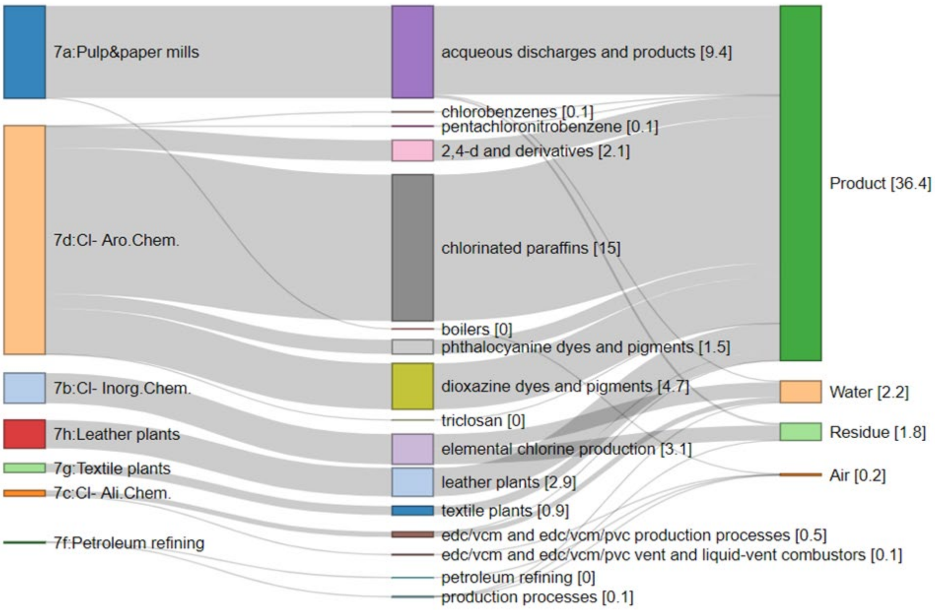

**Figure 3-17: Summary of 2017 PCDD/F emissions from Source Group 7: production and use of chemicals and consumer goods [unit: g TEQ/a]**

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## Annex 5. Supporting information for Source Group 7

### Table 3-129: Comparison of activity data from TPPIA and OIE datasets (units: ADt & tonnes)

| Product | Dataset | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|
| Pulp | OIE | 880,788 | 835,343 | 824,107 | 799,428 | 853,861 | 817,719 |
| | TPPIA | 1,135,000 | 1,107,000 | 1,131,000 | 1,242,000 | 1,137,000 | 1,231,000 |
| | Ratio | 0.78 | 0.75 | 0.73 | 0.64 | 0.75 | 0.66 |
| Kraft Paper | OIE | 2,187,465 | 2,138,892 | 2,192,449 | 2,169,530 | 2,271,439 | 2,390,785 |
| | TPPIA | 2,534,000 | 2,548,000 | 2,635,000 | 2,621,000 | 2,726,000 | 3,014,000 |
| | Ratio | 0.86 | 0.84 | 0.83 | 0.83 | 0.83 | 0.79 |
| Paperboard | OIE | 276,726 | 284,270 | 305,604 | 300,258 | 321,404 | 348,235 |
| | TPPIA | 420,000 | 403,000 | 399,000 | 379,000 | 416,000 | 430,000 |
| | Ratio | 0.66 | 0.71 | 0.77 | 0.79 | 0.77 | 0.81 |
| Writing Paper | OIE | 912,657 | 878,527 | 816,829 | 780,129 | 738,291 | 692,925 |
| | TPPIA | 1,230,000 | 1,194,000 | 1,126,000 | 1,162,000 | 1,353,000 | 1,140,000 |
| | Ratio | 0.74 | 0.74 | 0.73 | 0.67 | 0.55 | 0.61 |

### Table 3-130: HS Codes used for paper products mass balance calculation

| Class | HS Codes |
|---|---|
| Kraft Paper | 48041100, 48041900, 48042110, 48042190, 48042910, 48042990, 48043110, 48043130, 48043140, 48043150, 48043190, 48043910, 48043920, 48043990, 48044110, 48044190, 48044210, 48044210, 48044290, 48044910, 48044990, 48045110, 48045120, 48045130, 48045190, 48045210, 48045290, 48045910, 48045990, 48051100, 48051910, 48051990, 48052400, 48052510, 48052590, 48053010, 48053090, 48059110, 48059120, 48059190, 48059210, 48059290, 48059310, 48059320, 48059390, 48070000, 48081000, 48084000, 48089020, 48089030, 48089090, 48103130, 48103190, 48103290, 48103930, 48103990, 48191000, 48192000, 48193000, 48194000, 48195000, 48196000, 48221010, 48221090, 48229010, 48229090 |
| Newspapers | 48010010, 48010010, 48010010, 48010011, 48010012, 48010013, 48010014, 48010021, 48010022, 48010023, 48010024 |
| Paperboard | 48103290, 48103930, 48103990, 48109240, 48109290, 48109940, 48109940, 48109990 |
| Sanitary Paper | 48030030, 48030090, 48181000, 48182000, 48183010, 48183020 |
| Specialty Paper | 48054000, 48055000, 48061000, 48062000, 48063000, 48064000, 48111020, 48111090, 48114120, 48114190, 48114920, 48114990, 48115131, 48115139, 48115191, 48115199, 48115920, 48115941, 48115949, 48115991, 48115999, 48116020, 48116091, 48116099, 48119041, 48119042, 48119049, 48119091, 48119092, 48119099, 48120000, 48131000, 48132000, 48139010, 48139090, 48142010, 48142090, 48149000, 48185000, 48189000, 48211010, 48211090, 48219010, 48219090, 48232010, 48232090, 48234021, 48234029, 48234090, 48236100, 48236900, 48237000, 48239010, 48239020, 48239030, 48239040, 48239051, 48239059, 48239060, 48239070, 48239091, 48239092, 48239094, 48239095, 48239096, 48239099 |
| Writing Paper | 48021000, 48022010, 48022090, 48024010, 48024090, 48025411, 48025419, 48025421, 48025429, 48025430, 48025440, 48025450, 48025490, 48025520, 48025540, 48025550, 48025561, 48025561, 48025569, 48025570, 48025590, 48025620, 48025639, 48025641, 48025649, 48025650, 48025690, 48025690, 48025711, 48025719, 48025729, 48025790, 48025821, 48025829, 48025839, 48025891, 48025899, 48026130, 48026140, 48026159, 48026191, 48026199, 48026210, 48026220, 48026231, 48026239, 48026299, 48026911, 48026919, 48026920, 48026991, 48026999, 48092000, 48099010, 48099090, 48101310, 48101319, 48101391, 48101399, 48101411, 48101419, 48101499, 48101910, 48101991, 48101999, 48102210, 48102291, 48102299, 48102299, 48102910, 48102991, 48102999, 48102999, 48162010, 48162090, 48169010, 48169020, 48169030, 48169040, 48169050, 48169090, 48171000, 48172000, 48173000, 48201000, 48202000, 48203000, 48204000, 48205000, 48209000 |

**Table 3-131: Limits and monitoring results for emission to air from EDC/VCM/PVC production**

| Parameter | Location | Applicable Limits (Thai) | Frequency | Monitoring Results | EU BAT 2017[8] | Location | Frequency |
|---|---|---|---|---|---|---|---|
| Particulate (TSP) | Stack | 35[2] mg/$Nm^3$ (7% $O_2$) | Once every 6 month* | B:1.2 [ND-8.9] [6] | - | - | - |
| NOx | Stack (Crackers & Incinerators) | 150[2] mg/$Nm^3$(7% $O_2$) | Once every 6 month* | A: 35.2 [13.5-39] [7]<br>B: 30.5 [11.7-55.3] [6] | 50-100 mg/$Nm^3$ ($3\%_{O2}$) | EDC cracker furnace | daily average |
| Cl2 | Stack | 0.5- 24[5] mg/$Nm^3$ (7% $O_2$) | Once every 6 month* | A: 0.2 [0.017-0.39] [7] | <1-4 mg/$Nm^3$ (11%$O_2$) | EDC/VCM production | once every month |
| HCl | Stack | 30[1]-40[2] mg/$Nm^3$ (7% $O_2$) | Once every 6 month* | A: 0.6 [0.25-2.7] [7]<br>B: 0.9 [ND-6.5] [6] | 2-10 mg/$Nm^3$ (11%$O_2$) | EDC/VCM production | once every month |
| EDC | Stack | 5[1] mg/$Nm^3$ (7% $O_2$) | Once every 6 month* | A:ND [7]<br>B:ND [6] | | | |
| VCM | Stack | 5[1]- 20[3] mg/$Nm^3$ (7% $O_2$) | Once every 6 month* | A:0.38 [ND-0.73] [7]<br>B:ND [6] | | | |
| PCDD/F | Stack | 0.5[2] ng I-TEQ/$m^3$ (7% $O_2$) | Once a year | A:0.175 [0.154-0.195] [7]<br>B:0.139 [0.005-0.41][6] | 0.025-0.08 ng I-TEQ/$Nm^3$ (11%$O_2$) | EDC/VCM production | once every 6 month |

1) : ECVM/OSPAR BAT

2): DIW limits for emissions from waste incinerators

3): PCD early warning level

4): NEB ambient air quality standard

5): MNRE exhaust gas emission limits

6): 2017-2019 reports, data expressed at 7% $O_2$

7): 2018-2019 reports, data expressed at 7% $O_2$

8): Commission implementing decision (EU) 2017/2117 [140]

ND=Not detected

## Table 3-132: Limits and monitoring results for emission to water EDC/VCM/PVC production

| Substance | Location | Applicable Limits (Thai) | Frequency | Monitoring Results | EU BAT 2017 | Location | Frequency |
|---|---|---|---|---|---|---|---|
| Suspended solids (TSS) | Outlet of final WWTP | 50 mg /L$^{3)}$ | Monthly$^{2)}$ | A: ND<br>B: ND-27 | 10-30 mg/L | Outlet of pretreatment for solid removal | Every day |
| EDC | Outlet of final WWTP | 1 mg/L$^{1)}$ | Monthly$^{2)}$ | A: 0.003-0.097 mg/L<br>B: ND-0.013 mg/L | 0.1-0.4 mg/L | Outlet of WW stripper | Every day |
| | | | | | 0.01-0.05 g/t EDC purified | Outlet of final WWTP | Every month |
| VCM | Outlet of final WWTP | 1 mg/L$^{1)}$ | Monthly$^{2)}$ | A: 0.0075-0.04 mg/L<br>B: ND | <0.05 mg/L | Outlet of WW stripper | Every day |
| | | | | | | Outlet of final WWTP | Every month |
| Copper | Outlet of final WWTP | 2 mg /L$^{1)}$ | Monthly$^{2)}$ | A: -<br>B: 0.001-0.03 mg/L | 0.4-0.6 mg/L | Outlet of pretreatment for solid removal | Every day |
| | | | | | 0.04-0.2 g/t EDC produced by oxychlorination | Outlet of final WWTP | Every month |
| PCDD/F | Outlet of final WWTP | - | Once a year | A:-<br>B: 0.07 [0.067-0.073] ng TEQ/L | <0.8 ng I-TEQ/L$^{4)}$ | Outlet of pretreatment for solid removal | Once every 3 month |
| | | | | A:-<br>B: 0.2 µg I-TEQ/t EDC | 0.1-0.3 µg I-TEQ/t EDC produced by oxychlorination | Outlet of final WWTP | Once every 3 month |

1) EIA measures

2) In addition to routine quality control check

3) DIW quality of effluent water from factories [121]

4) 0.1 ng I-TEQ/L at final discharge [139]

### Table 3-133: Import and export of Hides and Leather in 2017

| HS4 | Description | Import | Export | Net |
|---|---|---|---|---|
| 4101 | Raw hides and skins of bovine; preserved but not tanned | 96,102 | 2,437 | 93,665 |
| 4102 | Raw skins of sheep or lambs; preserved, but not further prepared | 119 | 0 | 119 |
| 4103 | Raw hides and skins n.e.c in headings no. 4101, 4102; | 70,234 | 51 | 70,184 |
| | **Total Raw hides and skins** | **166,455** | **2,488** | **163,967** |
| 4104 | Tanned or crust hides and skins of bovine; not further prepared | 38,285 | 24,201 | 14,084 |
| 4105 | Tanned or crust skins of sheep and lambs; not further prepared | 186 | 6 | 180 |
| 4106 | Tanned or crust hides and skins of other animals; not further prepared | 316 | 22,189 | -21,873 |
| | **Total Tanned or crust hides and skins** | **38,787** | **46,396** | **-7,609** |
| 4107 | Leather further prepared after tanning or crusting of bovine | 7,296 | 18,174 | -10,878 |
| 4112 | Leather further prepared after tanning or crusting of sheep or lamb | 55 | 11 | 45 |
| 4113 | Leather further prepared after tanning or crusting of animals (other than ovine) | 59 | 6,347 | -6,288 |
| | **Total Leather further prepared after tanning** | **7,410** | **24,531** | **-17,121** |
| 4114 | Chamois (including combination chamois) leather | 24 | 2 | 22 |
| 4115 | Leather wastes | 387 | 477 | -90 |
| | **Total** | **213,063** | **73,894** | **139,169** |

**Part**
**3**

### Table 3-134: Import of Hides and Leather products by income class of producing countries

| Product | Income Class | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|
| Raw hides | High income | 95,279 | 105,301 | 125,870 | 153,544 | 175,602 |
| Raw hides | Upper middle income | 15,744 | 13,135 | 8,060 | 6,899 | 13,387 |
| Raw hides | Lower middle income | 5,354 | 3,739 | 2,438 | 5,564 | 4,716 |
| Raw hides | Low income | 137 | 50 | 280 | | |
| | **Total Raw hides** | **116,514** | **122,225** | **136,648** | **166,007** | **193,705** |
| Tanned | High income | 16,759 | 19,155 | 15,908 | 22,586 | 20,048 |
| Tanned | Upper middle income | 21,840 | 18,356 | 22,022 | 15,289 | 20,290 |
| Tanned | Lower middle income | 1,001 | 1,804 | 4,460 | 522 | 766 |
| Tanned | Low income | 177 | 138 | 74 | 415 | 304 |
| | **Total Tanned** | **39,777** | **39,453** | **42,464** | **38,812** | **41,408** |
| Leather | High income | 2,064 | 2,543 | 3,125 | 2,609 | 3,038 |
| Leather | Upper middle income | 4,853 | 2,285 | 3,098 | 3,811 | 3,043 |
| Leather | Lower middle income | 881 | 875 | 884 | 874 | 845 |
| Leather | Low income | 7 | 22 | | | |
| | **Total Leather** | **7,805** | **5,725** | **7,107** | **7,294** | **6,926** |

## 3.8 Source Group 8: Miscellaneous

The UNEP Toolkit considers 5 categories for this source group, as follows:

- Drying of biomass (8a)
- Crematoria (8b)
- Smoke houses (8c)
- Dry cleaning (8d)
- Tobacco smoking (8e)

The data sources used for the study of these categories are:

- Office of Industrial Economics (OIE) background data for the derivation of OIE industrial indices (as of 29 May 2019) [18], (“OIE statistics data”)
- Pollution Control Department (PCD), MNRE, “Thailand Municipal Waste Management Sites 2017” [5] (“PCD Waste Disposal Dataset”)
- PCD municipal waste water treatment dataset [116]
- Department of Industrial Works, M-Industry, “Factory Licensees Data” (last access February 2019)[19]
- DIW “Industrial Waste Transfer Manifest” [20]
- National Statistical Office (NSO) “Number of Total Deaths and Deaths in Hospital and Percentage of Deaths in Hospital per Total Deaths by Region and Province: 2008 - 2017” [158]
- NSO “Number of Congregations by Religion: 2008, 2011 and 2014” [159]
- Department of Fisheries, MOA, “Fisheries Statistics of Thailand 2017” [160]
- Tobacco Control Research and Knowledge Management Center (TRC) “Thailand’s tobacco consumption report 2019” (in Thai) [161]

### 3.8.1 Drying of biomass

Relevant activities

Drying of biomass refers to activities that involve using heat from combustions to dry woody or herbaceous biomass whereby combustion gases are brought into contact with the material being dried.

