ESTIMATING CO_2 EMISSION DUE TO FOREST FIRES IN SUMATRA, INDONESIA USING DATA DERIVED FROM SATELLITE IMAGERY

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Estimating CO_2 emission due to forest fires in Sumatra, Indonesia using data derived from satellite imagery

by

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Disclaimer

*I dedicate this thesis to my beloved wife Tipuk Purwandari
and my beloved son Silvan Galih Rustanto*

Abstract

Forest fire is one of the major problems in Indonesia. Forest fires that occurred in Indonesia have destroyed not only the vegetation over the burned areas but also huge amounts of organic matters in peats under the forested areas. The emissions from peat burning are much higher than those from the above ground biomass. Most of the resulted emissions from forest fires are in the form of CO_2. Forest fires in Indonesia are mostly related to human activities. Forest fires normally start from the edges of forest areas where human activities are more intense.

This research was aimed to analyze the CO_2 emissions due to forest fires that occurred in Sumatra, Indonesia, in 2000 – 2007 and to analyze the probability of forest fire occurrence in Sumatra using the available data. To estimates the CO_2 emissions due to forest fires there are several data needed mainly: the location and the extent of burned areas, the available fuel load per unit area, burning efficiency (fraction of fuel that actually burned during fires), and emission factor (amount of CO_2 emitted per unit of fuel burned). Logistic regression was used to analyze the relation between fire occurrence and the mentioned factors.

The amount of CO_2 emissions due to forest fires in 2000 – 2007 varied between 5.53 and 84.97 Tg CO_2 yr^{-1} mainly depending on the extent of the burned area per period. Although the extent of burned areas of peat lands is always smaller than that of the total burned forest areas, the CO_2 emissions from peat lands are much higher. The uncertainty of the emission from forest fires and peat land fires is 52% and 34% respectively. Results of the logistic regression show the forest fires are more likely to occur in the non-peat areas and degraded forests (which have lower NDVI values).

Keywords: Forest fires, CO_2 emissions, fire occurrence, Sumatra, Indonesia

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1. Introduction

1.1 Forest fires, greenhouse gas emissions and their importance in global warming

Deforestation and forest degradation have a significant impact on the amount of carbon emitted by terrestrial ecosystems. Emission from deforestation and forest degradation in the tropics accounts for up to 25% of the total anthropogenic emissions (IPCC, 2007). The world lost its forest area at a rate about 13 million ha annually causing a decrease of 5.5% of the global carbon stocks in forest biomass from 1990 to 2005 (FAO, 2007). One of the major causes of deforestation and forest degradation in tropical countries is forest fires (Levine, 2000).

Biomass burning due to forest fires plays an important role on the emission of CO_2 and other trace gases to the atmosphere (Kasischke and Penner, 2004; Palacios-Orueta *et al.*, 2005). Biomass burning mostly occurs in the tropical forests of South America and Southeast Asia and in the savannas of Africa and South America (Andreae, 1991). Most of the resulted emissions from forest fires are in the form of CO_2 (Andreae and Merlet, 2001).

Research to assess the amount of green house gas emissions has been conducted in several countries and continents in the world. Levine (2000) estimated the emission from the 1997 Indonesia fires (Kalimantan and Sumatra only) was 702.11 Tg CO_2. A different study came up with the result of 0.81 – 2.57 Pg of carbon (which is equivalent to 2.97 – 9.42 Pg CO_2) emitted during forest fires at the same year for the whole area of Indonesia, (Page *et al.*, 2002). A study by Venkataraman revealed an estimation of 49 – 100 Tg CO_2 yr^{-1} emitted from forest burning in India (Venkataraman, 2006). During SAFARI 2000 conducted in Africa, the amount of CO_2 emission from woodland and grassland burning in September 2000 has been quantified as 30.32 – 133.78 Tg CO_2. On a global scale, the wild land fire emission was 5,716 Tg CO_2 in the year 2000 (Hoelzemann *et al.*, 2004). An other study, by Andreae (1991), has resulted in a different estimate. He found that the total biomass amount consumed annually by biomass burning is 8,680 Tg, with a release of 3,500 Tg of carbon in the form of CO_2. From that amount, roughly 42% came from forests and another 18% came from wood fuels (Andreae, 1991).

