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Updated Emission Estimates of Ozone Precursors from Energy Consumption by Power Plants and Industrial Facilities in the Central and Eastern Regions of Thailand

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Abstract: Effective regional ozone (O3) pollution management necessarily requires a representative emission database of key O3 precursors. This work presents new results from the ongoing development of such an emission database of power plants and industrial facilities in the central and eastern regions of Thailand. The development is based on recent energy and industrial activity data compiled or available from several domestic sources in both governmental and private sectors. The O3 precursors considered are nitrogen oxides (NOX), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOC). The emission estimates were calculated using emissions factors recommended by the United State Environmental Protection Agency or by the Intergovernmental Panel on Climate Change. It was found that total annual emission estimates from power plants are 29.6×10^3 ton NOX (as NO2), 2.4×10^3 ton NMVOC, and 17.5×10^3 ton CO in the central region and 33.0×10^3 ton NOX (as NO2), 2.3×10^3 ton NMVOC, and 23.8×10^3 ton CO in the eastern region; the total annual emission estimates from industrial facilities are 89.9×10^3 ton NOX (as NO2), 14.4×10^3 ton NMVOC, and 508.1×10^3 ton CO in the central region, and 37.6×103 ton NOX (as NO2), 4.4×10^3 ton NMVOC, and 144.9×10^3 ton CO in the eastern region.

Keywords: Power Plants, Industrial Facilities, Emission Estimates, Ozone Precursors, Energy Consumption, Thailand

Introduction

Tropospheric ozone (O3) can cause adverse effects on human health and environment [1-4]. Unlike many other air pollutants, tropospheric ozone is not emitted directly but is formed in the atmosphere through complex chemical reactions involving nitrogen oxides (NOX), volatile organic compounds (VOC) and carbon monoxide (CO) under the presence of sunlight (Eq. 1) [5]. NOX and VOC are typically considered the O3 precursors of most concern. NOX is the combination of nitric oxide (NO) and nitrogen dioxide (NO2). NO is released from both combustion and natural processes (mostly, the former) and is converted to nitrogen dioxide (NO2) in the ambient air by direct oxidation with both O2 and O3. VOC (written as hydrocarbons, RH, in Eq.1) in the troposphere rapidly reacts with hydroxyl radical (OH), forming peroxyl radical (RO2) and then increasing NO2 production through the reaction with NO. Methane (CH4), however, is often excluded due to its relatively insignificant reactivity to O3 formation [6]. CO is also another O3 precursor and can be important when urban air pollution is considered. CO also reacts with OH, forming hydroperoxy radical (HO2) and then enhancing NO2 production through the reaction with NO. Understanding of source and sink processes/mechanisms of O3 precursors is an important step to control and mitigate O3 pollution problems [7].

$$
\begin{aligned}
&RH + OH \xrightarrow{[O_2]} RO_2 + H_2O \\
&CO + OH \xrightarrow{[O_2]} HO_2 + CO_2 \\
&RO_2 + NO \xrightarrow{[O_2]} R'CHO + HO_2 + NO_2 \\
&HO_2 + NO \xrightarrow{[O_2]} OH + NO_2 \\
&NO_2 + h\nu \longrightarrow NO + O \\
&O + O_2 \longrightarrow O_3
\end{aligned} \qquad (1)
$$

To achieve effective regional air quality management, a good information system is a must-have, in which an updated and representative emission inventory is desired. However, for Thailand, such an information system is typically not available or still far from being adequate or complete [8], particularly for regional scales. This work aims to fill a gap of what needs to be done in terms of emission data of O3 precursors. Here, we show results from the ongoing development of a new emission inventory of O3 precursors for power plants and industrial (i.e., non-power plant) facilities in Thailand. However, we limit our presentation only to NOX, NMVOC, and CO emission estimates from energy consumption by power plants and industrial facilities located in the central and eastern regions of Thailand (Fig. 2). Our work also does not include offshore facilities and waste disposal in power plants and industrial facilities. It is important to note that these two regions have the largest share of power plants and industrial facilities in Thailand (Table 1).

Table 1 Power plants and industrial facilities in central and eastern regions

Region	No. of Power Plants	Percent[a]	No. of Industrial Facilities	Percent[a]
Central	36	29.8	47,035	38.6
Eastern	39	32.2	8,560	7.0