The UNEP Toolkit defines 3 classes for drying of biomass based on the level of contamination of the fuel used:

- Class 1: highly contaminated fuels (PCP-treated woods, used textiles, etc.)
- Class 2: moderately contaminated fuels
- Class 3: clean fuels

Thailand has already banned the import and use of PCP since 1990s.

Based on the inventory team's interview with the Royal Forest Department officers, there was no report of any widespread uses of this substance for wood preservation in Thailand prior to the ban. Thus, PCP-contaminated woods were irrelevant to the country in 2017.

As an agricultural country, drying is a common method for food preservation. As a country in the tropical zone, the simplest and cheapest method for Thai farmers to dry their crops is natural solar drying. To allow for better control of the drying and the hygiene of the products, the government has provided both technical and financial supports to boost public adoptions of solar dryers [162], [163] and solar-hybrid dryers [164], [165].

Apart from drying food crops, wood lumber drying to produce kiln-dry timbers, block rubber drying to produce technically specified rubber[38] (TSR), and latex sheet drying to produce ribbed smoked sheet rubber (RSS) are activities that potentially consume large amount of biomass. The amounts of RSS and TSR produced in Thailand in 2017 are summarized in Table 3-135.

**Table 3-135: Production of rubber sheets and rubber block in 2017**

| TSIC | Activity | Production (tonne)* |
|---|---|---|
| 22191.010 | Ribbed smoked sheet rubber | 413,767 |
| 22191.020 | Block rubber | 1,183,473 |

*Data Source: OIE 2017* [18]

Most wood-kilns in Thailand use hot air from boilers which is already considered in Source Group 3, therefore beyond the scope of this section. On the other hand, TSR production process uses hot air for drying. However, based on MoEN survey data in 2007 [166], DIW process flow data [167], and inventory team's telephone interviews with producers, most TSR producers use fossil fuels, mostly LPG, for their drying process. This activity is, again, considered beyond the scope of this section.

In the production of ribbed smoked sheet rubbers (RSS), biomass is used not only to provide hot air to dry the rubber sheets but also to provide smoke to protect the sheets from mold attack. This activity could also be considered within the scope of Source Category 8c (smoke houses).

Since Source Category 8c addresses the smoke generation and clean-up technology, it is considered more appropriate to considered RSS in the smoke houses category. Therefore, the inventory team concludes that there is no relevant activity for this source category (8a, drying of biomass).

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[38] commonly known block rubber in Thailand

#### Emission factors and releases of dioxins and furans

An overview of the UNEP Toolkit’s emission factors for drying of biomass is shown in Table 3-136.

Since the there is no relevant activity, emission from this source category is estimated at zero.

**Table 3-136: PCDD/F emission factors for drying of biomass**

| 8a | **Drying of biomass** | **Emission Factors** | | **Concentration** |
|---|---|---|---|---|
| | | (µg TEQ/t dry product) | | (µg TEQ/t ash) |
| | Classification | Air | Product | Residue |
| 1 | Highly contaminated fuel (PCP treated) | 10 | 0.5 | 2,000 |
| 2 | Moderately contaminated fuel | 0.1 | 0.1 | 20 |
| 3 | Clean fuel | 0.01 | 0.1 | 5 |

**Table 3-137: Estimated PCDD/F emission from drying of biomass in 2017**

| **8a** | **Drying of biomass** | **Activity rates** | **Emission (g TEQ/a)** | | | |
|---|---|---|---|---|---|---|
| | Classification | Tonnes Dry Products | Air | Product | Residue | Subtotal |
| 3 | Clean fuel | 0 | 0 | 0 | 0 | **0** |
| | **Total** | **0** | 0 | 0 | 0 | **0** |

#### Uncertainty

The confidence level for the activity rate is high. Although other minor biomass drying activities may exist and has not been accounted for, it is likely that they also are not operated in a well-defined oven or chamber, hence should be counted toward Source Group 6 - open burning.

### 3.8.2 Crematoria

#### Relevant activities

The UNEP Toolkit designates 3 classes for cremation based on the level of technology and contamination of fuel used during the cremation process:

- Class 1: no control (single chamber operating below 850°C)
- Class 2: medium control (>850°C) or open-air cremation
- Class 3: optimal control with sophisticated APCS

Cremation is a very common practice in Thailand, especially among Buddhists, which is approximately 95% of the country’s population. Thai crematoria are under the control of local administration (cities/SAOs) according to the Cemetery and Crematory Act, B.E. 2528 (1985 A.D.). Although most Buddhist funerary rites are performed in temples, cremation takes place at nearby crematoria which may situate inside the grounds of temples or, in rural region, at city-provided facilities.

#### Emission factors

An overview of the UNEP Toolkit’s emission factors for cremation is shown in Table 3-138.

In 2010, Hatfield Consultants in collaboration with the PCD summarized PCDD/F measurements in various vectors (mostly stack gas, but also cremated ash and bottom ash) from several Thai crematoria, starting in 2001 until then-new 2009 measurements [168]. The report showed that nearly all the stack gas emission concentrations were well above 0.5 ng TEQ/m$^3$ (7% $O_2$ and 25°C), with dual-chamber crematoria generally performing better than single-chamber ones. Data from Hatfield-PCD crematoria study along with PCD’s additional studies for 2-chambers crematoria are summarized in Table 3-149 in the Annex. From this data, the estimated PCDD/F emission into air is 30.3[range: 17-42] ng TEQ/Nm$^3$.

In 2005, the PCD conducted a questionnaire survey to collect emissions related information (such as amount of decorative items, fuel uses, exhaust abatement, etc.) from 582 crematoria from 574 cemeteries/temples in 72 provinces [169]. Based on data from this dataset, a burning time for diesel-fired crematoria is estimated at 86 [range: 75-97] minutes. Assuming an average volume of flue gases of 1,200 Nm$^3$/hr [170], the emission factor in to air for Thai 2-Chambers diesel fired crematoria is estimated to be around 52±23 µg TEQ/cremation (note[39]).

PCDD/Fs created during burning also transfer to residues, including fly ash, cremated ash and bottom ash. Based on the Hatfield-PCD data, the concentration in cremated ash and bottom ash are estimated to be 29.9± 9.4 and 704±149 pg TEQ/g, respectively. There is no information about PCDD/Fs in the fly ash in the Hatfield-PCD report possibly because most of the crematoria did not have APCs.

Assuming an average bone (dry) mass of 3 kg per person, the emission factor for PCDD/Fs in cremated ash is estimated at 0.09 [range: 0.03-0.14] µg TEQ/cremation. Unfortunately, the emission factor for PCDD/Fs in bottom ash cannot be estimated due to lack of information about the amount of ashes generated.

**Table 3-138: PCDD/F emission factors for crematoria**

| **8b** | **Crematoria** | | | | **Emission Factors (µg TEQ per cremation)** |
|---|---|---|---|---|---|
| | Classification | Air (UNEP) | Air (PCD) | Residue (UNEP) | Cremate Ash (PCD) |
| 1 | No control | 90 | No data | No data | No data |
| 2 | Medium control or open air cremations | 10 | 52 [29-75] | 2.5 | 0.09 [0.03-0.14] |
| 3 | Optimal control | 0.4 | No data | 2.5 | No data |

---

[39] 95% confidence interval

## Activity rates

The PCD classifies crematoria in Thailand into the following 4 types [171]:

- Type 1: single chamber, no combustion control, biomass fuel
- Type 2: single chamber, 400-700°C, fuel oil or diesel
- Type 3: 2-chambers, 700-900°C in 1st chamber, at least 850°C in 2nd chamber (1 second minimum residence time), diesel or natural gas
- Type 4: 2-chambers, 700-900°C in 1st chamber, at least 1,000°C in 2nd chamber (1 second minimum residence time), diesel or natural gas or electricity, and APCS

PCD's Type 1 and Type-2 crematoria fall into the definition of Class 1 of the Toolkit. Type 3 and Type 4 are consistent with Toolkit's Class 2 and Class 3, respectively.

A 2018 survey by the PCD found that none of Thailand's crematoria can be categorized at PCD's Type-4 [172]. As a result, the PCD has proposed a campaign to improve the performance of about 20 Bangkok crematoria to Type-4 specification by 2019.

Data from the NSO indicates that the number of 2017 total registered deaths in Thailand was 468,911 [173]. Cremation was then assumed at 95% to reflect Thailand's Buddhist population, yielding a total of about 450,000 cremations in 2017.

A further investigation into cities and municipalities with PCD's Type-3 crematoria [172] allows for an estimation of the number of cremations that are classified as Class 2 according to the Toolkit at 50,000. The remaining 400,000 cremations are therefore assigned to Class 1.

Note that open-air cremation is still performed but existing data does not allow for a meaningful differentiation. The activity rate for this type of cremation is, therefore, set to zero.

Releases of dioxins and furans

The estimated PCDD/F emissions from crematoria in Thailand in 2017 are summarized in Table 3-139. The estimation for the release of Class 2 crematoria into air is based on the emission factor derived from the Hatfield-PCD studies.

Emission from Thai 2-chambers diesel-fired crematoria is higher than the default value. Thailand is planning to upgrade all crematoria to meet at least PCD's Type-3 specification. If the performance of the new crematory furnaces meet the UNEP Class 2's performance, this effort can significantly (88%) reduce the emission. However, if the newly upgraded furnaces deliver the same performance as in the previously studied 2-chambers furnaces, the improvement will be minimal (39%).

It is anticipated that operators and maintenance also play significant roles on this lower-than-expected performance. Further investigation into the root cause of this deficiency is, therefore, needed to ensure that the upcoming efforts will deliver the desired outcome.

**Table 3-139: Estimated PCDD/F emission from crematoria in 2017**

| **8b** | **Crematoria** | **Activity Rate** | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|
| | Classification | (cremation) | Air | Residue | **Subtotal** |
| 1 | No control | 400,000 | 36.00 | No data | **36.00** |
| 2 | Medium control or open air cremations | 50,000 | 2.60* | 0.125 | **2.73** |
| 3 | Optimal control | 0 | 0 | 0 | **0** |
| | **Total** | **450,000** | **38.60** | **0.13** | **38.73** |

(*)Calculated using EF derived from site specific data (see Table 3-138)

(**) amount in cremated ash for Thailand is estimated at 0.004 g TEQ

Uncertainty

The level of confidence for the activity rate is high. The confidence level for emission factors is medium due to relatively old emission data and the contribution of other factors, such as operators and maintenance.

### 3.8.3 Smoke houses

Relevant activities

The UNEP Toolkit designates 3 classes for smoke houses based on the level of wood fuel contamination and the use of APCS:

- Class 1: contaminated fuels
- Class 2: clean fuels, no afterburner
- Class 3: clean fuels, afterburner

As already mentioned for source category 8a, PCP-contaminated woods are generally irrelevant to Thailand as PCP has been banned for import & use for several years. Thus, Class 1 is not applicable.

The main activities that belong in this source category include smoking of fish and sausages/processed meat and smoking of sheet rubbers to produce ribbed smoked sheet rubbers (RSS) as mentioned previously in

Source Category 8a (drying of biomass).

## Emission factors

An overview of UNEP Toolkit's emission factors for smoke houses is shown in Table 3-140.

**Table 3-140: PCDD/F emission factors for smoke houses**

| 8c | Smoke houses | Emission Factors (µg TEQ/t product) | Concentration (µg TEQ/t ash) |
|---|---|---|---|
| | Classification | Air | Residue |
| 1 | Contaminated fuels | 50 | 2,000 |
| 2 | Clean fuels, no afterburner | 6 | 20 |
| 3 | Clean fuels, afterburner | 0.6 | 20 |

## Activity rates

**Ribbed smoked sheet rubbers (RSS):**

Uncured rubbers are known to be vulnerable to mold (fungi) formation and must be dried and smoked as soon as possible. Smoking is typically done using waste woods from nearby rubber tree[40] farms.

OIE data indicates that Thailand produced approximately 413,000 tonnes of RSS (TSIC 22191.010) in 2017. Smoking can be done at the farm, nearby cooperatives, and rubber sheet production plants. Exhaust cleaning is required by the Factory Act for plants operating at industrial scale. Since there is no data available for the proportion of RSS smoked at the farms, a rough estimate of 20% of RSS is assumed to be smoked by farmers using basic ovens without exhaust abatement.

Based on DEDE's Energy Efficiency Index in Rubber Industry study [166], the specific energy consumption (SEC) for rubber sheet industry in 2007 was 3.82 MJ/kg, with the targeted benchmark value of 2.24 MJ/kg. The proportion of electricity to heat energy consumption for this industry was about 16:84. Since this study was done more than 10 years ago, it is assumed that factories had already upgraded their oven to meet the targeted benchmark energy consumption rate while farmers were till operating at the SEC level.

Rubber tree residues in Thailand have an average heating value of 13.96 MJ/kg [174], [175] and about 2.3% ash [44][45]. The amounts of wood required for drying and smoking 413,000 tonnes of RSS and the associated ashes are estimated as shown in Table 3-141.