CO_2 emissions due to forest fires increase the amount of greenhouse gases in the Earth's atmosphere. Greenhouse gases are gases at the atmosphere that absorb the thermal infra red part of the sun's radiation. Although they only make up about 1 percent of the Earth's atmosphere, greenhouse gasses are very important to trap heat and maintain the temperature of the Earth so that it becomes habitable (UNFCCC, 2008). This process is called the greenhouse effect (see figure 1.1). However, the amount of these gases is increasing beyond the natural level and this situation will give negative impacts on life. Based on the 'best' model of the IPCC Special Report on Emissions Scenarios (SRES), the average global temperature will increase at least by 1.8°C to 4.0°C by the year 2100. A temperature increase of 0.74°C occurred last century and for the next two decades, a warming of about 0.2°C per decade is projected if greenhouse gas emissions continue to rise at their current pace and are allowed to double from their pre-industrial level (IPCC, 2007).

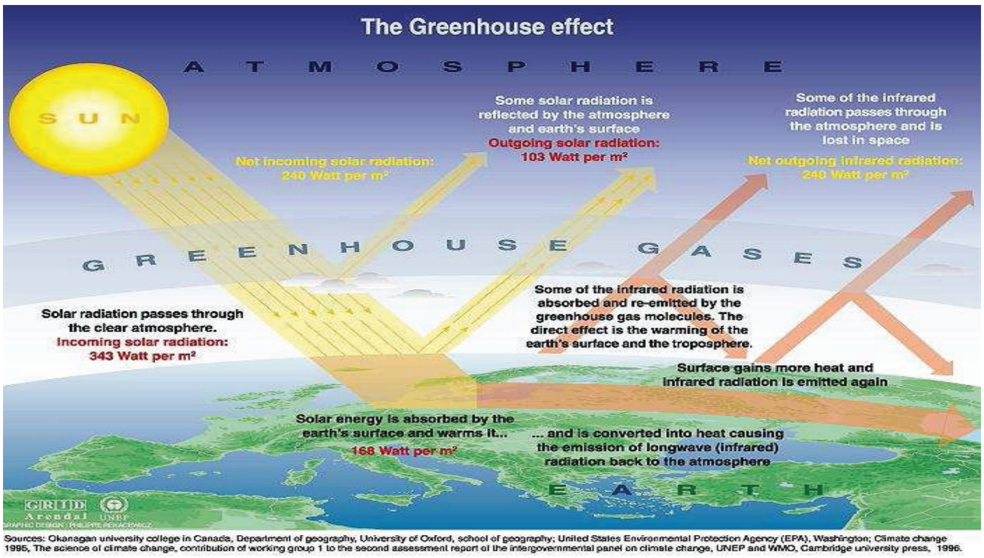

Figure 1.1. Greenhouse effect (cited in the UNFCCC's website: http://unfccc.int/)

According to United States Environmental Protection Agency (US-EPA), global warming is "an avera-ge increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, "global warming" often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities" (US-EPA, undated). Many evidences can be seen as results of global warming such as more powerful storms, hotter, and longer dry periods, significant increases in precipitation in eastern parts of North and South America, northern Europe and northern and central Asia, the decline of snow cover, average temperature increase in Arctic, and decreases in volume of glaciers in some parts of the world (UNFCCC, 2008).

Carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas in the atmosphere. It contributes to over than 60 percent of the causes of global warming. The global atmospheric concentration of CO_2 has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005 (IPCC, 2007). Land use/land cover change, particularly deforestation and forest degradation occurring in tropical areas, has a significant contribution (up to 25%) to the total amount of CO_2 and other green house gases emissions caused by human activities (Fearnside, 2000; Fearnside and Laurance, 2004; IPCC, 2007).

The parties of the United Nation Framework Convention on Climate Change (UNFCCC) are divided into three main groups: annex I countries, annex II countries and non-annex I countries. Most developing countries are included in the non-annex I countries. As one of the non-Annex I Parties of the UNFCCC, Indonesia shall prepare National Communications which include national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol but focused by the Kyoto Protocol i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). The first three are estimated to account for 50, 18 and 6 per cent, respectively, of the overall global warming effect arising from human activities. (UNFCCC, 2003; 2005). Since forest fires in Indonesia are mostly caused by human activities (Makarim *et al.*, 1998) , the emission due to forest fires have to be reported. The Intergovernmental Panel on Climate Change (IPCC), which was established by the World Meteorogical Organization (WMO) and the United Nations Environmental Programme (UNEP) in 1998, has provided methodologies for National Greenhouse Gas Inventories. Countries with more information and resources are allowed to use more detailed country-specific methodologies while retaining compatibility, comparability and consistency between countries (IPCC, 2006).

1.2 Forest fires in Indonesia

Forest fire is one of the major problems in Indonesia. Fires caused by human activities burned vast areas of tropical and peat forests throughout Kalimantan and Sumatra, Indonesia in 1997 (Makarim *et al.*, 1998; Fearnside, 2000; Levine, 2000; Page *et al.*, 2002; Heil *et al.*, 2007). The total burned areas were estimated about 4.56 million hectares between August and December 1997 (Levine, 2000). Large areas of forest in Indonesia were burned in 1982 and 1983. In Kalimantan alone, the fires burned between 2.4 to 3.6 million hectares of forest. Forest fires also occurred in Indonesia during extended dry periods in 1987 (49,323 ha), 1991 (118,881 ha) and 1994 (161,798 ha). The burned areas in 1987, 1991 and 1994 were larger than that of during years with normal rainfall, but not nearly as large as the area burned during the extended drought from June 1982 to April 1983 in East Kalimantan (Makarim *et al.*, 1998).

Peat soil is an important factor that makes forest fires in Indonesia release higher amount of CO_2 emissions compared with other forested areas in the world. Forest fires that occurred in Indonesia have destroyed not only the vegetation over the burned areas but also huge amounts of organic matter in peats under the forested areas. The emissions from peat burning are much higher than those from the above ground biomass (Levine, 2000; Page *et al.*, 2002; Hooijer *et al.*, 2006; Heil *et al.*, 2007). Therefore, it is important to include the emissions coming from peat burning when investigating the emission of CO_2 and other greenhouse gasses due to forest fires in Indonesia.

Tropical peat lands in south east Asia cover 27 million hectares area, of which about 83% are in Indonesia (Hooijer *et al.*, 2006). Among Indonesian islands, Sumatra and Kalimantan have the largest area of peat lands which cover about 7.2 million hectares and 5.8 million hectares respectively (Wahyunto and Suryadiputra, 2008). The carbon content in Sumatra peat lands has decreased with 3,469.82 million tons from 1990 to 2002 (Wahyunto *et al.*, 2003). The carbon stored in peat lands is released to the atmosphere through two mechanisms (Hooijer *et al.*, 2006):

- drainage of peat lands which leads to oxidation of peat material
- fires in peat lands.

During 1997 – 2006, CO_2 emissions from peat land fires in Indonesia were several times higher than those due to peat decomposition in drained peat land areas (Hooijer *et al.*, 2006).

