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Inventory of Greenhouse Gas Emissions for Phayao Province - An Agricultural City in Thailand

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Greenhouse gas (GHG) mitigation is one of the major challenges that all countries face. The impacts of GHG emissions cost people and ecosystem everywhere. Hence, it is the responsibility of all parties to tackle this serious problem. For instance, Thailand has agreed to decrease GHG emissions by 20 % from the projected business-as-usual (BAU) level by 2030 despite no commitment to target GHG emissions reduction. As a part of the contribution, this study aimed at preparing a GHG emissions inventory (EI) from the main pollution sources in Phayao province located in the North of Thailand. We investigated annual amount of GHG emissions by using a bottom-up approach. Both primary data from field survey and secondary data from governmental agencies in Thailand were employed in our analysis. From the preliminary study, Phayao's economy depends on agriculture, like other ASEAN countries. The major sources of GHG generation comprised of rice cultivation, open burning (including crop residue burning and forest fire), road transportation, industry, and livestock (from enteric fermentation and manure management). GHG emissions from rice fields, open burning, road transportation, industry, and livestock were estimated to be 773,325; 1,819,225; 195,497; 4,625 and 133,830 t CO_2-eq. Approximately 89 % of GHG emissions were emitted from agricultural sector (biomass open burning and rice cultivation). The results of this study suggest that the proper and effective measures for mitigating GHG emissions from agricultural ecosystems is the first priority to emphasise.

1. Introduction

Ocean and land temperatures demonstrate that the Earth has been warmed. This phenomenon is attributed to human-caused GHG emissions. The average global, land, and ocean temperature has now risen about 0.7, 1, and 0.6 °C above normal in the last 100 years (Prasad et al., 2017). Geographically, Thailand is one of the sixteen countries at extreme risk due to climate change impacts over the next thirty years with a higher growth rate of average temperature compared to the world (an increase of ~ 1 °C within ~ 50 years) (ONEP, 2015b). Also, Thailand is one of the seven countries in the Asia with high population, a major factor that can make things difficult for the protection of environment (Klemeš et al., 2017). Anyway, Thailand has committed to a voluntary 7 % - 20 % GHG reduction in the energy and transport sectors by 2020 and 20 % reduction from the projected BAU level (~ 555 Mt CO_2-eq) by 2030 (Leggett, 2015). Thailand is an agricultural country (Arunrat et al., 2016), same as most of the ASEAN countries (except Singapore and Brunei) (Shukun and Yanhua, 2014). Agriculture is the 2nd largest contributor to GHG emissions after energy sector (Bordoff, 2016) and this makes it a major source of GHGs emitted to the air from ASEAN. This should be the same with Phayao province, an agricultural city with an estimated population of 0.49 M in 2013 (NSO, 2013) that obtained 422 M USD or 43 % of gross provincial product from agricultural activities (NESDB, 2013). That income was created from ~ 228,920 ha of arable land, accounting for 36.1 % of the whole territory. Rice is the most important crop occupying ~ 132,798

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ha (58 %) of the total cultivated area in Phayao (Pimmasarn et al., 2013). Other economic crops (e.g., corn, longan, lychee, garlic, and shallot) occupy space less than 10 % of the provincial area (OAE, 2015). Apart from agricultural sector, from the preliminary observation, forest fire, transportation, industry and livestock can also be the main contributors to global warming potential (GWP) in this province. So as to meet the goal to reduce GHG emissions efficiently and cost-effectively, an initial task is to identify environmental hotspots. This study aims to develop a GHG EI for Phayao province, a northern city in Thailand, by using bottom-up approach that takes a detailed look at each potential source in an investigation (Song et al., 2017).