**Table 3-141: Estimated amounts of wood consumed and ash generated from rubber sheet smoke houses in 2017**

| Player | Technology Level | RSS produced (t) | Biomass Used (t) | Ash Generated (t) |
|---|---|---|---|---|
| **Farmers** | SEC | 82,600 | 19,000 | 436 |
| **Firms** | Benchmark | 330,000 | 44,500 | 1,020 |

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[40] Hevea brasiliensis

**Smoked fish and smoked sausages/meat:**
Department of Fisheries reported that in 2017 there were 27 fish smoking factories [160] with the amount of fish processed by smoking of about 622 tonnes [176].

According to OIE data [18], the 2017 production figure reported for hams and sausages (TSIC 10131 and 10132) were about 43,300 tonnes. Half of this amount was assumed to have been smoked.

Based on the relatively stringent production control generally applied to industrial food processing, and on the Factory Act's requirements for exhaust cleaning, all industrial smoking houses are assigned to Class 3.

Smoking of fish and other meats at household scale exists, but is often done using basic setups in loosely confined environment. This activity is, therefore, assigned Source Category 3d, Class 5 (open fire three stone stoves) as suggested by the Toolkit.

Since there is no data for the amount of biomass consumed by smoke houses, the inventory team assumed the amount of heat (per unit product) was of the same order as RSS drying and smoking process with fish smoking requiring more energy than sausage smoking, as summarized in Table 3-142.

**Table 3-142: Estimated amounts of wood consumed by smoke houses and amount of ashes generated in 2017**

| Product | Amount Smoked (tonne) | Heat Required (GJ/t) | Wood Required (tonne) | Ash Generated (tonne) |
|---|---|---|---|---|
| **Sausage** | 21,600 | 1.88 | 2,920 | 67.10 |
| **Fish** | 622 | 3.21 | 143 | 3.29 |

## Releases of dioxins and furans

The estimated PCDD/F emissions from smoke houses in Thailand in 2017 are summarized in Table 3-143.

**Table 3-143: Estimated PCDD/F emission from smoke houses in 2017**

| | **Smoke houses** | | **Activity Rate** | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|---|
| | Classification | Tonne Product | Tonne Ash | Air | Residue | Subtotal |
| 1 | Contaminated fuels | 0 | | 0.000 | 0.000 | 0.000 |
| 2 | Clean fuels, no afterburner | **82,600** | **436** | **0.496** | **0.0087** | **0.504** |
| | Smoked RSS | 82,600 | 436 | 0.496 | 0.0087 | 0.504 |
| 3 | Clean fuels, afterburner | **352,222** | **1,090** | **0.211** | **0.022** | **0.232** |
| | Smoked RSS | 330,000 | 1,020 | 0.198 | 0.0204 | 0.218 |
| | Fishes | 622 | 3.3 | 0.000 | 0.0001 | 0.000 |
| | Sausages | 21,600 | 67.1 | 0.013 | 0.001 | 0.014 |
| | | **434,822** | **1,526** | **0.707** | **0.031** | **0.737** |

## Uncertainty

The activity data for smoked sausages may have been overestimated due to the fact that this product is usually cooked before smoking and does not require heating to dryness.

Unlike typical smoke houses for foodstuffs where, according to the UNEP Toolkit, wet scrubbers are not used and no discharge to water occurs, smoke chambers for RSS do have wet scrubbers and, thus, discharge to water can be anticipated.

### 3.8.4 Dry cleaning

Relevant activities

The UNEP Toolkit defines 2 classes for dry cleaning based on the level of technology and contamination during the dry cleaning process:

- Class 1: heavy textiles, PCP-treated, etc.
- Class 2: normal textiles

As already mentioned for previous source categories, PCP is generally irrelevant to Thailand as its import & use has been banned for several years. Thus, Class 1 is not considered here.

The inventory team found 22 dry-cleaning factories registered in 2017. Smaller dry-cleaning businesses (with annual income below 1.8 million baht) were not required to register, however.

Emission factors

An overview of the UNEP Toolkit's emission factors for dry cleaning is shown in Table 3-144. The only PCDD/F release vector considered for this source category is in the residue of solvent recovery (distillation) process.

**Table 3-144: PCDD/F emission factors for dry cleaning**

| **8d** | **Dry cleaning** | **Concentration in distillation residue** |
|---|---|---|
| | Classification | (μg TEQ/t) |
| 1 | Heavy textiles, PCP-treated, etc. | 3,000 |
| 2 | Normal textiles | 50 |

Activity rates

Dry cleaning is an activity listed under M-Industry's factory type number 98 (laundry, dry cleaning, washing, ironing, or dyeing of textiles, carpets, and leathers.) Based on DIW waste transfer manifest data for 2017, a total waste from factory type 98 amounted to about 10,000 tonnes, as shown in Figure 3-18, with most of the waste sent to wastewater treatment plant (WWTP). To estimate for dry-cleaning distillation residue, residue from thermal processes (e.g., boilers) and residue sent to wastewater treatment and sorting were excluded, leaving only about 300 tonnes as the activity rate for dry-cleaning distillation residue.

**Figure 3-18: Waste from Factory Type 98**

### Releases of dioxins and furans

The estimated releases of PCDD/F from dry cleaning are presented in Table 3-145.

**Table 3-145: Estimated PCDD/F emission from dry cleaning in 2017**

| 8d | Dry cleaning | Activity<br>(tonne distillation residue) | Emission to residues<br>(gTEQ/a) |
|---|---|---|---|
| 2 | Normal textiles | 300 | 0.015 |
| | **Total** | **300** | **0.015** |

### Uncertainty

Due to the lack of waste specific data, the level of confidence for the activity rate is medium to low.

### 3.8.5 Tobacco smoking

### Emission factors

The UNEP Toolkit defines 2 classes for tobacco smoking. An overview of UNEP Toolkit's emission factors for tobacco smoking is shown in Table 3-146.

**Table 3-146: PCDD/F emission factors for tobacco smoking**

| 8e | **Tobacco smoking** | **Emission Factors (µg TEQ/million items)** | |
|---|---|---|---|
| | Classification | Air | Residue |
| 1 | Cigars | 0.3 | 0.3 |
| 2 | Cigarettes | 0.1 | 0.1 |

### Activity rates

Based on Thai Customs Data, 791 tonnes of cigars were imported in 2017. Assuming an average cigar weight of 10 grams yields a total of 79.1 million cigars imported.

According to report by Tobacco Control Research and Knowledge Management Center (TRC) [161], 1.951 million packs of cigarettes were sold in 2018. Assuming these cigarettes were all consumed in the country (no export), this sale figure translates to about 39,000 million items burned in 2018.

Releases of dioxins and furans

The estimated releases of PCDD/F from tobacco smoking are presented in Table 3-147

**Table 3-147: Estimated PCDD/F emission from tobacco smoking in 2017**

| **8e** | **Tobacco smoking** | **Activity Rate** | **Emission (g TEQ/a)** | | |
|---|---|---|---|---|---|
| | Classification | (Million item) | Air | Residue | Subtotal |
| 1 | Cigar (per million items) | 79.1 | 2e-5 | 2e-5 | 4.7e-5 |
| 2 | Cigarette (per million items) | 39,000 | 0.0039 | 0.0039 | 0.0078 |
| | **Total** | | **0.004** | **0.004** | **0.008** |

## 3.8.6 Summary

The overall emissions from miscellaneous sources are summarized in Table 3-148 and Figure 3-19. As seen in the table, emission from crematoria is dominant for this source group. Crematoria were identified in the Thailand's 2006 inventory report as a potential source and actions had been taken to reduce the emission.

Comparing with the previous inventory, the ratio of Class 2 crematoria had increased from about 6% in 2004 to 11% in 2017. Nevertheless, the improvement appears moderate because there were differences in the EFs used for the estimation. Emissions from Class 2 crematoria in this report were estimated based on country-specific emission factors – made available as a result of efforts laid down by the previous NIPs.

The difference in country-specific EFs and UNEP suggested EFs points toward the interaction of other important factors particularly operators and maintenances. As Thailand is planning to upgrade all crematoria to meet at least PCD's Type-3 specification, it is crucial that responsible agencies put in place measures to ensure that the performance of the upgraded crematoria also meet at least UNEP's Class 2 performance.

**Table 3-148: Summary of estimated PCDD/F emissions from Source Group 8 - miscellaneous sources in 2017**

| **8** | **Miscellaneous** | **Emission (g TEQ/a)** | | |
|---|---|---|---|---|
| | Source category | Air | Residue | **Subtotal** |
| a | Drying of biomass | 0 | 0 | **0** |
| b | Crematoria | 38.60 | 0.125 | **38.73** |
| c | Smoke houses | 0.707 | 0.031 | **0.74** |
| d | Dry cleaning | 0 | 0.015 | **0.02** |
| e | Tobacco smoking | 0.004 | 0.004 | **0.01** |
| | **Total Miscellaneous** | **39.31** | **0.175** | **39.49** |

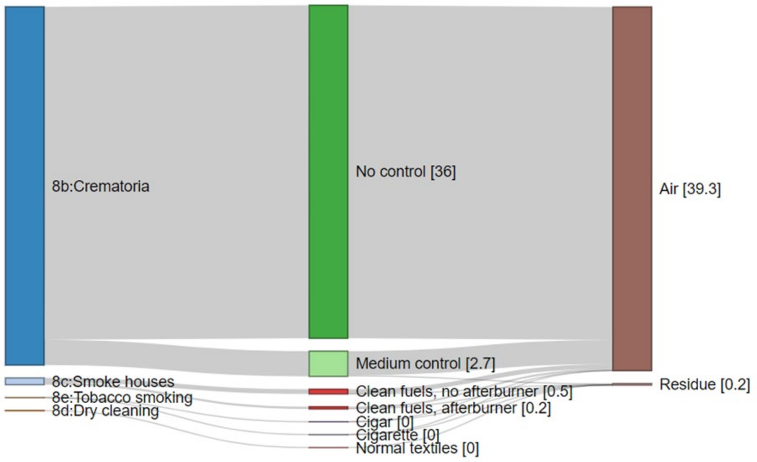


**Figure 3-19: Overview of PCDD/F emissions from Source Group 8 – Miscellaneous [unit: g TEQ/a]**

□□□

## Annex 6. Summary of PCDD/F emissions from the Hatfield-PCD Studies

**Table 3-149: Summary of PCDD/F emissions from the Hatfield-PCD Studies**

| Temple | Province | Year | Stack at 7% $O_2$ ng I-TEQ/$Nm^3$ | Stack at 11% $O_2$ ng I-TEQ/$Nm^3$ | Cremated Ash pg I-TEQ/g | Bottom Ash pg I-TEQ/g |
|---|---|---|---|---|---|---|
| **A1** | Bangkok | 2009 | 50.82 | 36.20 | 37.60 | |
| **A2** | Bangkok | 2009 | 82.62 | 58.84 | 33.50 | 997 |
| **B1** | Chiang Mai | 2009 | 100.11 | 71.30 | 11.70 | 367 |
| **B2** | Chiang Mai | 2009 | 273.78* | 195.00* | | 574 |
| **C1** | Bangkok | 2009 | 32.02 | 22.80 | | |
| **C2** | Bangkok | 2009 | 46.57 | 33.17 | 2.76 | |
| **D** | Bangkok | 2009 | 46.26 | 32.95 | 63.80 | |
| **E1** | Bangkok | 2009 | 12.39 | 8.82 | | 1,200 |
| **E2** | Bangkok | 2009 | 30.81 | 21.95 | | |
| **F** | Bangkok | 2009 | 7.98 | 5.68 | | 382 |
| **J** | Nonthaburi | 2011 | 15.76 | 11.22 | | |
| | **Results Summary**** | | 42.5± 9.0 | 30.3± 6.4 | 29.9± 9.4 | 704±149 |

I-TEQ=WHO2005 TEQ, (*) denote outlier, ** Bootstrap estimates with 10,000 replications

## 3.9 Source Group 9: Disposal/Landfill

The UNEP Toolkit considers disposal and landfill in 5 source categories as follows:

- Landfills, waste dumps and landfill mining (9a)
- Sewage/sewage treatment (9b)
- Open water dumping (9c)
- Composting (9d)
- Waste oil treatment (non-thermal) (9e)

Data sources for disposal/landfill-related activities are:

- PCD municipal solid waste disposal sites 2017 [5]
- PCD municipal waste water treatment 2017 [177]
- DIW Industrial Waste Transfer Manifest 2017 [30]

This report does not include the emission of PCDD/Fs from non-thermal treatment of waste oil because emission factors for this activity are not available in the Toolkit.

### 3.9.1 Landfills, waste dumps and landfill mining

This source category covers disposal (i.e., storage) of wastes in landfills, waste dumps, and open dumps. Landfills differ from waste dumps in the way they are constructed and contain wastes. Engineered landfills have liners and caps in place to contain wastes while open dumps typically have little to no barrier against the release of pollutants into the surrounding environment.

Emission factors

The UNEP Toolkit classifies activities within this source category into 3 classes based on the characteristics of the wastes being stored, namely:

- Class 1: Hazardous wastes,
- Class 2: Mixed wastes, and
- Class 3: Domestic wastes

This source category addresses only the PCDD/F releases from specific portions of wastes that are deposited into landfills and dump sites over a specific reference time period (i.e., not the releases from waste deposited beforehand or afterwards). In addition, to prevent double counting, Class 1 does not include the amounts of PCDD/Fs that are embedded inside the wastes (residues) associated with Source Groups 1 to 8, which are already accounted for as described in their respective sections. Rather, it addresses only the subsequent release of PCDD/Fs into leachate water. Classes 2 and 3 account for landfilling or dumping of waste (typically MSW) that may or may not contain hazardous components, and address PCDD/Fs both in leachate water and in residue (PCDD/Fs embedded in their respective waste materials).

An overview of UNEP Toolkit's emission factors for landfills, waste dumps, and landfill mining is shown in Table 3-150.

Table 3-150: PCDD/F emission factors for landfills, waste dumps and landfill mining

| **9a** | **Landfills, Waste Dumps and Landfill Mining** | **Emission Factors (µg TEQ/t waste disposed of)** | |
|---|---|---|---|
| | Classification | Water | Residue |
| 1 | Hazardous wastes | 5 | 0[2] |
| 2 | Mixed wastes | 0.5 | **5**[1] |
| 3 | Domestic wastes | 0.05 | 5 |

Note: [1] EF modified according to the recommendation of UNIDO-assigned project advisor

[2] Residue already counted in the waste-generating source groups (G1 to G8)

## Relevant activities and activity rates

**Hazardous waste to landfill:**

There are mainly 2 types of hazardous waste (HW): industrial hazardous waste (IHW), and household or municipal hazardous waste (HHW).

HHW includes electronic waste (e-waste), batteries, light bulbs, spray bottles, household chemicals containers, etc. End-of-life products with some economic values (such as e-waste or empty containers) can be sold to waste dismantlers or 'recycle shops' for small amounts of money. Small items or HHWs without monetary values are typically disposed of as municipal solid waste.