Indonesia has established a special committee called National Committee on Climate Change and Environment in 1992 through Minister of Environment decree KEP-35/MENKLH/8/1992. This committee is coordinated by the Minister of Environment with members from academia, non governmental organizations (NGOs), and several governmental agencies including the Ministry of Forestry (State Ministry for Environment, 1999). This study can provide information for the National Committee on Climate Change and Environment about CO_2 emission caused by forest fires which occurred between 2000 and 2007. This research only focused on Sumatra Island. Most forest fires in Indonesia are occurred in Sumatra and Kalimantan. A project called South Sumatra Forest Fire Management Project (SSFFMP) has many data related to forest fires in Sumatra can be used in this study.

1.3 Methodologies to estimate CO_2 emission from forest fires

Based on a review by Palacios-Orueta *et al.* (2005), approaches to estimate emission from biomass burning can be grouped into three different methods namely:

- direct measurements and experimental efforts,
- remote sensing methods, and
- modelling approach.

Direct measurement and experimental approach can be conducted in natural or prescribed fires or in a laboratory. Results from these approaches provide information about relationships between emissions, vegetation complexes and environmental conditions useful to develop modelling techniques which can be applied on global and regional scales to make accurate estimates. Direct emission measurements have also been applied using remote sensing methods. Three kinds of methods were used to derive emission values by remote sensing: reflectance differences between optical bands, multi angular observation to derive atmospheric optical thickness, and direct observation to detect gas concentration using specific sensors. An example for the last method is the use of MOPITT (Measurements of Pollution In The Troposphere) on board the Terra satellite to measure the concentration of CO and CH_4 in the atmosphere. Direct remote sensing to estimate emissions show high levels of uncertainty (Palacios-Orueta *et al.*, 2005).

Modelling methodologies are the most realistic way to estimate emissions at regional or global scale. Direct measurements are unlikely applicable to estimate emissions on large areas of natural forest fires. Remote sensing data seems to be a feasible way to estimate those parameters needed for the models (Palacios-Orueta *et al.*, 2005). Fire emissions are commonly calculated as the product of burned area, fuel load, and combustion completeness, integrated over the time and spatial scale of interest. Burned area is usually considered to be the most uncertain parameter in emission estimates (van der Werf *et al.*, 2006). Differences in the extent and location of areas burned among products generated from MODIS, SPOT-VEGETATION, and ATSR-2 data are significant and result in different emissions estimates in Southern Africa. Accurate burned area information is important in terms of the total area and its spatial distribution (Korontzi *et al.*, 2004).

Biomass burning estimates are becoming better by new satellite information on burned area (van der Werf *et al.*, 2006). The Joint Research Centre of the European Commissions has made available to the scientific community a long term (covering seven global fire seasons between 2000 and 2007), moderate spatial resolution (1 km^2), high temporal resolution global burned area product derived from direct observations from the SPOT VEGETATION sensor. The product has been evaluated against a large number of Landsat TM images and a number of regional products derived from in situ or remote means. The validation results show the difference of the number of burned areas between the products is not more than 7% (Tansey *et al.*, 2008).

Most countries have joined the United Nations Framework Convention on Climate Change (UNFCCC) to begin to consider what can be done to reduce global warming. The member countries are required to report their greenhouse gas emissions to the convention. In calculating the emissions for reporting to the UNFCCC, there are three levels of accuracy that can be used depending on data availability and countries circumstances (IPCC, 2006):

Tier 1 Method

This method is feasible when country specific estimates of activity data and emission factors are not available. In tier 1, emission is estimated as a function of the amount of fuel, burning efficiency and emission factor. It uses default values provided in the 2006 IPCC guidelines. If the fire is of sufficient intensity to kill a portion of the forest stand, under this methodology, the carbon contained in the killed biomass is assumed to be immediately released to the atmosphere. The amount of fuel that can be burned is given by the area burned and the density of fuel present on that area. The burning efficiency is a measure of the proportion of the fuel that is actually combusted, which varies as a function of the size and architecture of the fuel load, the moisture content and the type of fire. The emission factor gives the amount of a particular greenhouse gas emitted per unit of dry matter combusted, which can vary as a function of the carbon content of the biomass and the completeness of combustion.

