Influences of Agricultural Activities, Forest Fires and Agro-industries on Air Quality in Thailand

Dissertation

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Graduate School of Natural Science and Technology

Kanazawa University

Division of Environmental Science and Engineering

WORRADORN PHAIRUANG

Abstract

Annual and monthly base emission inventory (EI) in Thailand, where agriculture and related agro-industries are so intensive, were estimated to discuss the contribution of agricultural activity including forest fires and related agro-industries to the air quality in corresponding provinces. The monthly base emission inventories of air pollutants for various agricultural crops, which have not been summarized for each province so far, were estimated based on the production amount of typical crops rice, corn, sugarcane, cassava, soybean and potato using emission factors and other parameters of country-specific values taking into account climate and crop type. The estimated monthly emission was compared with the monitoring data obtained at monitoring stations operated by Pollution Control Department, Thailand (PCD) for the validation of estimated EI and contribution of other emission sources. As the most influencing agroindustry in the discussed regions, the EI of sugar factory that use sugarcane both as raw material and fuel for the boiler was estimated to discuss the contribution. An emission from the full biomass boilers in Thailand, in the case study, Songkhla from the southern part of Thailand displayed the types of solid biomass energy use, the fuelwood mainly utilized in the process. The monitoring of biomass burning was studied in Bangkok and Chiang Mai. The carbon components in Particulate matter revealed that the ambient air effects from biomass activities. The special episode of biomass burning took place in the dry season (November to April) that associated with local sources from biomass burning activities in each region.

1. Contents of this Research

This research composes of 3 parts, namely chapter 2; Influence of biomass burning on air quality in Thailand, chapter 3; Environmental impact from agro-industries on air quality in Thailand and chapter 4; Carbon components in size-segregated distribution of particulate matter in Thailand.

1.1 Influence of Biomass Burning on Air Quality in Thailand by Emission Inventory Analysis

Air pollutant emissions from open biomass burning in Thailand, including forest fire and agricultural residue burning, were investigated for reporting to Emission Inventory (EI) in Thailand year 2014. The emission inventory analysis method was integrated with satellite, government and review literature data for the best emission estimate. Moreover, the leading agro-industry for consuming biomass residues was investigated to complete the EI. The pollutants were studied during a one year period and include particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x) and sulfur dioxide (SO_2). Emitted amounts from forest fires and crop residue burning was examined, including rice, sugarcane, cassava, corn, soybean, and potato. All selected crops are subject to burning in the field before and after harvesting. The Emission Factors (EFs) and other parameters were mostly derived from country-specific values for Thailand and nearby regions. Monthly emission amounts were compared with data from air monitoring stations representative to the air quality in Thailand.

1.2 Environmental Impact from Agro-industries to Air Quality in Thailand

Biomass solid fuel is commonly used in agricultural-based countries. Many agricultural solid wastes are utilized for producing energy and electricity for product processing. In Thailand, the economy is shifting from the agricultural sector to the industrial and service sectors. The biomass energy consumption in the agricultural production process may produce a considerable amount of air pollutions such as particulate matter and toxic gases. The environmental impact on the atmosphere of residues, including bagasse, palm oil trash, rice husk, rubber wood and so on, was estimated by emission inventory analysis. The complete results were added to the total biomass burning in Thailand for integrated emission source from biomass burning.

1.3 Carbon Components in Size-segregated Distribution of Particulate Matter in Thailand

Carbonaceous aerosols are largely distributed from biomass burning. To understand the effect of particulate matter on the environment as well as human health, it is crucial to identify the chemical composition in each particle size. In this research, the author used a Nano-sampler that

consists of a five stage impactor to separate particulate matter according to size and analyze chemical composition from 2 station sites in Thailand, namely Bangkok (Central) and Chiang Mai (Northern). This study aims to reach a better understanding of the major carbon components (OC and EC) in PM. Moreover, these results may confirm the particle sources and identify potential sources from spatial and temporal EI.