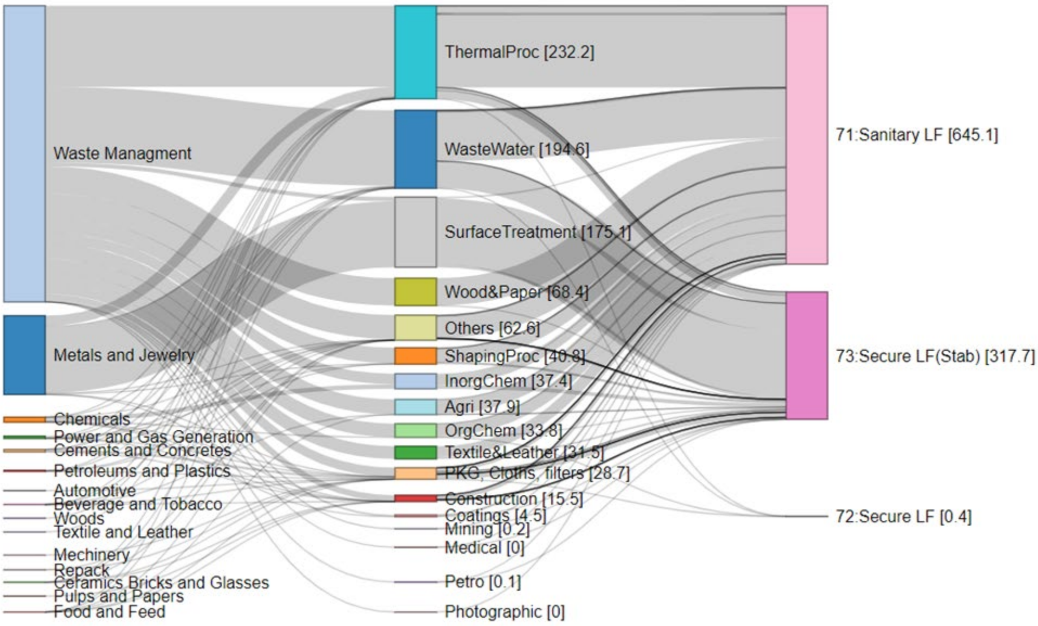
The PCD estimated that there were about 0.58 million tonnes of HHW in 2014 [3], about 65% were e-waste, with only 11 provinces having set up HHW collection centers. In 2015, there were 12 provinces with high (>4000 t/a) HHW generation rates. The National Municipal Waste Management Master Plan 2016-2021 acknowledged the problems and had set up plans to prevent HHW from being dispose of as MSW and, instead, to manage them properly. By 2017, all 7,852 SAO/cities were expected to provide drop-off stations within their communities and 10% of the HHW were expected to be properly managed. The percentage of the properly managed HHW is expected to increase to 30% by 2021.

For IHW, based on DIW Waste Transfer Manifest data 2017 [30], about 0.96 million tonnes of industrial hazardous waste were transferred to 3 different types of landfill, as summarized in Table 3-151. An overview of the waste producers by sectors, the associated M-Industry's classes of the wastes, and the final destinations of these wastes is presented in Figure 3-20. All these wastes are assigned to Class 1.

**Table 3-151: Industrial hazardous wastes (IHW) sent to landfills in 2017**

| Code | Treatment | Amount (t) |
|---|---|---|
| 71 | Sanitary landfill | 645,075 |
| 72 | Secure landfill | 375 |
| 73 | Secure landfill of stabilized and/or solidified wastes | 317,702 |
| | **Total** | **963,152** |

*Data source: DIW Industrial Waste Transfer Manifest, 2017* [30]



Unit: thousand tonnes

*[Data source: DIW Industrial Waste Transfer Manifest, 2017* [30]*]*

**Figure 3-20: Profiles of industrial hazardous wastes destined to landfills in 2017**

### Municipal solid waste (MSW):

Based on PCD's MSW disposal data [5], in 2017 there were 122 landfill sites in 63 provinces, disposing on average 188 tonnes MSW per day. All MSW landfill operations were rated 'proper' by the PCD.

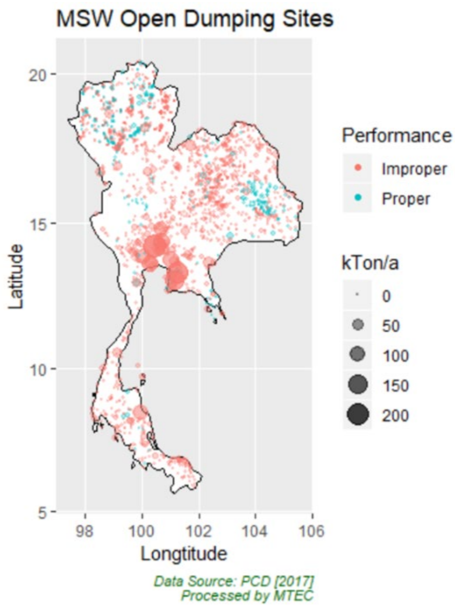


Figure 3-21: Distribution of open dump sites

On the other hand, as illustrated in Figure 3-21, 2,528 cities/SAOs in virtually every province dumped a combined total of about 5.2 million tonnes of wastes in 2017, of which 83% were into open dumps and the remaining 17% were into controlled dumps. All open dumps were considered ‘improper’ by the PCD. Controlled dumping was considered ‘acceptable’ if the dumping rate was kept below 50 tonnes/day [5].

Most open/controlled dump sites in rural areas were small. Controlled dump sites that were rated ‘acceptable’ were located mostly in Northern and Northeastern regions of the country. Open dump sites with large amounts of waste open dumped were mostly located in provinces adjacent to Bangkok and in the Eastern Seaboard.

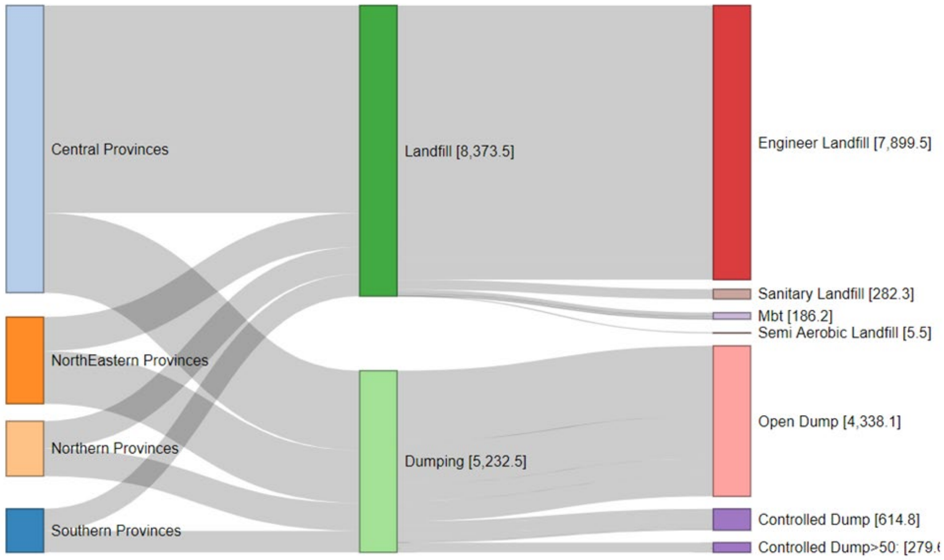
The classification of MSW landfilling and dumping in the Toolkit is defined based on whether or not the waste in question contains hazardous components. Assuming that waste generated in rural areas are mostly domestic (non-hazardous) waste, this inventory team proposes the use of 10 tonnes/site/day as the upper cut-off waste dumping rate to indicate whether a dump site is located in rural areas. That is, open and controlled dump sites with average loads below 10 tonnes/site/day are assigned to Class 3 (non-hazardous domestic wastes), while sites with higher loads are placed in Class 2 (mixed wastes). Similarly, landfilled MSW is assigned to Class 2 due to their relatively large daily loads. Table 3-152 illustrates details on Thailand’s MSW disposal and their classification.

A summary of the amounts of MSW destined to landfills and open dumps is shown in Table 3-152. More details of the flow of these wastes are illustrated in Figure 3-22.

**Table 3-152: Summary of MSW landfill and open dump operations**

| Treatment | PCD’s Rating | No of Sites | No of Province | Average (T/d/site) | Total (T/year) | Assigned Class |
|---|---|---|---|---|---|---|
| Landfill | Proper | 122 | 63 | 188 | 8,373,538 | 2: Mixed waste |
| Controlled dump | Proper | 467 | 41 | 3.6 | 614,832 | 3: Dom. waste |
|  | Improper | 6 | 5 | 128 | 279,575 | 2: Mixed waste |
| Open dump | Improper | 1,892 | 68 | 2.5 | 1,720,624 | 3: Dom. waste |
|  | Improper | 163 | 56 | 44 | 2,617,479 | 2: Mixed waste |
| Total |  | **2,650** | **73** |  | 13,606,048 |  |

*Data source: PCD Waste Disposal Report 2017* [5]



Unit: thousand tonnes

*Data source: PCD 2017* [5]

**Figure 3-22: Profiles for MSW disposed by landfilling and open dumping in 2017**

### Landfill mining and landfill re-habitation:

To the inventory team’s best knowledge, there has been no landfill mining project in operation in Thailand. However, the National MSW Management Masterplan 2016-2021 dictated the clean-up of existing ‘improper’ dump sites as well as the rehabitation/relocation of landfill sites [3], with an aim to fully clear up all ‘improper’ dump sites by the year 2019. PCD estimated there were about 102 sites with high potential for producing refuse-derived fuel (RDF) [3].

In the attempt to free up landfill spaces and clear up waste stockpiles, SAO/cities had approved several MSW landfill ‘rehabitation’ projects, usually operated by firms associated with cement kilns. The process involved using heavy machineries to sort out and collect combustible materials from the stockpiles, and deposit the residues either back to the original sites or into new landfill sites, depending on the situation. The collected combustible materials were typically transferred to nearby cement production plants for further processing before they could be used as alternative fuels for cement kilns.

The amount of combustible wastes recovered is already accounted for in Source Group 1 when considering incineration of waste to convert to energy (WTE). No other information, such as material flows and hazardous contents in the excavated wastes, is available to the inventory team to assess this source in more detail.

However, the Toolkit indicates: *“The quantity of PCDD/PCDF in landfills being excavated is site specific and needs to be individually assessed in each case. … The excavated wastes need to be treated in an environmentally sound manner as described in the BAT and BEP*

*Guidelines”,* and

*“For landfills having received specific wastes in the past, especially from the organochlorine industry or industries using elemental chlorine, site-specific PCDD/PCDF inventories need to be compiled (see source group 10)”*

To our best knowledge, there is no excavation project for hazardous waste landfills. However, through illegal dumpings, PCDD/F may be present in MSW landfills especially in areas near industrial sites. Therefore, the risk from excavation projects associated with these dump sites will need to be addressed as part of the upcoming action plans.

## Releases of dioxins and furans

The estimated PCDD/F emissions from landfills and waste dumps in Thailand in 2017 are summarized in Table 3-153.

The emissions are dominated by the releases into residues (87%). It should be noted that for MSW (Classes 2 and 3), the residue values do not really indicate releases, but rather storage of PCDD/F embedded within MSW. This value will become important when landfills are excavated. Therefore, care should be taken when considering excavating landfills suspected to contain PCDD/F-relevant residues (see Landfill Mining and Landfill Re-habitation section, above).

It should be noted also that actual hazardous wastes landfills do contain PCDD/F-relevant residues despite the estimated value of zero displayed in the table. As mentioned in the Emission Factors section above, this estimation sets emission from HW to zero to avoid double counting. In fact, almost all residues reported in Source Group 1 to 8 (about 400 g TEQ/a) will be stored in hazardous waste landfills. Therefore, care should be taken to keep track of the type and amount of waste deposited, especially hazardous waste landfills.

Although not a significant contribution, leachate water from landfills should also be taken into consideration due to fact that the monitoring data for PCDD/F in landfill leachates are still missing, making it difficult to assess the risks and appropriate mitigation measures.

Readers shall be cautious when interpreting emissions from LFs which are essentially storages of PCDD/Fs. The emission values conventionally reported in the unit g I-TEQ/year shall not be interpret as yearly emission from landfills as a whole but rather only from the portions that were deposited during the baseline year. When storages are piled up, emissions accumulate. Higher amount of PCDD/F in every pathway should be anticipated since, in reality, the entire mass stored within landfills contributes to the releases.

**Table 3-153: Estimated PCDD/F emission from landfills, waste dumps and landfill mining in 2017**

| **9a** | **Landfills, Waste Dumps and Landfill Mining** | **Activity Rate** | | | **Emission (g TEQ/a)** |
|---|---|---|---|---|---|
| | Classification | (tonne*) | Water | Residue | Subtotal |
| 1 | Hazardous wastes | 963,000 | 4.816 | 0[1] | **4.816** |
| 2 | Mixed wastes | 11,300,000 | 5.635 | 56.353[2] | **61.988** |
| 3 | Domestic wastes | 2,340,000 | 0.117 | 11.677 | **11.794** |
| | **Total** | **14,600,000** | **10.57** | **68.03** | **78.60** |

(*): Tonnes of waste disposed (rounded to 3 significant figures),

[1] Residues already counted in the waste generating source groups, [2] Estimated using revised EF (see Table 3-150)

Uncertainty

The level of confidence for activity rates is high due to the availability activity data from virtually every landfill and dump site. The confidence level for the class assignment for municipal waste LF, however, is given a medium due to unknown waste composition. Finally, the level of confidence for the EF is assigned a medium to low by the Toolkit.

**Worst-case scenario:**
Because Class 2 and Class 3 have been assigned the same EF for residues, the end results would not be affected very much if all the municipal wastes were to be assigned to Class 2 (contaminated with hazardous wastes). The amount of PCDD/F in leachates would increase by only 1g TEQ and the overall emission from this source category would increase by 1.3%, which can be considered insignificant when compared with the uncertainty from the emission factors.

### 3.9.2 Sewage and sewage treatment

Emission factors

PCDD/F in waste water may come from water run-off with atmospheric deposition of PCDD/Fs from combustion sources, water run-off from contaminated areas, or from washing of PCDD/F-contaminated items (such as clothes and textiles treated with contaminated biocides). PCDD/F may be formed if chlorine is used to disinfect treated effluent [37].

There is no data for PCDD/F from sewage treatment or sewage sludge in Thailand. The estimation of PCDD/F emissions from this source category therefore relies on the default EFs given by the UNEP Toolkit.