Tier 2 Method

Tier 2 employs the same general approach as tier 1 but make use of more refined country-derived emission factors and/or more refined estimates of fuel density and burning efficiencies than those provided in the default tables. Tier 2 can be used in countries where country specific estimates of activity data and emission factors are available or can be gathered at reasonable cost.

Tier 3 Method

This approach is more comprehensive and includes considerations of the dynamics of fuels. Implementation may differ from one country to another, due to differences in inventory methods, forest conditions and activity data. Transparent documentation of the validity and completeness of the data, assumptions, equations and models used is therefore a critical issue at tier 3. It requires use of detailed national forest inventories.

The methodological choice for individual source and sink categories is important in managing overall inventory uncertainty. Generally, inventory uncertainty is lower when emissions and removal are estimated using the most rigorous methods (tier 3 methods). However, these methods generally require more extensive resources for data collection, so it may not be feasible to use more rigorous method for every category of emissions and removals. A category which has a significant influence on a country’s total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty is called a key category.

A key category of emissions or removals should be prioritized within the national inventory system (IPCC, 2006). The guidelines to choose the appropriate methodology when estimating emission from fires can be seen in the figure 1.2. Due to lack of information about country specific data on the emission factors, the IPCC default values will still be used in this research. The available data for the study area is limited so that this research estimates CO_2 emission due to forest fires by using tier 1 method.

1.4 Uncertainty assessment of the CO_2 emission estimates

Uncertainty in general can be defined as “lack of knowledge of the true value of a variable that can be described as a probability density function characterizing the range and likelihood of possible values. Uncertainty depends on the analyst’s state of knowledge, which in turn depends on the quality and quantity of applicable data as well as knowledge of underlying processes and inference methods” (IPCC, 2006).