2. Methods

2.1 Activity data

Detailed data for the estimation and development of a GHG EI for Phayao province were obtained from many sources including governmental organisations. The summary of activity data and sources of information are presented in Table 1. Major sources of emissions based upon data availability can be categorised as rice field, open burning, transport, industry, and livestock. Aside from on-site data collection, related information for the estimation of GHGs for paddy field was mainly acquired from Phayao Provincial Agricultural Extension Office (DOAE, 2011). The emission factor (EF) values for rice field were adopted from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). To estimate emissions from open burning of all main agricultural residues and forest fire, high-resolution satellite images from the Moderate Resolution Imaging Spectroradiometer (MODIS) were utilised to identify the location and size of the burn (NASA, 2012). The EF values from literatures for crop residue burning (rice, and corn) (Kanabkaew and Oanh, 2011) and forest fire were used (Andreae and Merlet, 2001). Actually, forest fire (with or without intention) is a cause of land-use change, a crucial factor that impact on GHG balance (Prueksakorn, 2017). To develop a GHG EI for transport section of Phayao province, data for traffic, car speed, registered car, and fuel amount were obtained from Department of Highway (DOH, 2012), Highway Police Division (HPD, 2012), Department of Land Transport (DLT, 2012), and Ministry of Energy (MOE, 2015). Traffic data observed by DOH was collected from 7.00 am – 7.00 pm, and data for the remaining time to complete the 24 h sampling was further collected on site, manually. The EF values for transport were determined based on fuel used, year of cars, and type of cars, from the research project studied in Bangkok, Thailand (ESMAP, 2009). For industries, the activity data were partly received from Phayao Province Industry Office (PIO, 2012). Additional survey was performed to complete activity data. The values of EF were extracted from the guideline of United States Environmental Protection Agency (US EPA, 2005). The data for livestock were collected from provincial livestock office and site survey (Muenchan and Pimonsree, 2012). The EF values for livestock were derived from the IPCC (IPCC, 2006).

Table 1: The activity data from major sources of GHGs generation in Phayao

Emission sources	Related data for the estimation	The source of data
Rice cultivation	Registered farmer, area, plantation method	DOAE, 2011 Pimmasarn et al., 2013
Open burning	Hotspot	NASA, 2012
Transportation	Traffic	DOH, 2012
	Speed of car	HPD, 2012
	Registered car	DLT, 2012
	Fuel	MOE, 2015
Industry	Location, production capacity,	PIO, 2012
Livestock	Pollution control technology, animals, farm locations, sex, and weight	Muenchan and Pimonsree, 2012

2.2 Emissions Estimation

To estimate GHG emissions in the study period, carbon assessment manual 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Inventories is used in this study. GHG substances i.e., CO_2, CH_4, and N_2O are then converted to the single unit – CO_2 equivalent (CO_2-eq) for 100 years with the conversion factors based on IPCC (2006); 1 time for CO_2, 25 times for CH_4, and 298 times for N_2O.

2.2.1 Rice cultivation

The emissions for rice cultivation are estimated by using Eq(1) (IPCC, 2006).

$$E = EF \cdot t \cdot A \tag{1}$$

where E is the amount of CH_4 emissions from rice cultivation (t CH_4), EF is emission factor (t CH_4 ha^{-1} day^{-1}), A is the cultivation area of rice field (ha), and t is the cultivation period of rice field (day).

2.2.2 Biomass burning
The emissions for biomass open burning are estimated by using the following Eq(2) and Eq(3).

$$E = M \cdot EF \quad (2)$$

where E is quantities of CO_2 or CH_4 emissions from burning (t CO_2 or t CH_4 respectively), M is the quantities of biomass burning ($kg_{dry\ mass}$), EF is emission factor from different biomass crops (t CO_2 or t $CH_4 \cdot kg_{dry\ mass}^{-1}$). Two methods are applied to determine the amount of biomass (M). Biomass burning at the forest area was calculated by using Eq(3) and biomass burning at the agriculture area was calculated by using Eq(4).

$$M = A \cdot B \cdot C \quad (3)$$

where A is the burned area (km^2), B is the biomass density in the forest area ($kg_{dry\ biomass} \cdot km^{-2}$), and C is burning efficiency.

$$M = P \cdot N \cdot D \cdot \beta \cdot F \quad (4)$$

where P is crop production (kg), N is the residue to crop ratio, D is dry matter to crop residue ratio, β is the fraction burned in the field, and F is the crop specific burn efficiency ratio (IPCC, 2006).

2.2.3 Transportation
The estimation for emissions generated from transport was done using Eq(5).

$$E = A \cdot EF \quad (5)$$

where E is quantifies of CO_2 emissions from transportation (t CO_2), A is activity data (km) of emission source, and EF is the emission factor (t $CO_2 \cdot km^{-1}$). Activity data for this sector can be calculated using Eq(6).

$$A = \sum [(N \cdot Y \cdot F) \cdot distance] \quad (6)$$

where N is the number of car, Y is the proportion of car, and F is the fraction of car (IPCC, 2006).