The UNEP Toolkit classifies sewage and sewage sludge treatment into 3 classes depending on the source of the sewage:

- Class 1: Mixed domestic and industrial inputs – for waste water sources where industrial effluents from PCDD/F-relevant sources are mixed into domestic waste water system
- Class 2: Urban and industrial inputs – for waste water from urban and industrial areas without specific potential to contain PCDD/Fs.
- Class 3: Domestic inputs – for waste water in remote areas with

no known PCDD/F sources and urban areas with only domestic inputs.

An overview of UNEP Toolkit's emission factors for sewage and sewage treatment is shown in Table 3-154.

**Table 3-154: PCDD/F emission factors for sewage and sewage treatment**

| **9b** | **Sewage/sewage treatment** | | **Emission factors** |
|---|---|---|---|
| | Classification | Water (pg TEQ/L) | Residue (µg TEQ/t dry matters) |
| 1 | Mixed domestic and industrial inputs | | |
| 1a | No sludge removal | 10 | NA |
| 1b | With sludge removal | 1 | 200 |
| 2 | Urban and industrial inputs | | |
| 2a | No sludge removal | 1 | NA |
| 2b | With sludge removal | 0.2 | 20 |
| 3 | Domestic inputs | | |
| 3a | No sludge removal | 0.04 | NA |
| 3b | With sludge removal | 0.04 | 4 |

## Activity rates

Direct discharges of effluent water from factories into domestic/municipal sewer systems are not allowed without prior treatment to meet M-Industry's Notification on Standards for Effluent Water from Factories, B.E. 2560 (2017)[41][121]. This notification prescribes limits on 16 key wastewater parameters[42] which include free chlorine and pesticides. Therefore, to our best knowledge, there is no source for Class 1 sewage water.

There is also a requirement from MNRE's Ministerial Regulation on the Definition of Rules, Methods, and Forms for Collecting Statistics and Data, Detail and Summary Record of Sewer Treatment Systems, B.E. 2555 (2012) for all business operators (except SMEs) who discharge water to public water body, to keep track of the performance of their sewage treatment system and report all the required data to local authorities every month.

According to data obtained from PCD [177], Thailand has 92 operational municipal sewage management plants (SMP) in 56 provinces, treating 522.5 Mm$^3$/year. The treatment processes employed by LAOs/cities were as follows:

| **Technology** | **No. of sites** | **Proportion of total MWW treated** |
|---|---|---|
| Activated Sludge (AS) | 13 | 59.0% |
| Aerated Lagoon (AL) | 14 | 10.8% |
| Oxidation Ditch (OD) | 19 | 10.1% |

---

[41] Supersedes the B.E. 2539 (1996) version

[42] 1.pH, 2.Temperature, 3.Color, 4.Total Dissolved Solids (TDS), 5.Total Suspended Solids, 6.BOD, 7.COD, 8.Sulfide, 9.Cyanides 10.Oil and Greases, 11.Formaldehyde, 12.Phenols, 13.Free Chlorine, 14.Pesticides, 15.TKN (Total Kjeldahl Nitrogen), 16. Heavy metals

| | | |
|---|---|---|
| Stabilization Pond (SP) | 36 | 9.6% |
| SP+AS | 1 | 3.5% |
| SP+ Constructed Wetland | 2 | 3.4% |
| Others | 7 | 3.6% |

Water discharged from these sewage treatment plants must comply with the MNRE's Notification on Quality of Water Discharged from Municipal Sewage Treatment Plants, B.E. 2553 (2010) [178]. Parameters to be controlled include pH, BOD, suspended solid, fat, oil and grease, total nitrogen, and total phosphorus.

According to PCD, these plants treated only domestic inputs (from city sewage pipes network), and there was no sludge removal. All these treatment plants were in each province's central area. Therefore, activities related to these plants are assigned to Class 2.

Based on data obtained from PCD, there is no municipal sewage water treatment plant in remote areas. Hence, activity rate for Class 3 is estimated at zero.

## Releases of dioxins and furans

The estimated PCDD/F emissions from sewage and sewage treatment in Thailand in 2017 are summarized in Table 3-155.

**Table 3-155: Estimated PCDD/F emission from sewage/sewage treatment in 2017**

| | **Sewage/sewage treatment**<br>Classification | **Activity Rate**<br>($m^3$)* | Emission (g TEQ/a)<br>Water | <br>Residue | <br>**Subtotal** |
|---|---|---|---|---|---|
| 1 | Mixed domestic and industrial inputs | 0 | 0.000 | 0.000 | **0** |
| 1a | No sludge removal | 0 | 0.000 | | 0 |
| 1b | With sludge removal | 0 | 0.000 | 0.000 | 0 |
| 2 | Urban and industrial inputs | 523,000,000 | 0.523 | 0.000 | **0.523** |
| 2a | No sludge removal | 523,000,000 | 0.523 | | 0.523 |
| 2b | With sludge removal | 0 | 0.000 | 0.000 | 0 |
| 3 | Domestic inputs | 0 | 0.000 | 0.000 | **0** |
| 3a | No sludge removal | 0 | 0.000 | | 0 |
| 3b | With sludge removal | 0 | 0.000 | 0.000 | 0 |
| | **Total Sewage/sewage treatment** | **523,000,000** | **0.523** | **0.000** | **0.523** |

*: number rounded to 3 significant figures

## Uncertainty

Level of confidence for the activity rates is considered high because they are national data obtained from responsible agency and also because of the existence of national infrastructure to keep track of activity rates on a monthly basis. The emission factor values are also assigned a high confidence level by UNEP based on geographic coverage and consistency among results used.

Confidence level for class assignment is considered medium. Although the location of the plants can be cited with confidence, the same is not true for sludge removal. Because the EF values from the Toolkit are based on the dry mass of the sludge generated, estimation of emission through this path is not possible without data inputs from sewage plant operators.

### 3.9.3 Open water dumping

Emission factors

Open water dumping is defined as the discharge of untreated wastewater directly into surface waters. The UNEP Toolkit classifies open water dumping activities into 3 classes:

- Class 1: Mixed domestic and industrial wastewater -- for water discharged from sources suspected to contain PCDD/F or storm water runoff from urban, peri-urban or industrialized areas
- Class 2: Urban and peri-urban wastewater -- similar to Class 1 but with little or no industries.
- Class 3: Remote environments -- for open dumping of water in remote areas with no known PCDD/F sources.

An overview of UNEP Toolkit's emission factors for open water dumping is shown in Table 3-156.

**Table 3-156: PCDD/F emission factors for open water dumping**

| **9c** | **Open water dumping** | **Emission Factors (µg TEQ/m$^3$)** |
|---|---|---|
| | Classification | Water |
| 1 | Mixed domestic and industrial wastewater | 0.005 |
| 2 | Urban and peri-urban wastewater | 0.0002 |
| 3 | Remote environments | 0.0001 |

Activity rates

There is no data available at the national level for activity rates within this source category. In order to estimate the activity rates, the inventory team considers the average water consumption by the general public in Thailand as follows.

The Provincial Waterworks Authority (PWA) and the Metropolitan Waterworks Authority (MWA) reported selling 1,234 and 656.8 Mm$^3$ of tap water to 4.3 and 1.9 million household customers in 2017, respectively [179][180]. The average number of persons per household in 2017 calculated from NSO statistical data [181] was 1.97 for Bangkok and 2.65 for the rest of the country. Based on these figures, the average water consumption per person per day are 520 liters for Bangkok residents and 306 liters for those outside Bangkok.

MWA and PWA supplied 1,912 Mm$^3$ of water to customers in urban and peri-urban areas. Of this total amount, 522.5 Mm$^3$ are already accounted for in Source Category 9b (sewage treatment). The remaining amount (1,390 Mm$^3$) was likely directly discharged from points of use.

PWA provided services to about 11.8 million persons in 2017. The rest of the population living in remote areas (48.7 million persons) relied on community water services. Assuming similar consumption pattern as PWA customers, the water consumption in remote areas in 2017 is estimated at 5,444 Mm$^3$.

There is no information available for estimation of the proportion of discharged water that flow to surface water bodies. Therefore, in order to provide a rough estimate, a worst-case scenario where all the water consumed was discharged to surface water bodies is assumed.

#### Releases of dioxins and furans

The estimated releases of PCDD/F from open water dumping are summarized in Table 3-157.

**Table 3-157: Estimated PCDD/F emission from open water dumping in 2017**

| **9c** | **Open Water Dumping**<br>Classification | **Activity Rate**<br>($m^3$)* | **Emission (g TEQ/a)**<br>Water |
|---|---|---|---|
| 1 | Mixed domestic and industrial wastewater | 0 | 0.000 |
| 2 | Urban and peri-urban wastewater | 1,390,000,000 | 0.278 |
| 3 | Remote environments | 5,440,000,000 | 0.544 |
| | **Total Open water dumping** | **6,830,000,000** | **0.822** |

*: number rounded to 3 significant figures for legibility.

#### Uncertainty

The confidence level for the activity rate is at low due to lack of data at the national level, and because several assumptions have to be made. Particularly, a worst-case scenario is assumed for the estimation of Class 3 activity rates. The confidence level for EF values cannot be determined due to lack of information.

### 3.9.4 Composting

Composting process can form (or alter) PCDD/F via the action of microorganisms on chlorinated phenolic compounds [182]. However, high concentrations of PCDD/F are attributed to carry-over from organic feedstocks [37]: studies have found higher PCDD/F contents in composts produced from feedstocks where organic fractions have been contaminated prior to collection (so-called “grey composts”) than in “green composts” made from clean materials.

#### Emission factors

There is no data related to PCDD/F in composts in Thailand. The default EF values provided by the UNEP Toolkit are thus used to estimate the emission from this source category.

The UNEP Toolkit classifies composts into 2 classes base on the origin of the feedstock:

- Class 1 refers to the “grey composts” made from organic fractions that have been mixed with other wastes prior to collection
- Class 2 refers to the clean or “green composts” made from organic matters that have been separated at source

An overview of UNEP Toolkit’s emission factors for composting is shown in Table 3-158.

**Table 3-158: PCDD/F emission factors for composting**

| 9d | Composting<br>Classification | Emission Factors (µg TEQ/t d.m.)<br>Product |
|---|---|---|
| 1 | Organic wastes separated from mixed wastes | 50 |
| 2 | Clean compost<br>(note: d.m. = dry mass) | 5 |

Activity rates

**Municipal organic wastes:**

According to PCD MSW disposal data [5], nine (9) LAOs/cities reported separate MSW collection for composting in 2017. The total amount of waste disposed by composting was 1,413 tonnes/day (about 516,000 t/year). These organic wastes were collected from fresh markets, restaurants, garden trims, etc.

Based on interviews with two large composting operators, the composting yield (dry mass) was about 0.2, leading to an estimation of 103,200 tonnes (dry mass) of composts produced from MSW management. Composts from these sources are assigned to Class 2 based on SAO/cities' separate collection practice.

**Industrial organic wastes:**

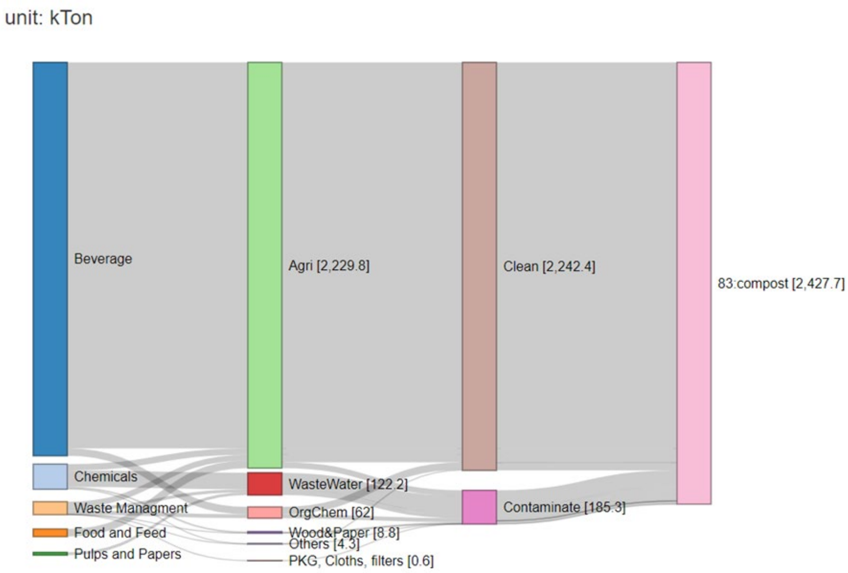
DIW allows disposal of industrial wastes (IW) via composting or for use as soil conditioners (Treatment Code 083), provided the proposed disposals are approved by responsible authorities prior to the transfer.

Based on data from DIW waste transfer manifest dataset [30], about 2.6 million tonnes of IWs were transferred to this route. Wastes in this code also included inorganic wastes and sludge from WWTP. Ashes, limes, and other inorganic residues from thermal processes are excluded from this assessment.

An overview of IW relevant to composting, shown in Figure 3-23, indicate that most industrial organic wastes for composting came from the beverage industry.

Wastes from waste treatment operators (factory codes 101 and 106) and sludge from WWTP (waste group 19) are treated as contaminated waste (185,330 tonnes) and, hence, are assigned to Class 1. The remaining 'clean' wastes (2.24 million ton) are mostly from waste group 02 (wastes from agriculture, food processing, etc.), 07 (wastes from organic chemical processes), and 16 (wastes not otherwise specified in the list). Composts from these sources are assigned to Class 2.

There is no information on the amount of composts (dry mass) obtained from composting these wastes. An aforementioned approximate compost yield of 0.2 is therefore used to estimate the amount of composts produced in 2017.



*[Data source: DIW Industrial Waste Transfer Manifest, 2017]*

**Figure 3-23: Profile of industrial organic wastes disposed by composting in 2017**

## Releases of dioxins and furans

The estimated releases of PCDD/F from composting are presented in Table 3-159. Unlike other source categories, the PCDD/Fs from this source category are embedded in the products which, by their nature, are intended to be directly applied to soil.

Particularly, the PCDD/F contribution from composts from contaminated IW is relatively high. This activity helped dispose only 6.7% of all relevant organic wastes but was responsible for nearly half (40.2%) of overall releases from composting. The possibility of having high amounts of PCDD/F from this source transferred into the food chain deserves confirmative actions to ensure safety of the public and the environment.

It should be noted that the DIW’s threshold limit of 0.01 mg/kg as prescribed in M-Industry’s B.E. 2548 (2005) Notification on Industrial Waste Disposal [10] is about 200 times higher than the EF value used in this study. If all Class 1 composts were approved at this threshold level, the amount of PCDD/F could be 200 times higher than the value estimated in this study, which would make this source a major source for PCDD/F emission.