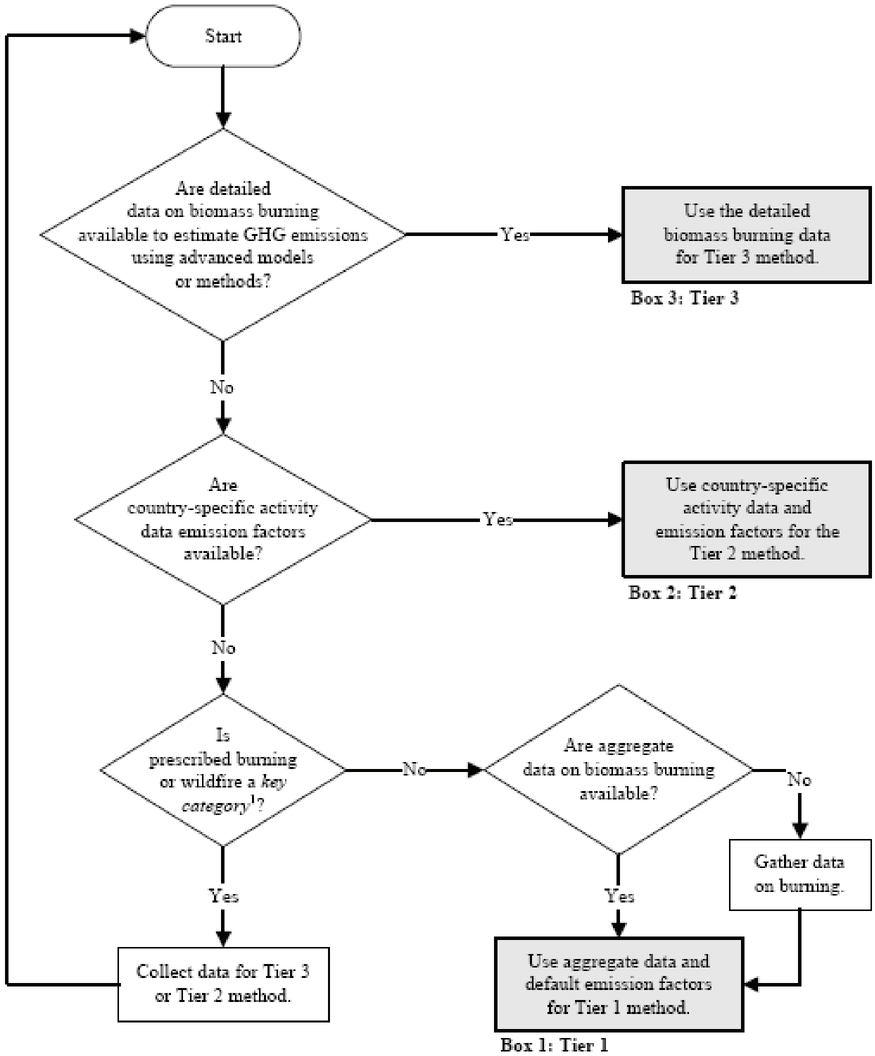

Figure 1.2. 2006 IPCC guideline to indentify the appropriate tier to estimate emissions from fires in land-use category (IPCC, 2006)

Information about uncertainty of the emission estimates is needed to help prioritize efforts to improve the accuracy of the estimation in the future and guide decision and methodological choice. Uncertainty estimates are an essential element for a complete inventory of CO_2 and other greenhouse gas emissions and removals. They should be derived for both the national level and the trend estimate, as well as for the component parts such as emission factors, activity data and other estimation parameters for each category (IPCC, 2006).

Indonesia signed the United Nations Framework Convention on Climate Change (UNFCCC) on 5 June 1992 (State Ministry for Environment, 1999). As a consequence, Indonesia shall report its emissions including the emissions caused by deforestation and forest degradation. Fire is the most important factor accelerating deforestation and forest degradation in Indonesia and other countries in south East Asia. It is likely that all of the fires burning in lands and forests in Indonesia are caused by man and as such are manageable and preventable (Makarim et al., 1998). Emissions caused by forest fire as a consequence of forestry practices need to be assessed and reported in National Communications.

Table 1.1. Indonesia's CO_2 emissions in 1990 – 1994 (in Gg CO_2 $year^{-1}$)

Category	1990	1991	1992	1993	1994
CO_2 Emission (I+II+III)	665,929.63	765,956.30	732,326.15	614,316.22	748,607.40
I. Energy (B)	128,398.19	140,410.40	149,925.55	158,321.85	170,016.31
A. Reference Approach	156,492.70	174,150.50	186,633.70	193,483.30	203,592.30
B. Sectoral Approach (Tier-1)	128,398.19	140,410.40	149,925.55	158,321.85	170,016.31
Industry	36,953.41	39,902.76	42,975.57	46,371.50	50,014.38
Transport	34,588.32	37,580.82	39,881.09	42,007.57	47,047.16
Residential/commercial	19,555.26	20,150.30	21,346.25	21,548.75	22,252.53
Energy Industry	37,301.20	42,776.52	45,722.64	48,394.03	50,702.24
Statistical Discrepancy (A-C)	28,094.51	33,740.10	36,708.15	35,161.45	33,575.99
II. Industrial Processes	14.29	14.69	15.58	17.36	19.13
Mineral Product	8.44	8.61	9.28	10.22	11.83
Chemical Industry	4.88	4.79	4.75	4.91	4.88
Metal Product	0.97	1.29	1.55	2.23	2.42
III. Forest & Land Use Change	523,241.44	610,855.90	566,820.60	438,634.37	559,471.09
Forest Harvesting	196,771.28	190,358.12	199,006.40	119,890.58	198,993.64
Forest and Grassland Conversion	320,051.12	377,908.89	357,545.31	300,351.90	303,237.35
Forest Fire	6,419.04	42,588.89	10,268.89	18,391.89	57,240.10
Information Note					
Biomass	113,831.50	116,218.40	119,043.40	122,084.70	124,417.10
International Bunker	2,038.11	1,038.38	1,205.02	1,482.44	1,684.35
O_2 Removal					
Forest and Land Use Change	335,102.61	354,309.00	371,081.79	388,574.62	403,846.64