2.2.4 Industry
The emissions for industry is calculated by using Eq(7).

$$E = A \cdot EF \cdot \left(\frac{1 - ER}{100}\right) \quad (7)$$

where E is the quantities of CO_2 emissions from industry (t CO_2), A is activity data (Mg), EF is emission factor (t $CO_2 \cdot Mg^{-1}$), and ER is overall emission reduction efficiency (%) (US EPA, 2005).

2.2.5 Livestock
The emissions from livestock can be mainly caused by two activities consisting of enteric fermentation and manure management estimated by using Eq(8) and Eq(9) respectively (IPCC, 2006).

$$E = EF_{(T)} \cdot [N_{(T)}] \quad (8)$$

where E is quantities of CH_4 emissions from enteric fermentation and manure management (t CH_4), $EF_{(T)}$ is emission factor for the defined livestock population (t CH_4 $head^{-1}$), and $N_{(T)}$ is the number of livestock (while T is the category of livestock).

$$N_2O_D = \left[\sum_S \left[\sum_T (N_{(T)} \times Nex_{(T)} \times MS_{(T,S)})\right] \times EF_{3(S)}\right] \times \frac{44}{28} \quad (9)$$

where N_2O_D is direct N_2O emissions from manure management (tCO_2-eq), S is manure management system, T is division of livestock, N(T) is the number of head of each category of livestock T, $Nex_{(T)}$ is average N excretion per head of each category of livestock T (kg N $animal^{-1}$), $MS_{(T,S)}$ is the fraction of total annual nitrogen excretion for each category of livestock T that is managed in manure management system S, $EF_{3(S)}$ is emission factor for direct N_2O emissions from manure management system S (t N_2O-N kg N^{-1}), 44/28 is the conversion factor which is converted from N_2O-N emissions to N_2O emissions.

3. Results and discussion

3.1 GHG emissions in Phayao province
Within the scope of study, the total annual GHGs emitted from rice field, biomass burning, transportation, industry, and livestock were 2.9 Mt CO_2-eq (Table 2). GHG emissions were mostly contributed by biomass open

burning (1,819,225 tCO_2-eq, 62 % of the total) even though the investigation includes only rice and corn. Other minor crops were omitted due to unavailability of data but it should be acceptable with the similarity to China's case that rice and corn were the major sources (90 %) of air pollutions from all kinds of crop residues (Huang et al., 2012). Apart from biomass burning, GHG emissions can also be produced during the cultivation process (Arunrat et al., 2016), especially CH_4 from rice field (Guo et al. 2017). This also corresponds to the study result in Vietnam (Delafield, 2015) that agriculture is the biggest contributor to GHG production. GHGs from other major processes were emitted with the following shares: 6.7 % from transportation, 0.2 % from industry, and 4.6 % from livestock.

Table 2: GHG emission (t y^{-1}) generated from major sources in Phayao

Emission sources	CO_2	CO_2-eq	CH_4	CO_2-eq	N_2O	CO_2-eq	Total CO_2-eq
Rice field			30,933	773,325			773,325
Open burning	1,675,050	1,675,050	5,767	144,175			1,819,225
Transportation	195,497	195,497					195,497
Industry	4,625	4,625					4,625
Livestock			4,371.2	109,280	82.4	24,555	133,830
Total	1,875,172	1,875,172	41,071.2	1,026,780	82.4	24,555	2,926,502

3.2 Comparison with other cases in ASEAN

Benchmarks for the verification and interpretation of GHG emissions generated in Phayao province are presented in Table 3, mainly from case studies in ASEAN countries.