**Table 3-159: Estimated PCDD/F emissions from composting in 2017**

| **9d** | **Composting** Classification | **Activity Rate** (tonne dry mass)1) | **Emission to Product** (g I-TEQ/a) |
|---|---|---|---|
| 1 | Organic wastes separated from mixed wastes | 37,000 | 1.853 |
| 2 | Clean compost | **552,000** | **2.758** |
| | Industrial organic waste | 448,000 | 2.242 |
| | MSW separate collection | 103,000 | 0.516 |
| | **Total Composting** | **589,000** | **4.612** |

1) number rounded to 3 significant figures for legibility.

**Uncertainty**

The confidence level for the activity rate values is rated medium because of the lack of activity data on the dry mass basis and the assumption made on the compost yield.
The associated class assignment is given a high level of confidence due to availability of local nodes' aggregation data for the entire country.

The emission factor values have been assigned by UNEP a high level of confidence with a note for uncertainties associated with composts from organic industrial residues.

### 3.9.5 Summary

Thailand's total PCDD/F emission from disposal and landfill activities during the year 2017 is summarized in Table 3-160 and Figure 3-24, where the emissions to residue, water, and product account for 80.5%, 14% and 5.5% of total emission, respectively.

The main contributor (93%) for this source group was from activities related to landfills and waste dumps particularly landfilling or open dumping of wastes contaminated with hazardous components or mixed wastes, with residue being the main pathway. Emission into residue in engineered or secured landfills does not constitute a release per se, but rather storages of PCDD/F which will accumulate and take part in the release into water overtime, and will become important when excavated. Readers shall be reminded that the value reported for landfill residues excludes the portions that are already counted in respective waste-generating source groups (G1 to G8) to avoid double counting. Thus, the amount of PCDD/F stored in landfills are actually higher than reported in this source group (by about 400 g TEQ/a) and will further accumulate every year unless care is taken to remove contaminated items from waste streams prior to landfilling.

The emission into water, on the other hand, can be released to nearby receptors. As cautioned earlier, the reported value for the release into leachate water from landfills shall not be misinterpret as emission from the entire landfills, but rather only from the portions that were deposited during the 2017 baseline year. The total amount of PCDD/F anticipated to have been released is thus higher, depending on the accumulated amount of waste landfilled over years.

At the time of this report, there is no requirement to monitor PCDD/F released from landfills and landfill excavations; thus, no preventive action is yet in place to assure public and environmental safety. This gap, particularly for landfills near urban and industrial areas, should be addressed in the upcoming action plans.

**Table 3-160: Summary of the estimated 2017 PCDD/F emission from Source Group 9: disposal and landfill**

| **9c** | **Disposal and Landfill** | | | **Emission (g TEQ/a)** | |
|---|---|---|---|---|---|
| | Subcategory | Water | Product | Residue | **Subtotal** |
| a | Landfills, Waste Dumps and Landfill Mining | 10.57 | 0 | 68.03* | **78.60** |
| b | Sewage/sewage treatment | 0.52 | 0 | 0 | **0.52** |
| c | Open water dumping | 0.82 | 0 | 0 | **0.82** |
| d | Composting | 0 | 4.61 | 0 | **4.61** |
| | **Total Disposal and Landfill** | **11.91** | **4.61** | **68.03** | **84.56** |

*: Excluding the amounts of PCDD/F embedded in residues that were already counted in respective waste generating source group.

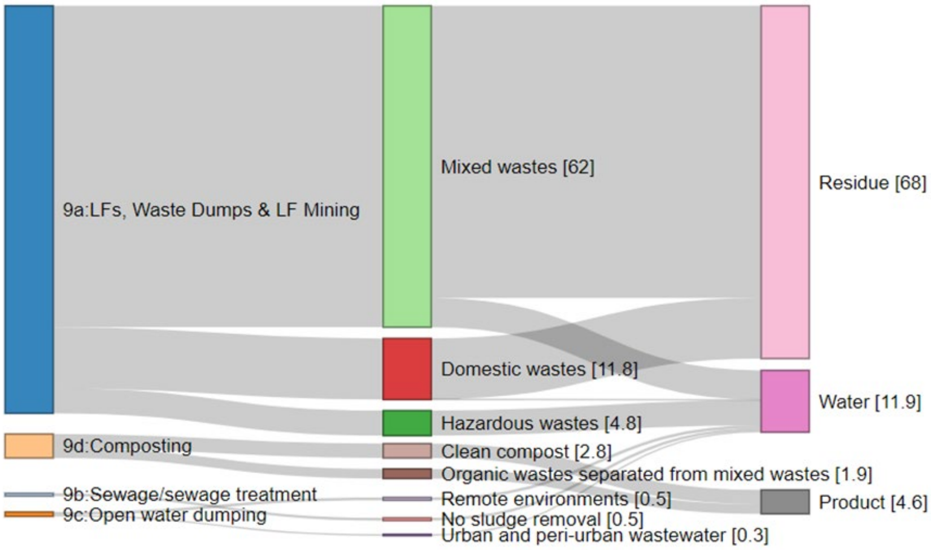


**Figure 3-24: Summary of PCDD/F emissions from Source Group 9: disposal and landfill in 2017 [unit: g TEQ/a]**

□□□

## 3.10 Source Group 10: Contaminated Sites and Hotspots

The UNEP Toolkit considers "Contaminated Sites and Hotspots", activities that might have resulted in the contamination of soil and sediments with PCDD/Fs and other unintentional POPs, in 12 source categories as follows:

- Production sites of chlorine (10a)
- Production sites of chlorinated organics (10b)
- Application sites of PCDD/F-containing pesticides and chemicals (10c)
- Timber manufacture and treatment sites (10d)
- Textile and leather factories (10e)
- Use of PCBs (10f)
- Use of chlorine for production of metals and inorganic chemicals (10g)
- Waste incinerators (10h)
- Metal industries (10i)
- Fire accidents (10j)
- Dredging of sediments and contaminated flood plains (10k)
- Dumps of wastes/residues from groups 1-9 (10l)
- Kaolin or ball clay sites (10m)

The contamination of soil and sediments can act as reservoirs that can be important sources of human exposure.

The approach recommended for the inventory of this source group comprises three tasks [37]:

I. Identifying historical activities that could have caused contamination and identifying the potentially contaminated sites;
II. Assessing these sites for the likely magnitude of the contamination and ranking by their exposure risk;
III. Assessing the degree of contamination of the most significant sites by detailed analysis.

Due to the lack of monitoring data, the magnitude of the contamination cannot be assessed. This chapter is, therefore, limited to the provision of a list of likely contaminated sites, based on information of historical activities that have potential to result in high releases of PCDD/Fs in the past.

It is recommended that the sites on this list be assessed in more details in the upcoming NIP.

### 3.10.1 Production sites of chlorine (10a)

This source category covers the formation and releases of PCDD/Fs from chlorine production processes, namely:

- Chlor-alkali production, and
- Leblanc process and associated chlorine/bleach production

Chlor-alkali production

As mentioned in Source Group 7, there are currently 7 factories registered for chlor-alkali (CAK) related chemicals in 4 provinces. This industry is an established industry in Thailand, with the average age of factory licenses of over 30 years.

Manufacturing of chlorine using graphite anodes can release significant amounts of PCDD/F into residues, with the UNEP-assigned EF of 1,000 µg TEQ/ECU. Although all of the registered CAK production plants in Thailand are currently based on membrane technology with titanium electrodes for their chlorine productions, graphite anodes may have been used in the past. According to the UNEP Toolkit, graphite anodes were gradually replaced by metal anodes and other technologies starting in the 1970s.

Based on information from DIW database, the oldest CAK plant in Thailand was built in 1972 and the 4 newer plants were built in 1982. These plants are located in Samut Prakan and Rayong Provinces.

According to the Toolkit, past uses of graphite anodes should be investigated. If found relevant, the possible contamination/deposition into land and sediments in nearby rivers should be assessed.

Leblanc process and associated chlorine/bleach production

The Leblanc process was a soda ash (sodium carbonate) production process used in the 19th century mainly in factories in the UK, France and Germany [37]. High levels of PCDD/F of up to 100,000 µg TEQ/tonne have been reported from a relevant factory in Germany.

To our best knowledge, there is no registered factory in Thailand that used the Leblanc process.

### 3.10.2 Production sites of chlorinated organics (10b)

Sites where chlorinated organics were produced and/or used are potentially contaminated with large amount of PCDD/F and other UPOPs. This UNEP Toolkit addresses the potential contamination from the following 5 source categories:

- Production sites of chlorophenol
- Former lindane production where HCH waste isomers have been recycled
- Former production sites of other chemicals suspected to contain

PCDD/Fs

- Production sites of chlorinated solvents and other “HCB waste”
- (Former) PCBs and PCBs-containing materials/equipment production

As mentioned in Source Group 7, Thailand does not have production sites for any of the chlorinated aromatic chemicals and chlorinated solvents. However, there are two chlorinated paraffins (CPs) plants built in the 1980s. Based on the Toolkit’s PCDD/F, PCB, and HCB emission factors for chlorinated paraffins as shown in Table 3-161, the CPs production plants and nearby environment should be assessed for possible contamination of PCDD/Fs, PCBs, and HCB.

**Table 3-161: PCDD/F, PCBs, and HCB emission factors for chlorinated paraffins**

| Class | Chlorinated Paraffins | PCDD/F (µg TEQ/t) | PCBs (µg/t) | HCB (µg/t) |
|---|---|---|---|---|
| **1** | Low-End Technologies | No data | 210,000,000 | 8,900,000 |
| **2** | Mid-Range Technologies | 500 | 165,000,000 | 7,500,000 |
| **3** | High-End Technologies | 140 | 40,000 | 7,000 |

### 3.10.3 Application sites of PCDD/F-containing pesticides and chemicals (10c)

As seen in Source Group 7, several chlorinated aromatic pesticides and chemicals may contain PCDD/F especially those produced using old technologies (see Table 3-162 below). Substances with high EFs -- particularly PCP, chloronitrofen, and p-chloranil -- were either never imported into Thailand or had their uses stopped for almost 20 years through being listed as hazardous substances of Category 4 (ban) or Category 3 (without any request for processing). Nevertheless, several pesticides/chemicals that are allowed for uses as pesticides and pigments in Thailand may contain PCDD/F. An estimated amount of PCDD/Fs that may have been released from the uses of these products in 2017 is about 8.5 g TEQ (see Table 3-163).

Unfortunately, current pesticide management system in Thailand does not yet allow for the tracing of the high-use/high-risk areas, nor are there establish systems to monitor the releases of PCDD/F into the environment.

Therefore, it is recommended that chemicals with high risks of PCDD/F contamination be compiled and a pesticide tracing system (spatial and temporal) be established to enable an intelligence-based monitoring system for current and future substances of concerns.

### Table 3-162: List of PCDD/F emission factors for chlorinated aromatic chemicals

| d | | Chlorinated Aromatic Chemicals (per ton product) | EF in Product (µg TEQ/t) | Remark |
|---|---|---|---|---|
| **da** | | **Chlorobenzenes** | | **HS Cat.3 for 1,2-DCB** |
| | 1 | 1,4-Dichlorobenzene | 39 | **(CAS 95-50-1) [1995]** |
| **dc** | | **PCP and PCP-Na** | | **HS Cat.4** |
| | 1 | PCP | 634,000 | **[Agriculture:1995,** |
| | 2 | PCP-Na | 12,500 | **Industry:2001]** |
| **dd** | | **2,4,5-T and 2,4,6-2,4,6-trichlorophenol** | | **HS Cat.4 [2003]** |
| | 1 | 2,4,5-T | 7,000 | |
| | 2 | 2,4,6-trichlorophenol | 700 | |
| **de** | | **Chloronitrofen (CNP)** | | **HS Cat.3 [2003]** |
| | 1 | Old technologies | 9,200,000 | |
| | 2 | New technologies | 4,500 | |
| **df** | | **Pentachloronitrobenzene (PCNB)** | | **HS Cat.3 [1995]** |
| | 1 | Low-End Technologies | 5,600 | |
| | 2 | Mid-Range Technologies | 2,600 | |
| | 3 | High-End Technologies | 260 | |
| **dg** | | **2,4-D and derivatives** | | **HS Cat.3, mostly in** |
| | 1 | Low-End Technologies | 5,688 | **1995** |
| | 2 | Mid-Range Technologies | 170 | |
| | 3 | High-End Technologies | 0.1 | |
| **di** | | **p-Chloranil** | | **HS Cat.4/3 [2004]– No** |
| | 1 | Direct chlorination of phenol | 400,000 | **request for** |
| | 2 | Chlorination of hydroquinone with minimal purification | 1,500,000 | **authorization found** |
| | 3 | Chlorination of hydroquinone with moderate purification | 26,000 | |
| | 4 | Chlorination of hydroquinone with advanced purification | 150 | |
| **dj** | | **Phthalocyanine dyes and pigments** | | **Not listed** |
| | 1 | Phthalocyanine copper | 70 | |
| | 2 | Phthalocyanine green | 1,400 | |
| dk | | Dioxazine dyes and pigments | | **Not listed** |
| | 1 | Blue 106 | 35,000 | |
| | 2 | Blue 108 | 100 | |
| | 3 | Violet 23 | 12,000 | |
| dl | | Triclosan | | **Not listed** |
| | 1 | Low-End Technologies | 1,700 | |
| | 2 | Mid-Range Technologies | 60 | |
| | 3 | High-End Technologies | 3 | |

**Table 3-163: Estimated PCDD/F in chlorinated aromatic chemicals that may have been released to land and sediment in 2017**

| 7d | Chlorinated Aromatic Chemicals | Activity Rate (Tonne)* | Amount in Product (g I-TEQ/a) |
|---|---|---|---|
| da | Chlorobenzenes | **1,450** | **0.057** |
| df | Pentachloronitrobenzene (PCNB) | **27.8** | **0.072** |
| dg | 2,4-D and derivatives | **12,600** | **2.134** |
| dj | Phthalocyanine dyes and pigments | **2,000** | **1.470** |
| dk | Dioxazine dyes and pigments | **300** | **4.710** |
| dl | Triclosan | **100** | **0.006** |
| | **Total** | | **8.45** |

*: number rounded to 3 significant figures for legibility

### 3.10.4 Timber manufacture and treatment sites (10d)

PCP has been listed as a Category 4 hazardous substance (total ban) under the Hazardous Substances Act since 1995[20]. According to the Department of Agriculture (DOA), PCP has never been approved for agricultural uses in Thailand. Based on interviews with the Royal Forest Department officers, there has been no report of any widespread use of this substance for wood preservation in Thailand prior to the ban. Similarly, response from the State Railway of Thailand (SRT) also indicates no recollection of PCP use for SRT sleepers or utility poles. Finally, a search for reports on PCP detection in Thailand in scientific literatures did not yield any result. Therefore, the inventory team concluded that there is no evidence for the availability of PCP in Thailand.