2. Results and discussion

2.1 **Annual and Monthly-based Emissions from Biomass Burning**

Table 1 Emissions of air pollutants from forest fires and the burning of each crop residue in Thailand for the year 2014 (unit: tons/year)

Type	PM_{10}	$PM_{2.5}$	NO_x	SO_2
Rice	88,541	80,757	54,625	7,644
Corn	7,734	7,734	2,928	461
Sugarcane	54,177	39,506	19,274	4,603
Soybean	166	166	101	29
Potato	78	78	34	10
Cassava	2,781	2,781	1,212	342
Forest fire	69,640	69,640	7,312	1,516
All Type	223,117	200,662	85,486	14,605

Table 1 shows the annual emissions for emission inventory analysis of open biomass burning for 2014. The emission estimates from forest fires and crop residue burning were as follows; PM_{10} 223,117 tons, $PM_{2.5}$, 200,662 tons, NO_X 85,486 tons and SO_2 14,605 tons. Fig. 2.3 displays the percentage of each type of air pollutant emission from open biomass burning for 2014. Rice is the largest contributor in all species: PM_{10} and $PM_{2.5}$ around 40%, NO_x 64% and SO_2 52%. Overall, for most pollutants from agricultural residue burning, rice residue burning contributes the largest emissions, followed by sugarcane and cassava residue burning. Emissions from other plants, including corn, soybean and potato, are too small to be shown in this figure. Fig. 1 displays the distribution of estimated PM_{10} emission per year, representing PM_{10} emission is important in northern and north-eastern parts of Thailand.