Table 3: Comparisons with studies in ASEAN

Emission Sources	Region & References	Area (ha)	Population (Persons)	CO_2-eq from CO_2	CO_2-eq from CH_4	CO_2-eq from N_2O
Rice field	This study	228,920			3.4	
	Vietnam (Torbick et al., 2017)	1,078,783			10.7	
Biomass burning	This study			7.3	0.6	
	Phichit (Arunrat et al., 2016)					
	Rice residue for irrigated area			2.1[a]		
	Rice residue for rainfed area			3.0[a]		
Transportation	This study	6,335	0.49×10^6	1.1[a]		
	Malaysia (Ong et al., 2011)	329,750	1.76×10^6	2.5	0.02	0.03
	Brunei (Dotse et al., 2016)	5,765	0.39×10^6	4.2	0.01	0.08
Industry	This study			4,625[a]		
	Thailand (ONEP, 2015a)			18.2×10^6 [a]		
Livestock	This study				109,280	24,555
	Philippines (Lingad et al., 2014)			26,018[a]		

[a] from all GHGs (CO_2, CH_4 and N_2O)

Note: All units for rice field are in t CO_2-eq ha^{-1} y^{-1}, for biomass burning are in t CO_2-eq ha^{-1} y^{-1}, for road transportation are in t CO_2-eq $vehicle^{-1}$ y^{-1} from industry are in t CO_2-eq y^{1}, and from livestock are in t CO_2-eq y^{-1}

For the comparison of GHGs emitted from rice field, the case of Vietnam is chosen (Torbick et al., 2017). The gap of values is about 3 times (per plantation area) which is possible due to the difference of estimation techniques. The data collected in this study is based on bottom up approach while the data in Vietnam's case is based on satellite remote sensing. Further comparison using the same approach is important. The case of Phichit province, Thailand (Arunrat et al., 2016) was chosen for the comparison of GHGs emitted from biomass burning. The gap of values (5 to 7 times) is a lot larger than that of cultivation. This is because the GHGs value presented in this study is for overall biomass while in the Phichit's case is only for rice straw. Forest fire has the highest rate of emitting GHGs per weight compared to all other types of biomass especially since the forest fire from this study is in the tropical zone (high-density) (Permadi et al, 2013). Comparing by type (forest and agricultural biomass) is highly necessary for the distinction. For the comparison of transportation sector, the cases of Malaysia (Ong et al., 2011) and Brunei (Dotse et al., 2016) are selected. The number of vehicle of this study, Malaysia's case, and Brunei's case are 193,374, 16,813,943, and 399,800. GHGs emitted from transportation sector in Malaysia and Brunei's cases are around 2 and 4 times higher compared to the results from this study. The gaps of values are not low, but they are in possible ranges. The shortest reason to explain about this difference is the higher gross domestic product (GDP), implying more activities of the country, possibly causing more traffic density. GDP of Thailand is usually >20 % lower than that of Malaysia and Brunei (US-ASEAN, 2016). A lot more accurate analysis and explanation can be obtained if road distance, study size, vehicle type, vehicle year, fuel type, and fuel consumption are interpreted. Most of GHG emissions are produced by fossil fuels generated from transportation as stated by Lee et al. (2017), it constitutes 20 % of 2013 total world CO_2 emissions. For industrial sector, due to the variety of industrial types with the varieties of energy type and chemicals used, it is not easy to find a fair comparison. GHGs values are presented in terms of the ratio with its national number, which is 2.5×10^{-4}. This low fraction implies that industry is a small economic sector in this agricultural province. For the last sector – livestock, it is compared with Salikneta farm – Philippines' case. The number of animals for this study and Philippines' case are 19,275 and 726 heads. The gap of GHG values is about 194 times (6.9 and 0.04 t CO_2-eq per head for this study and Philippines' case). The reason of this big gap is the animal type, especially for cow – the major contributor to GWP (Lingad et al., 2014). The number of cow for this study and Philippines' case are 747 and 6 heads (124.5 times – close value to the gap of GHGs). Even this is not a fair comparison either, this analysis emphasises the significant release of GHGs from cow.

4. Conclusions

This paper focuses on illustrating GHG emissions from rice cultivation, biomass burning, road transportation, industry and livestock – considered as major contributors in Phayao Province, Thailand – from 2012 - 2013. Almost 90 % of GHG emissions were emitted from agricultural sector (biomass open burning and paddy cultivation) even though the data in this part are incomplete compared to other sectors. From this study, the initial and most effective mitigation should be the control of open burning which is the biggest contributor to GWP. If the control is successful, the side benefit is to control smog problem that is a serious environmental problem in ASEAN. The verification of investigation is also performed but due to space constraint, more data and analysis are necessary for the comprehensive explanation and reliability before any further mitigation is initiated.

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