### 3.10.5 Textile and leather factories (10e)

Textile and leather factories use several chemicals that may contain PCDD/F and other UPOPs. Chemicals used for tanning and finishing as well as incidental chemicals, such as organochlorine biocides in raw hides and raw fibers, have been identified as potential sources of PCDD/Fs. Particularly, the Toolkit and BAT/BEP guidelines identify two high-risk organochlorine chemicals: PCP and chloranils (CAS No 118-75-2). These chemicals were banned in Thailand 15-20 years ago (see Source Category 7d). Additionally, other mentioned organochlorines such as lindane and chloronitrofen (CNP, CAS No. 2836-77-7) were also banned or restricted with no record of request for registration.

PCDD/F may also be unintentionally produced via bleaching processes and/or burning of residues. High PCDD/F releases into air, wastewater, sludge and products can be anticipated. However, due to the lack of measurement data, the estimation of the releases of PCDD/F into these vectors has not been possible. It is therefore suggested that PCDD/F releases from this industry be systematically studied to investigate the potential magnitude of contamination in Thailand.

Note, however, that areas with high concentration of textile and leather factories also coincide with other source categories, such as 10a, 10b, and 10g. It may be beneficial to consider area-based studies of several potentially contaminated sites that are located in the same areas.

### 3.10.6 Use of PCBs (10f)

PCBs and HCB were included in the initial list of POPs under the SC and, hence, had been addressed in Thailand’s first NIP. According to the UNEP Toolkit, sites with PCB-containing equipment in use or storage should be treated as potential hotspots [37].

PCBs and any devices that contain PCBs have been banned in Thailand since 2004 as Category 4 substances under the HSA. The ban covers all activities, including the production, import, export or possession of HCB/PCBs and/or devices that contain PCBs.

In 2008, the DIW announced a plan to totally phase-out PCB-containing devices by 2012 [183]. The announcement obligated device holders to prepare and implement a plan to phase-out and completely dispose of PCBs by 2012. According to the PCD, all PCBs oils were collected and exported to capable countries (France, the Netherlands, etc.) for final destruction.

As it is now illegal for anyone to have PCBs or PCB-containing devices in their possession, and there is no site with PCB-containing equipment in use or in storage. However, apart from the report from key stakeholders, the inventory team did not find any record of surveillance and/or any form of confirmation check. There is also no record of levels of PCBs at any storage site. It is, therefore, recommended that these gaps be addressed in the upcoming NIP.

### 3.10.7 Use of chlorine for production of metals and inorganic chemicals (10g)

Industries where elemental chlorine is used can generate and release PCDD/F into residues. Examples of production processes that could lead to such PCDD/F formation and releases include pulp and paper sludge from bleaching process using elemental chlorine, magnesium production and titanium dioxide production [37]. Only pulp and paper sludge is considered relevant to Thailand. However, as mentioned in Source Category 7a, pulping mills in Thailand have mostly moved away from elemental chlorine ($Cl_2$) technology to accommodate the updated wastewater emission limits [14], [15], [21].

Residues from pulp and paper sludge may be approved for uses as soil conditioners, provided that they do not possess hazardous characteristics, which include having dioxin (2,3,7,8-TCDD) contents of less than 10µg/kg [10]. (Note that this level is of the same order as the Basel convention's provisional low POPs content of 15 µg TEQ/kg for PCDD/F in waste but is about 3-4 orders of magnitude higher than the relevant EF given by the UNEP Toolkit). However, the inventory team found no data related to PCDD/F contents in these residues.

Since the application of to land can result in the contamination into the food chain, an thus human exposure, it is imperative to assess the levels of PCDD/F in pulp and paper sludge (and similar residues), both from the old $Cl_2$ technology and the modern $ClO_2$ technology.

Since the uses of such residues as soil conditioners can be repeatedly applied to the same land areas, PCDD/F can accumulate over time. Therefore, safe PCDD/F contamination limits to be allowed for uses in such sensitive applications should be studied.

### 3.10.8 Waste incinerators (10h)

Results reported for Source Group 1 (waste incineration) indicated that waste incineration is the largest source for PCDD/F emission in Thailand, releasing about 421.1 gTEQ (297 gTEQ into air and 124 gTEQ into ashes) in 2017. Municipal solid waste (MSW) incineration and medical waste (MW) incineration contribute to 83% and 16% of the emission from this source group, respectively.

The high releases from MSW incinerators were mostly (75%) contributed by 57 small and inefficient incinerators. Areas around non-BAT incinerators that have been operated over extended time periods are likely contaminated sites.

Ashes from waste incinerators as well as other thermal facilities are likely contaminated with PCDD/F and other UPOPs. Table 3-164 summarizes top 5 thermal activities that release highest amounts of PCDD/F into residues in 2017. Residues from these facilities should be disposed of in environmentally sound manners. Areas that received ashes from these facilities should be regarded as potentially contaminated sites.

**Table 3-164: Top 5 thermal activities that release highest amount of PCDD/F in to residues in 2017**

| Group | Category | Residue (gTEQ/a) |
|---|---|---|
| 1a | Municipal solid waste incineration | 81.01 |
| 1c | Medical waste incineration | 37.80 |
| 3b | Biomass power plants | 28.42 |
| 3a | Fossil fuel power plants | 20.71 |
| 1b | Hazardous waste incineration | 5.48 |

It should be note, however, that the 2013 UNEP toolkit does not yet account for water releases from wet scrubbers. Therefore, water releases from these top 5 thermal activities should also be assessed.

### 3.10.9 Metal industries (10i)

Metal production released about 278 g TEQ/a in 2017, mostly (87%) into the residues. Therefore, residues from metal productions should be monitored to ensure proper disposal.

PCDD/F emissions from thermal wire reclamation and e-waste recycling, particularly open burnings of halogenated cables and circuit boards, can be very high. Although emission from thermal wire reclamation and e-waste recycling into air has been accounted for in this study, emissions into soil are missing due to the lack of representative EFs. It should be noted also that the extent of open burning of cables and ewaste in the past could be much higher than the values reported for 2017 due to the improved public knowledge of the impacts, which have led to higher pressure from communities. To our best knowledge, there is no study to assess levels of PCDD/F and other UPOPs released from thermal wire reclamation and e-waste recycling activities in Thailand. However, PCDD/F have been detected in chicken eggs taken from free-range chickens raised in/near areas known to have burned cables [184], indicating a cause for concern.

Therefore, areas known to have large amounts of cable and ewaste burnings in the past should be regarded as likely contaminated sites and the levels of PCDD/Fs and other UPOPs should be investigated.

### 3.10.10 Fire accidents (10j)

Based on Department of Disaster Prevention and Mitigation (DDPM) fire statistics, there were about 250 factory and commercial building fire incidents reported in 2017, with estimated damage values of about 1,300 million baht. A brief summary of factory and commercial building fire incidents reported in 2017 is presented in Table 3-165.

Unfortunately, there is no system to record the nature of the chemicals burned in the fires. The inventory team could not find data related to the collection of sample (soot) or records of the amount of PCDD/F or any UPOPs released from these incidents. Therefore, a guideline for responding to fire accidents with potentially high PCDD/F releases should be developed, samples (soot) from high risk fires should be collected and analyzed, and guideline for proper clean-up actions should be provided to ensure safety to human health and the environment.

**Table 3-165: A summary of factory and commercial building fire incidents in 2017**

| Group | No of Incident | No of Fire Truck used | Fire truck per incident | Damage Costs | Cost per incident | No of casualty |
|---|---|---|---|---|---|---|
| Factory (incl. Warehouse) | 106 | 718 | 6.77 | 1,053,200,000 | 9,935,849 | 14 |
| Commercial Building | 141 | 515 | 3.65 | 238,615,000 | 1,692,305 | 23 |

### 3.10.11 Dredging of sediments and contaminated flood plains (10k)

Dredging is an important activity for managing seasonal floods, particularly for the greater Bangkok area. The Department of Drainage and Sewerage (DDS) of the Bangkok Metropolitan Administration (BMA) regularly dredges sediments in canals as part of their direct duty.

According to the DDS annual report [185], canal maintenance-related works conducted in 2017 were preparation works (building of concrete dikes, etc.) to support dredging works in the upcoming years. Canal dredging projects were based on the monitored water quality (DO and BOD). There were only minor dredging activities in 33 canals in 2017, covering about 118 meters.

While the DOA has regularly monitored contamination of pesticides in water and sediments, monitoring of UPOPs and other POPs are still lacking. The inventory team did not find any analytical data for UPOPs and other POPs in dredged sediments.

Therefore, it is imperative to assess the level of UPOPs and other POPs in surface water and sediments downstream from the top 5 thermal facilities (Table 3-164) and metal smelters and ewaste ‘recyclers’. Also, an inventory of major dredging activities should be considered.

### 3.10.12 Dumps of wastes/residues from Source Groups 1-9 (10l)

Several activities release high amounts of PCDD/F into residues (see Table 3-166). While some of these residues are destroyed in cement kiln, the majority are believed to be disposed of in waste dumps or landfills. Unfortunately, as mentioned in Source Group 9, there is currently no regulatory requirement to monitor the releases of PCDD/F and other POPs from landfills. There is also no requirement to keep inventory of residues stored in each site.

It should be reminded that, apart from residues from industrial settings under the Factory Act, there is currently no system to keep track of the amounts and the movement of residues from their generation sources to their final destinations. Such a system should be considered in the upcoming action plan. As mentioned in Source Category 10h, areas that received residues from the top 5 thermal activities that release highest amounts of PCDD/F-contaminated residues should be regarded as potentially contaminated sites.

In case of disposal in secured landfill, as PCDD/F and other POPs within residues are likely to outlive landfill liners, and engineered landfill systems will eventually lose their ability to contain POPs [37]. Therefore, it is recommended that actions outlined in the UNEP Toolkit [37] (page 149) should be considered.

**Table 3-166: Top 10 activities that released highest amounts of PCDD/F into residues in 2017**

| Source Group | | Category | Residue (g TEQ/a) | Contribution (%) | Cumulative Contribution (%) |
|---|---|---|---|---|---|
| 2 | e | Aluminum production | 150.00 | 30.85 | 30.85 |
| 2 | ca | Iron and steel plants | 85.84 | 17.66 | 48.51 |
| 1 | a | Municipal solid waste incineration | 81.01 | 16.66 | 65.17 |
| 9 | a | Landfills, Waste Dumps and Landfill Mining | 68.03 | 13.99 | 79.16 |
| 1 | c | Medical waste incineration | 37.80 | 7.78 | 86.94 |
| 3 | b | Biomass power plants | 28.42 | 5.85 | 92.79 |
| 3 | a | Fossil fuel power plants | 20.71 | 4.26 | 97.04 |
| 1 | b | Hazardous waste incineration | 5.48 | 1.13 | 98.17 |
| 3 | d | Household biomass burning for heating & cooking | 2.09 | 0.43 | 98.60 |
| 2 | h | Brass and bronze production | 2.00 | 0.41 | 99.01 |

### 3.10.13 Kaolin or ball clay sites (10m)

According to DPIM, there are currently 28 Prathanabat (patent permit) to mine kaolin and ball clay in 10 provinces in Thailand, covering areas of about 704 hectare. To the best of our knowledge, there is no study to assess the amounts of PCDD/Fs in kaolin and ball clay in Thailand. However, due to the proximity of clay products to humans and the associated risks from the use of contaminated clays, levels of PCDD/F in Thai kaolin should be investigated. Particularly, as suggested by the UNEP Toolkit, clays used for human consumption and/or animal feed should be inventoried as a matter of urgency.

□□□

## 3.11 Unintentional emissions of PCBs and HCB

In addition to PCDD/Fs, 5 other substances: HCB, PCBs, PeCB, PCNs and HCBD, have been added to Annex C of the Stockholm Convention. These substances are usually formed from the same sources that produce PCDD/Fs. However, only EFs for HCB, PCBs, and dioxin-like PCBs are currently available. The inventory for the unintentional emissions of these substances are provided here to allow relevant parties to set measures and develop action plans to minimize releases of all unintentional POPs.

### 3.11.1 PCBs and dioxin-like PCBs

EFs for PCBs and dioxin-like PCBs (DL-PCBs) are currently available for 4 source groups (G2, G3 (only for simple stoves), G5 (only for heavy oil-fired engines), and G7 (only for CPs)) and 2 source groups (G6, and G7 (only for PCNB)), respectively (see Table 3-170 and Table 3-171 in Annex 7 for more detail). The unintentional emissions of PCBs and DL-PCBs have been estimated using these EFs and the results are summarized in Table 3-167 and Table 3-168, respectively.

The unintentional release of PCBs in 2017 is estimated at 4,960 kg TEQ; about 4,950 kg TEQ and 10 kg TEQ are released into products and air, respectively. Due to the very high EF for chlorinated paraffins (CPs), the estimated emissions of PCBs in 2017 is dominated by the emission from CPs

On the other hand, open burning processes further added about 23 g TEQ of dioxin-like PCBs, with about 90% going to air and 10% released into land.

**Table 3-167: Summary of the estimated annual releases of unintentionally produced PCBs in 2017**

| Group | Source Groups | Annual Releases (g TEQ/a) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Air | Water | Land | Product | Residue | Subtotal |
| 1 | Waste Incineration | | | | | | 0 |
| 2 | Ferrous and Non-Ferrous Metal Production | 2.50 | | | | 4.02 | 7 |
| 3 | Heat and Power Generation | 9,349.12 | | | | | 9,349 |
| 4 | Production of Mineral Products | | | | | | |
| 5 | Transportation | 642.77 | | | | | 643 |
| 6 | Open Burning Processes | | | | | | 0 |
| 7 | Production of Chemicals and Consumer Goods | | | | 4,950,000 | | 4,950,000 |
| | Total | **9,994** | | | **4,950,000** | **4** | **4,959,998** |

**Table 3-168: Summary of the estimated annual releases of unintentionally produced dioxin-like PCBs in 2017**

| Group | Source Groups | Annual Releases (g TEQ/a) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Air | Water | Land | Product | Residue | Subtotal |
| 1 | Waste Incineration | | | | | | |
| 2 | Ferrous and Non-Ferrous Metal Production | | | | | | |
| 3 | Heat and Power Generation | 0.93 | | | | 0.01 | 0.94 |
| 4 | Production of Mineral Products | 0.01 | | | 0.01 | | 0.01 |
| 5 | Transportation | | | | | | |
| 6 | Open Burning Processes | 20.73 | | 2.25 | | | 22.98 |
| 7 | Production of Chemicals and Consumer Goods | | | | 0.04 | | 0.04 |
| | **Total** | **21.67** | **0.00** | **2.25** | **0.05** | **0.01** | **23.99** |

### 3.11.2 HCB

EFs for HCB are available for 5 source groups: G2, G3, G4, G5, and G7 (see Table 3-172 for more detail).