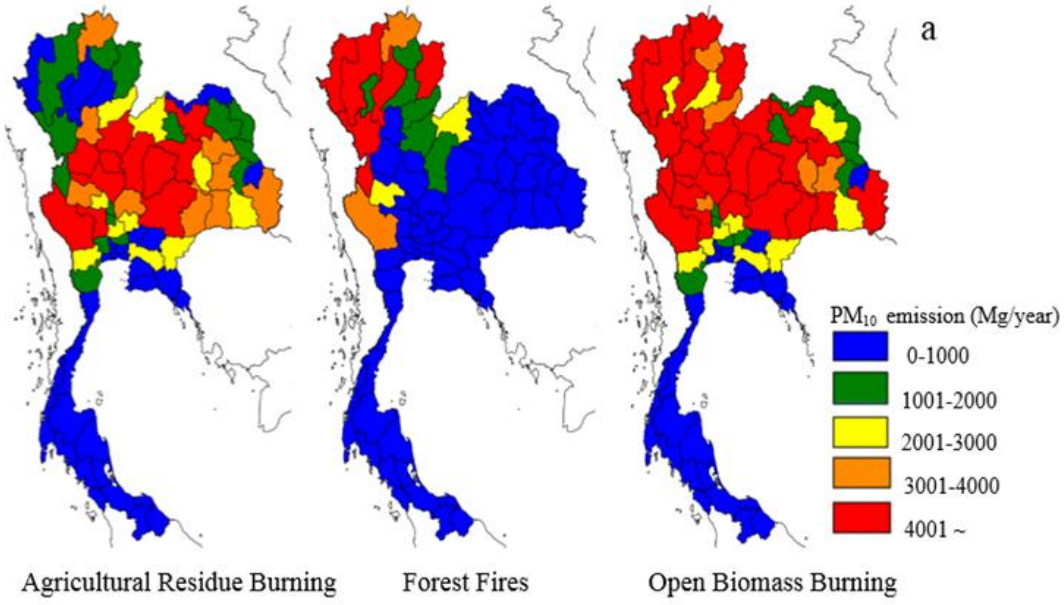

Fig. 1 Contribution of PM_{10} emission from open biomass burning

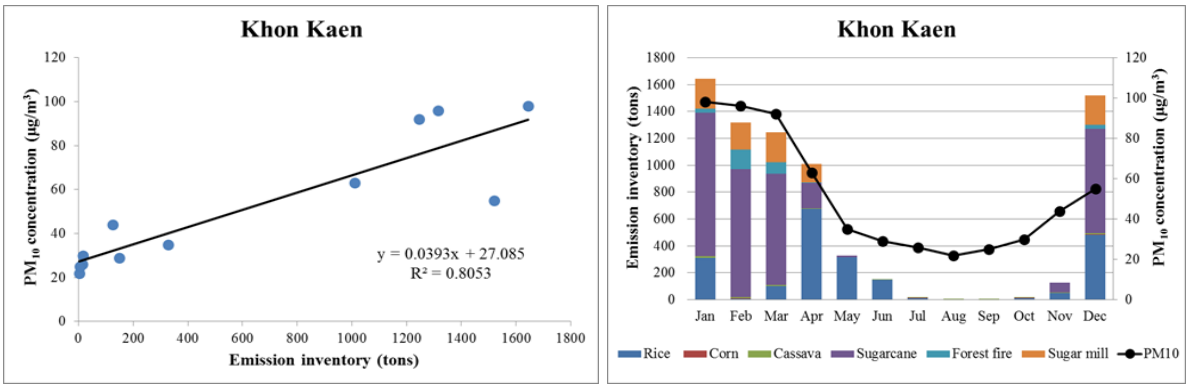

Fig. 2 Correlation of monthly averaged PM_{10} and monthly emission inventory from crop residue and agro-industry in Khon Kaen, 2014

Fig. 2 shows correlations of emission inventory and average PM_{10} concentration in the typical province of Thailand, *Khon Kaen* in the north-eastern region. The emission from rice and sugarcane are major crops and sugarcane residue is used as solid biomass fuel for energy supply. A good correlation between total emission inventory and average PM_{10} concentration was found between these amounts, indicating contributions of crop residue burning, forest fires and sugar mills are vital to the air pollutions by particulate matter in this area.

2.2 Emission Inventory from Agro-industries

2.2.1 Emission from Agro-industries in Thailand

Table 2 The total emissions of air pollutants from biomass boilers in Thailand, 2014

Biomass type	PM_{10}	$PM_{2.5}$	NO_X	SO_2
	(tons/year)			
Bagasse	13,451	13,361	33,627	8,608
Wood (Chip, dust, etc.)	48,367	48,044	48,367	12,382
Rice husk	9,238	9,176	9,238	2,365
Oil palm	5,862	5,823	5,862	1,501
Wood + oil palm shell	4,069	4,042	4,069	1,042
Wood + bagasse	1,918	1,906	1,918	491
Corn peel	581	577	581	149
Coconut shell	411	408	411	105
Wood + rice husk	263	261	263	67
Wood + corn cobs	217	215	217	56
Corn cobs	215	214	215	55
Coffee grounds	73	72	73	19
Wood + coconut shell	36	36	36	92
Soybean meal	31	31	31	8
Cotton shell	12	12	12	3
Banana peel	5	5	5	1
Total	84,748	84,183	104,924	26,944

PM_{10}, $PM_{2.5}$ and NOx emissions were comparatively equivalent between different boiler types, relying on EFs that are quite similar for estimating emissions in industrial boilers. However, PM emissions from bagasse boilers were slightly lower compared to NO_x. The main reason is that all sugar mills in Thailand already use installed multi-cyclones before releasing dust into the atmosphere. There were lacking data on collection efficiency for NO_x and SO_2 as well as PMs from other biomass boilers (except bagasse). Sugar factories make up such a large part of the food and beverage industry in Thailand that the enormous emissions from the production process had to be controlled, which is why the mills were equipped with pollution control devices.

2.2.2 Emission Inventory from Agro-industries in Songkhla

Agro-industries in Songkhla province mainly consumed biomass energy for the production process. Total PM_{10} and $PM_{2.5}$ emissions from biomass fuel were 2,674 and 2,859 tons/year, respectively (Table 3). Regarding types of solid biomass energy used, wood was the main fuel in the process and accounted for up to 93% of total PM emissions from the agro-industry sector (Fig. 3). On the other hand, the percentage of NO_x and SO_2 emitted from agro-industry is different from PMs. The amount of NO_x from biomass boilers is quite similar to the PM amount, around 2,625 tons/year, but only represent 61% of total NO_x emissions. NO_x from other fuel types, including diesel and C grade fuel oil, account for approximately 1,710 tons (39%) of the emissions. Also, SO2 is widely released from fossil fuel types, with emissions up to 8,691 tons (92%), while a much smaller amount is emitted from solid biomass fuel; 731 tons (8%). Regarding energy sources used in agro-industry, fuel wood is largely used in the southern region of Thailand. Biomass fuel releases an enormous amount of PM in the atmosphere. There is a lack of reliable data for an emission control device for controlling particles from the industry processes that is subject to causing considerable air pollution in this area.