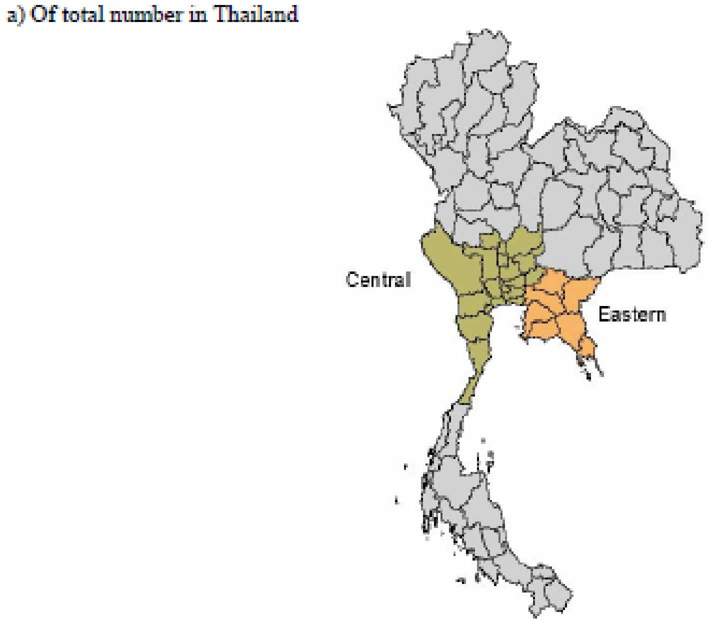

Fig. 1 Map of Thailand

Methodology

The general formula to estimate the emission rate of a pollutant emitted from a source [9] is given as follows:

$$E = EF_{uncontrolled} \times A \times \left(1 - \frac{ER}{100}\right) = ER_{controlled} \times A, \quad (2)$$

where E: Emission rate [mass per time],
$EF_{uncontrolled}$: Emission factor without control technology [mass per activity unit],
$EF_{controlled}$: Emission factor with control technologies [mass per activity unit],
A: Activity rate [activity unit per time], and
ER: Control efficiency (in percent).

It is simply the product of the emission factor and the activity rate of an emission source. The emission factor is directly dependent on the control technology applied to the source and its control efficiency.

In Thailand, power plants are divided into four production sectors: Electricity Generating Authority of Thailand (EGAT), Independent Power Producer (IPP), Small Power Producer (SPP), and Very Small Power Producer (VSPP). Based on year 2004, for thermal power plants, the contributions of the first three sectors to total electricity generation are approximately 45%, 43%, and 11% (i.e., ~99% in total) [10]. Thus, only emissions from these three sectors were estimated, i.e., emissions from the VSPP sector were excluded due to its relatively small contribution. Moreover, it was assumed that other forms of power generation (e.g., hydro-power, solar energy, and wind turbine) were not significant emission sources and were then not accounted for. For the EGAT and IPP power plants, emissions were calculated based on the combination of both fuel consumption rates and some specific data of each power plant (Table 2). NOX and CO emission factors were taken from the AP-42 document of the US Environmental Protection Agency (US EPA) [9] and NMVOC emission factors were taken from the Intergovernmental Panel on Climate Change (IPCC) [11]. For the SPP power plants, fuel consumption rates were only used (with simplification due to lack of detailed information), and emission factors were taken from the IPCC. It is noted that many power plants in Thailand are equipped with emission control technology for their emission reduction. Unfortunately, to estimate or obtain the control efficiency estimates of such control technology was found to be very difficult due primarily to lack or inaccessibility of data. We, nevertheless, chose controlled NOX emission factors from the AP-42 [9] for the EGAT and IPP power plants where low NOX burner, water injection are usually employed [12]. For the SPP power plants, no control technology was assumed due to the absence of information.

To estimate emissions from energy consumption by industrial facilities, a comprehensive list of those facilities was requested and obtained from the Department of Industrial Works (DIW), containing the types, sizes, locations, and boiler/machine installed power requirements of (nearly) all industrial facilities in Thailand. Those industrial facilities were then grouped into nine categories, following the Thai Standard Industrial Classification (TSIC). Table 3 shows the national energy consumption by industrial facilities in each category. Emission factors used in calculation for industrial facilities were here chosen from the IPCC [11], and they were assumed to be uncontrolled at this point (due to lack of reliable control technology information available). It was also assumed that electricity usage in an industrial facility does not produce emissions. Here, emission from an industrial facility is calculated as the product of emission factor (per power unit), installed power requirement, and number of operating hours. The survey of operatinghour information is still underway, and the information has not yet been incorporated herein. The assumption of 48-hour per week operation was used for the time being and applied to each industrial facility.

Table 2 Fuel consumption by EGAT and IPP sectors in central and eastern regions [10]

Type of Power Plants	Natural Gas (10^9 m^3)	Fuel Oil (10^6 m^3)	Diesel Oil (10^3 m^3)
Steam	4.6	1.4	1.5
Combined Cycle	13.4	-	92.1
Gas Turbine	-	-	0.2

Table 3 National energy consumption by industrial facilities (in percent [10]