As summarized in Table 3-169, the unintentional release of HCB in 2017 is estimated at 920 kg; about 341 kg, 578 kg, and 1 kg are released into air, products, and residue, respectively. There are two major sources of HCB releases: brick production which contributed about 57% of total releases and the production and use of chlorinated chemicals which contributed about 41% of total releases.

It should be noted that this estimation does not yet account for the releases from two other potential sources: waste incineration and open burning processes, due to the lack of representative emission factors.

**Table 3-169: Summary of the estimated annual releases of unintentionally produced HCB in 2017**

| Group | Source Groups | Annual Releases (g/a) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Air | Water | Land | Product | Residue | Subtotal |
| 1 | Waste Incineration | | | | | | 0 |
| 2 | Ferrous and Non-Ferrous Metal Production | 20,200.17 | | | | | 20,200 |
| 3 | Heat and Power Generation | 934.91 | | | | 26.80 | 961.71 |
| 4 | Production of Mineral Products | 320,000.00 | | | 200,000 | 1,000 | 521,000 |
| 5 | Transportation | 163.62 | | | | | 164 |
| 6 | Open Burning Processes | | | | | | 0 |
| 7 | Production of Chemicals and Consumer Goods | | | | 377,550 | | 377,550 |
| | **Total** | **341,298.70** | **0** | **0** | **577,550** | **1,026.8** | **919,875** |

□□□

## Annex 7. Emission factors and the corresponding unintentional emissions of PCBs, DL-PCBs, and HCB in 2017

**Table 3-170: Emission factors and estimated PCBs emission in 2017**

| Source | Class | Source Group & Classification | Emission Factor (µg TEQ/t) | | | Activity Rate (t/a) | Emission (g TEQ/a) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Air | Product | Residue | | Air | Product | Residue |
| **2c** | | **Iron and steel production plants and foundries** | | | | **7,561,808** | **0.04** | | **0.02** |
| **2ca** | | **Iron and steel plants** | | | | **6,761,808** | **0.00** | | **0.000** |
| | 3 | Clean scrap/virgin iron or dirty scrap, EAF equipped with APC designed for low PCDD/PCDF emission, BOF furnaces | 0.001 | | | 1,046,468 | 0.001 | | |
| **2cb** | | **Foundries** | | | | **800,000** | **0.041** | | **0.02** |
| | 3 | Cold air cupola, fabric filter or wet scrubber | 0.5 | | 0.1 | 80,000 | 0.040 | | 0.008 |
| | 4 | Hot air cupola or induction furnace, fabric filter or wet scrubber | 0.002 | | 0.01 | 720,000 | 0.001 | | 0.007 |
| **2d** | | **Copper production** | | | | **300,000** | **0.000** | | **0.0** |
| | 1 | Sec. Cu - Basic technology | | | | 0 | | | |
| | 2 | Sec. Cu - Well controlled | 5 | | 40 | 0 | 0.000 | | 0.000 |
| | 3 | Sec. Cu - Optimized for PCDD/PCDF control | 0.3 | | | 0 | 0.000 | | |
| | 4 | Smelting and casting of Cu/Cu alloys | | | | 300,000 | | | |
| | 5 | Prim. Cu, well-controlled, with some secondary feed materials | 0.01 | | | 0 | 0.000 | | |
| **2e** | | **Aluminum production** | | | | **1,350,000** | **2.032** | | **4.000** |
| | 1 | Processing scrap Al, minimal treatment of inputs, simple dust removal | 40 | | | 50,000 | 2.000 | | |
| | 2 | Scrap treatment, well-controlled, fabric filter, lime injection | 0.1 | | 20 | 200,000 | 0.020 | | 4.000 |
| | 3 | Optimized process for PCDD/PPCDF abatement | 0.02 | | | 600,000 | 0.012 | | |
| | 4 | Shavings/turnings drying (simple plants) | | | | 100,000 | | | |
| | 5 | Thermal de-oiling, rotary furnaces, afterburners, fabric filters | | | | 400,000 | | | |
| **2f** | | **Lead production** | | | | **84,080** | **0.011** | | **0.0** |
| | 1 | Lead production from scrap containing PVC | 2 | | | 4,000 | 0.008 | | |
| | 2 | Lead production from PVC/Cl2 free scrap, some APCS | 0.2 | | 0.1 | 16,080 | 0.003 | | 0.002 |
| | 3 | Lead production from PVC/Cl2 free scrap in highly efficient furnaces, with APC including scrubbers | 0.002 | | | 64,000 | 0.0001 | | |
| **2g** | | **Zinc production** | | | | **20,000** | **0.000** | | **0.00** |
| | 4 | Zinc melting and primary zinc production | 0.001 | | | 20,000 | 0.000 | | |
| **2l** | | **Thermal wire reclamation and e-waste recycling** | | | | **5,000** | **0.412** | | **0** |
| | 1 | Open burning of cable | 400 | | | 1,000 | 0.400 | | |

| Source | Class | Source Group & Classification | Emission Factor (µg TEQ/t) Air | Product | Residue | Activity Rate (t/a) | Emission (g TEQ/a) Air | Product | Residue |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | Open burning of circuit boards | 3 | | | 4,000 | 0.012 | | |
| | | **Total Ferrous and Non-Ferrous Metal Production** | | | | | **2.498** | | **4.017** |
| **3d** | **6** | **Household heating and cooking – Biomass: Simple stoves (virgin wood)** | **100,000** | | | **93,491** | **9,349** | | |
| **5d** | **1** | **Transport: Heavy oil fired engines** | **550** | | | **1,168,679** | **642.77** | | |
| **7dh** | **2** | **Chlorinated Paraffins: Mid-Range Technologies** | | **165E6** | | **30,000** | | **4.95E6** | |
| | | **Total PCB** | | | | | **9,994.40** | **4.95E6** | **4.02** |

## Table 3-171: Emission factors and estimated dioxin-like PCBs emissions in 2017

| Source | Class | Source Group & Classification | Emission Factor (µg TEQ/t) Air | Land | Product | Activity Rate (t/a) | Emission (g TEQ/a) Air | Land | Product |
|---|---|---|---|---|---|---|---|---|---|
| **6a** | | **Biomass burning** | | | | **14,317,832** | **20.50** | **2.253** | |
| | 1 | Agricultural residue burning in the field, impacted, poor burning conditions | | | | 0 | 0.000 | 0.000 | |
| | 1a | Rice, Paddy | 3 | 0.3 | | 4,751,764 | 14.255 | 1.426 | |
| | 1b | Maize | 3 | 0.3 | | 1,921,950 | 5.766 | 0.577 | |
| | 3 | Sugarcane burning | 0.05 | 0.01 | | 5,704,230 | 0.285 | 0.057 | |
| | 4 | Forest fires | | | | 0 | 0.000 | 0.000 | |
| | 4a | Humid tropical forest | 0.1 | 0.1 | | 47,061 | 0.005 | 0.005 | |
| | 4b | Other forest | 0.1 | 0.1 | | 1,892,827 | 0.189 | 0.189 | |
| 6b | | **Waste burning and accidental fires** | | | | **232,772** | **3.825** | **0.000** | |
| | 1 | Fires at waste dumps (compacted, wet, high Corg content) | 30 | | | 120,000 | 3.600 | | |
| | 2 | Accidental fires in houses, factories | | | | 0 | 0.000 | 0.000 | |
| | 3 | Open burning of domestic waste | 2 | | | 112,420 | 0.225 | | |
| | 4 | Accidental fires in vehicles (per vehicle) | | | | 352 | | | |
| | 5 | Open burning of wood (construction/demolition) | | | | 0 | 0.000 | 0.000 | |
| | | **Total Open Burning Processes** | | | | | **24.325** | **2.253** | |
| **7df** | | **Pentachloronitrobenzene (PCNB)** | | | | **28** | | | **0.042** |
| | 1 | Low-End Technologies | | | 2,400 | 0 | | | 0.000 |
| | 2 | Mid-Range Technologies | | | 1,500 | 28 | | | 0.042 |
| | 3 | High-End Technologies | | | 680 | 0 | | | 0.000 |

## Table 3-172: Emission factors and estimated HCB emissions in 2017

| Source | Class | Source Group & Category | Emission factor (µg/t ) | | | Activity Rate (t/a) | Emission (g/a) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Air | Product | Residue | | Air | Product | Residue |
| **2** | | **Ferrous and Non-Ferrous Metal Production** | | | | | **20,200.17** | **0.00** | **0.00** |
| **c** | | **Iron and steel production plants and foundries** | | | | **7,561,808** | **19,520.69** | **0.00** | **0.00** |
| ca | | Iron and steel plants | | | | 6,761,808 | 19,520.69 | 0 | |
| | 1 | Dirty scrap, scrap preheating, limited controls | 2500 | | | 0 | 0.000 | | |
| | 2 | Clean scrap/virgin iron or dirty scrap, afterburner, fabric filter | 2500 | | | 6,761,808 | 16904.520 | | |
| | | EAF | 2500 | | | 1,046,468 | 2616.170 | | |
| | | BOF | 2 | | | 0 | 0.000 | | |
| **e** | | **Aluminum production** | | | | **1,350,000** | **425.000** | **0.000** | **0.000** |
| | 1 | Processing scrap Al, minimal treatment of inputs, simple dust removal | 500 | | | 50,000 | 25.000 | | |
| | 2 | Scrap treatment, well-controlled, fabric filter, lime injection | 500 | | | 200,000 | 100.000 | | |
| | 3 | Optimized proces for PCDD/PPCDF abatement | 500.0 | | | 600,000 | 300.000 | | |
| | 4 | Shavings/turnings drying (simple plants) | | | | 100,000 | 0.000 | | |
| | 5 | Thermal de-oiling, rotary furnaces, afterburners, fabric filters | | | | 400,000 | 0.000 | | |
| **f** | | **Lead production** | | | | **84,080** | **84.080** | **0** | **0.0** |
| | 1 | Lead production from scrap containing PVC | 1000 | | | 4,000 | 4.000 | | |
| | 2 | Lead production from PVC/Cl2 free scrap, some APCS | 1000 | | | 16,080 | 16.080 | | 0.000 |
| | 3 | Lead production from PVC/Cl2 free scrap in highly efficient furnaces, with APC including scrubbers | 1000 | | | 64,000 | 64.000 | | |
| **g** | | **Zinc production** | | | | **20,000** | **20.000** | **0** | **0.00** |
| | 4 | Zinc melting and primary zinc production | 1,000 | | | 20,000 | 20.000 | | |
| **h** | | **Brass and bronze production** | | | | **20,000** | **150.400** | **0** | **0.0** |
| | 1 | Thermal de-oiling of turnings | 9400 | | | 0 | 0.000 | | |
| | 2 | Simple melting furnaces | | | | 4,000 | | | |
| | 3 | Mixed scarp, induction furnace, bag filter | 9400 | | | 16,000 | 150.400 | | 0.000 |
| **3** | | **Heat and Power Generation** | | | | | | | |
| d | | Household heating and cooking - Biomass | | | | 222,586 | 934.912 | 0 | 26.800 |
| | 6 | Simple stoves (virgin wood) | 10000 | | 200.0 | 93,491 | 934.912 | | 26.800 |
| **4** | | **Production of Mineral Products** | | | | | **320,000** | 200,000 | 1,000 |
| c | | Brick | | | | 10,000,000 | 320,000 | 200,000 | 1,000 |

| Source | Class | Source Group & Category | Emission factor (μg/t ) | | | Activity Rate (t/a) | Emission (g/a) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Air | Product | Residue | | Air | Product | Residue |
| | | No emission abatement in place and using contaminated fuels | 225,000 | 100,000 | 1,000 | 0 | 0 | 0 | 0 |
| | | No emission abatement in place and using non-contaminated fuels; Emssion abatement in place and using any kind of fuel; No emission abatement in place but state of the art process control | 32,000 | 20,000 | 100 | 10,000,000 | 320,000 | 200,000 | 1,000 |
| 5 | | **Transport** | | | | | **163.615** | | |
| d | | Heavy oil fired engines | | | | 1,168,679 | 163.615 | 0 | 0 |
| | 1 | All types | 140 | | | 1,168,679 | 163.615 | | |
| 7 | | **Production and Use of Chemicals and Consumer Goods** | | | | | **0.000** | **377,550** | **0.000** |
| **dh** | | **Chlorinated Paraffins** | | | | **30,000** | **0.000** | **225,000** | **0.000** |
| | 1 | Low-End Technologies | | 8.9E6 | | 0 | | | |
| | 2 | Mid-Range Technologies | | 7.5E6 | | 30,000 | | 225,000 | |
| | 3 | High-End Technologies | | 7,000 | | 0 | | 0 | |
| **dj** | | **Phthalocyanine dyes and pigments** | | | | **1,000** | **0.000** | **110,500** | **0.000** |
| | 1 | Phthalocyanine copper | | 200E6 | | 500 | | 100,000 | |
| | | Phthalocyanine copper BAT | | 10 E6 | | 500 | | 5,000 | |
| | 2 | Phthalocyanine green | | 10E6 | | 500 | | 5,000 | |
| | 2 | Phthalocyanine green BAT | | 1E6 | | 500 | | 500 | |
| dm | | Tetrachlorophthalic acid (CAS 632-58-6) | | | | | | 0 | |
| | 1 | General | | 2,000E6 | | 0 | | 0 | |
| | 2 | BAT | | 200E6 | | 0 | | 0 | |
| dn | | Solvent Red 135 (CAS 20749-68-2) | | | | | | 10,500 | |
| | 1 | General | | 200E6 | | 50 | | 10,000 | |
| | 2 | BAT | | 10E6 | | 50 | | 500 | |
| do | | Pigments Yellow 110 (CAS 5590-18-1 ) & 138 (CAS 30125-47-4) | | | | | | 20,500 | |
| | 1 | Pigment Yellow | | 200E6 | | 50 | | 10,000 | |
| dq | | Pigment Green 7 (CAS 1328-53-6) | | | | | | 10,500 | |
| | 1 | General | | 200E6 | | 50 | | 10,000 | |
| | 2 | BAT | | 10E6 | | 50 | | 500 | |
| dr | | Pigment Green 36 (CAS 14302-13-7) | | | | | | 550 | |

| Source | Class | Source Group & Category | Emission factor (µg/t ) | | | Activity Rate (t/a) | Emission (g/a) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Air | Product | Residue | | Air | Product | Residue |
| | 1 | General | | 10E6 | | 50 | | 500 | |
| | 2 | BAT | | 1E6 | | 50 | | 50 | |

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