Table 3 Emission of air pollutants from industry in Songkhla, Thailand, 2014

Types	Emission (tons/year)			
	PM_{10}	$PM_{2.5}$	NO_x	SO_2
Emission by biomass fuel	2,674	2,656	2,625	731
Emission except biomass	203	203	1,710	7,960
Emission by industry	2,877	2,859	4,335	8,691

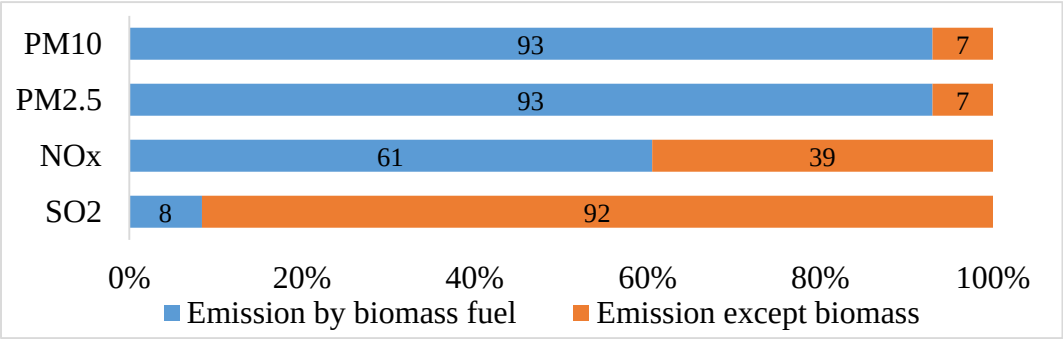

Fig. 3 Contribution of air pollutant emission from agro-industry in Songkhla, Thailand

2.3 Carbon Components in Size-segregated Distribution of Particulate Matter in Thailand

2.3.1 Bangkok

The ratio of Char-EC to Soot-EC is more efficient for source identification of carbonaceous aerosol than the OC/EC ratio. The Char-EC/Soot-EC at the KMUTNB site was separated into the wet and the dry season for each size-segregated distribution of PMs. The same pattern was found for $PM_{0.5\text{-}1.0}$, $PM_{1.0\text{-}2.5}$ and $PM_{2.5\text{-}10}$, with average Char-EC/Soot-EC ratios of 4.73 ± 2.36, 3.94 ± 1.83, 2.60 ± 1.05 for the respective sizes in the wet season, compared to 3.25 ± 3.20, 4.52 ± 3.79, 2.40 ± 1.63 in the dry season. These ratios suggest that the PM samples are more highly affected by the biomass burning activities. On the other hand, Char-EC/Soot-EC values for particulate sizes $PM_{0.1}$ and $PM_{>10}$ were less than 1.0 both in the rainy and in the dry season. These samples are influenced to a higher degree by vehicle exhausts. A higher Char-EC/Soot-EC ratio indicates the dominance of biomass burning associated Char-EC contributions to total EC contents; while ratio < 1.0 suggests that Soot-EC from fossil fuel combustion is a large contributor to total EC.

2.3.2 Chiang Mai

The observed correlations of Char-EC and Soot-EC with EC in size-segregated of PMs in Chiang Mai are plotted together to provide an overview and demonstrate the relationships. Char-EC displayed the strongest correlation with EC in all size distribution, indicating that Char-EC dominated the total EC, whereas Soot-EC showed a good correlation with EC in $PM_{0.1}$ and $PM_{>10}$. Unlike the Bangkok site, the Chiang Mai University site was near biomass burning sources. The Char-EC/Soot-EC ratio in $PM_{0.1}$ was lower than 1.0 in the wet season, suggesting that motor vehicles and transportation were the primary sources. The dry season, however, was influenced by forest fires in the area.