Category	Coal & Lignite	Petroleum[a]	Natural Gas	Electricity	Renewable Energy[b]
Food & Beverage	1.3	14.5	0.7	10.2	73.3
Textile	7.3	47.9	-	44.8	-
Wood & Furniture	-	21.7	-	69.8	8.5
Paper	52.7	31.4	-	15.9	-
Chemicals	24.5	28.1	16.2	26.5	4.7
Non-Metal	62.8	10.5	14.0	8.6	4.1
Basic Metal	14.3	37.0	-	48.7	-
Fabrication	-	17.7	17.3	65.0	-
Other (Unclassified)	6.5	85.2	-	8.3	-

a) For example, fuel oil, gasoline diesel, and kerosene
b) Mostly, biofuels (e.g., paddy husk, bagasse, fuel wood, garbage, and agricultural waste)

Results

It was found that total annual emission estimates from power plants are 29.6×10^3 ton NOX (as NO2), 2.4×10^3 ton NMVOC, and 17.5×10^3 ton CO in the central region and 33.0×10^3 ton NOX (as NO2), 2.3×10^3 ton NMVOC, and 23.8×10^3 ton CO in the eastern region (Table 4). As seen in the table, CO is large in the SPP sector due to relatively large biofuel consumption by this sector. The eastern region releases more CO because more SPP power plants are located in this region. In the central region, NOX is largest in the IPP sector while, in the eastern region, it is largest in the SPP sector. It should be noted that NOX in the EGAT sector in the eastern region comes only from one EGAT power plant which is one of the largest thermal power plants in Thailand. For industrial facilities, the total annual emission estimates are 89.9×10^3 ton NOX (as NO2), 14.4×10^3 ton NMVOC, and 508.1×10^3 ton CO in the central region, and 37.6×10^3 ton NOX (as NO2), 4.4×10^3 ton NMVOC, and 144.9×10^3ton CO in the eastern region (Table 5). Table 5 also shows the emission estimates by category of industry. Note that the last category (i.e., Other (Unclassified)) are quite large, the reason of which is that both installed power requirement (Table 4) and petroleum consumption (Table 3) are large in this category. In the central region, Food & Beverage and Non-Metal categories have large installed power requirements while, in the eastern region, they are Chemicals and Basic Metal categories, explaining large emissions from these categories.

Table 4 Emission estimates for thermal power plants in the central and eastern regions

Sector	Central			Eastern		
	NOX (10^3 ton)	NMVOC (10^3 ton)	CO (10^3 ton)	NOX (10^3 ton)	NMVOC (10^3 ton)	CO (10^3 ton)
EGAT	10.6	0.8	2.8	8.0	0.4	3.2
IPP	14.6	1.0	4.7	7.0	0.6	1.6
SPP	4.4	0.6	10.0	18.0	1.3	19.0
Total	29.6	2.4	17.5	33.0	2.3	23.8

Table 5 Emission estimates for industrial facilities in the central and eastern regions by category

Category	Central				Eastern			
	Installed Power Requirement[a] (hp[b])	NOX (10^3 ton)	NMVOC (10^3 ton)	CO (10^3 ton)	Installed Power Requirement[a] (hp[b])	NOX (10^3 ton)	NMVOC (10^3 ton)	CO (10^3 ton)
Food & Beverage	36.8×10^2 [5,325]	13.8	5.1	200.4	9.4×10^2 [1,957]	1.3	0.5	19.0
Textile	9.3×10^2 [5,486]	3.5	0.3	10.2	14.7×10^2 [300]	0.3	0[c]	0.9
Wood & Furniture	2.4×10^2 [3,442]	0.3	0[c]	1.0	5.3×10^2 [749]	0.1	0[c]	0.5
Paper	7.5×10^2 [2,748]	1.6	0.7	29.2	29.7×10^2 [189]	0.4	0.2	8.0
Chemicals	7.1×10^2 [6,380]	3.3	0.9	32.9	64.4×10^2 [1,143]	5.4	1.4	53.5
Non-Metal	39.5×10^2 [1,919]	5.5	3.4	132.4	12.3×10^2 [501]	0.5	0.3	10.8
Basic Metal	30.0×10^2 [835]	1.5	0.3	9.7	175.4×10^2 [129]	1.3	0.2	8.7
Fabrication	2.7×10^2 [16,969]	1.9	0.1	0.2	8.0×10^2 [2,367]	0.8	0[c]	0.1
Other (Unclassified)	125.2×10^2 [3,931]	58.3	3.6	92.1	189.3×10^2 [1,225]	27.5	1.7	43.5
Total		89.9	14.4	508.1		37.6	4.4	144.9

a) Mean value among all facilities in a category [No. of facilities]
b) Horsepower
c) Less than 0.05

Ongoing work

This work presents the new estimates of O3 precursor emissions from energy consumption by power plants and industrial facilities in the central and eastern regions of Thailand. They represent the results obtained so far from the ongoing study. Some of these estimates may need to be adjusted before being finalized. The scope of the ongoing work covers entire Thailand, other gaseous and particulate emissions (associated with many criteria air pollutants) from both energy consumption and industrialprocesses, offshore facilities, physical characterization of emission sources (e.g., stack parameters and source locations), and development of temporal distribution profiles of emission sources.

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