$PM_{0.5\text{-}1.0}$, $PM_{1.0\text{-}2.5}$, and $PM_{2.5\text{-}10}$ showed a good correlation between Char-EC and EC. The result suggests that the most important contributions of Char-EC to total EC contents in Chiang Mai ambient air originated from biomass combustion in the suburban area. In contrast, both Char-EC and Soot-EC had high correlations with EC in $PM_{0.1}$. This result could explain the high Soot-EC content relative to Char-EC in $PM_{0.1}$.

3.Conclusion

Annual and monthly-based emission inventories were estimated to discuss the contribution of agricultural activity including crop residue burning, forest fires and related agro-industries to

the air quality monitored in corresponding provinces in Thailand. An Emission Inventory (EI) of total biomass burning in Thailand was estimated for one year, from January to December 2014. Air quality in Thailand was found affected by biomass burning, including open burning as well as agro-industry with biomass consumption. The estimated monthly emission inventory was compared with air monitoring data obtained at monitoring stations operated by the Pollution Control Department, Thailand (PCD) to validate the estimated emission inventory and the contribution of other emission sources. The emission inventory identified sugar production as the agro-industry with the largest influence, and the contribution of sugarcane being used both as raw material and boiler fuel is discussed. However, emission sources were different in each region. Chiang Mai in upper northern Thailand was distinguished by PM_{10} mainly coming from forest fires, whereas emissions in the lower northern part (Nakhon Sawan) and the northeast (Khon Kaen and Nakhon Ratchasima) were predominantly related to open crop burning and sugarcane agro-industry. In the south of Thailand, Songkhla ambient air was affected by agricultural waste burning in biomass boilers. Moreover, characteristics of the size distribution of particulate matter and carbon components in Bangkok and Chiang Mai suggest that biomass activities influenced both study sites. In Bangkok, the carbon compositions pointed to agricultural activities in neighboring provinces. On the other hand, Chiang Mai ambient air was mainly affected by forest fires and crop residue burning in the area.

平成２８年２月２日

学位論文審査報告書（甲）

１．学位論文題目（外国語の場合は和訳を付けること。）

Influences of Agricultural Activities, Forest Fires and Agro-industries on Air Quality in Thailand （農業・森林火災・アグロインダストリーがタイの空気質に及ぼす影響）

２．論文提出者 (1) 所　　属　環境科学　専攻

(2) 氏（ふり）名（がな）　Worradorn Phairuang （ウォラドーン　ファイルアン）

３．審査結果の要旨（600～650字）

提出された論文に対し，書面および口述審査を実施し，以下のように判断した。

本論文は，農業・アグロインダストリーで行われるバイオマス燃焼および森林火災による大気環境負荷に着目し，タイを対象として以下の項目を検討・考察したものである。すなわち１）月別・県別・農作物別排出インベントリ，森林火災排出インベントリに基づく大気汚染物質排出量推定および大気汚染モニタリングデータとの比較による環境負荷影響の評価，２）工場でのバイオマス燃料利用時の大気汚染物質排出インベントリ評価，３）バンコク周辺部での気中粒子中の炭素成分特性と農業起源排出インベントリの関係の考察である。これらの検討・考察の結果，タイ北部では森林火災，中部・東北部では農作物残渣の野焼きと砂糖工場での農作物残渣の燃料利用による粒子排出が気中粒子濃度をほぼ支配すること，タイ南部では工場排出粒子に占める古木燃料寄与が90%を超えること，バンコクでは乾季にタイ東北部からの野焼き煙輸送の影響が顕著になること，気中ナノ粒子へのバイオマス燃焼影響が農業起源粒子排出インベントリと正の相関があることなどを明らかにした。

以上のとおり，本成果は環境に配慮したバイオマス生産・利用を進める上で極めて有用なものであり，学術的価値も高い。またこれらは１編の英語論文にまとめられており，国際学会での成果発表回数も多く，語学力も十分と認められる。

４．審査結果　(1) 判　　定（いずれかに○印）（合　格）・　不合格

(2) 授与学位　博　士（　学術　）

５．学位論文及び参考論文に不適切な引用や剽窃が無いことの確認

☑　確認済み

（確認方法：ithenticate による確認　　）

☐　未確認

（理由：　　）