Source: (State Ministry for Environment, 1999)

Based on the Indonesia's first National Communication to the UNFCCC (State Ministry for Environment, 1999), CO_2 emissions account for 83 percent of the national greenhouse gas emissions. Forest and land use change was the greatest contributor for the total CO_2 emissions during 1990 – 1994 (see table 1.1). It accounted for about 71 – 79 percent of the total CO_2 emissions. CO_2 emissions from forestry sector resulted mainly from burning of biomass during forest and grassland conversion activities. The emission data for CO_2 for the energy sector may be regarded as having high reliability. Whereas, for forestry sector the reliability may be much less and can be rated as having low reliability (State Ministry for Environment, 1999). In order to increase the accuracy of the GHG inventory in forestry sector, activity data, emission factors and methodology need to be improved.

1.5 Reducing emissions from deforestation and forest degradation in developing countries (REDD)

Reducing emissions from deforestation and forest degradation in developing countries (REDD) is a United Nations Framework Convention on Climate Change (UNFCCC) initiative which can give benefit to the quality of forests in developing countries. Under the REDD mechanism, countries that are successful in reducing their rates of emission through improved forest protection and sustainable production methods would be eligible to receive benefits on the basis of carbon credits saved. If REDD is approved to be one of mechanisms to reduce emission after 2008-2012 period, financial flows between US$ 1 million and 18 million will be available which can be used to increase the quality of forests (Ministry of Forestry, 2007b). Indonesia is no exception and looks to gain significantly from a future regime to reduce emissions from deforestation and forest degradation (Ministry of Forestry, 2007b).

Information about the amount of carbon emissions that occurred before the first commitment period of the protocol (2008-2012) can provide a baseline to calculate the emission reduction achieved by any REDD projects. This research is conducted to assess the amount of carbon emissions due to forest fire in Sumatra, Indonesia which occurred between 2000 and 2007. Hopefully, the results of this research can provide the required information about CO_2 emission that can be used to define a project baseline.

One of the decisions resulted from the UNFCCC conference in Bali in 2007 is the Bali Action Plan. Under the Bali Action Plan, if REDD is to be included in a post-2012 framework, a decision about what a REDD mechanism will look like and what it will include needs to be agreed by the 15^{th} Conference of Parties (COP15) in Copenhagen in December 2009 (UNFCCC, 2007; Parker *et al.*, 2008). Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) has made available a publication with methodologies that can be used for estimating emission from deforestation with acceptable levels of certainty alongside the

IPCC guidelines (GOFC-GOLD, 2008). The methodologies applied in this research will follow those two publications (GOFC-GOLD source book and 2006 IPCC guidelines) so that the results will comply with the UNFCCC requirements. Thus, it will be useful not only for a REDD project's owner but also for other interested parties like Annex I countries who need to reduce emission using this REDD mechanism by providing a transparent results and methodologies.

1.6 Forest fires in Indonesia and their relation to human activities

Possible causes of forest fires are important to be analyzed. This information can help to identify ways to reduce emissions in the future under the REDD scheme. Forest fires in Indonesia are mostly related to human activities. A study by Langner *et al*. shows that there is a strong correlation between fire and forest degradation in some part of Indonesia. They concluded that forest fires normally start from the edges of forest areas where human activities are more intense (Langner *et al.*, 2007). The most important direct causes of fires in Indonesia, particularly Sumatra and Kalimantan are as a tool for land clearing or site preparation (Applegate *et al.*, 2001). As an effort to reduce fire occurrences, the Government of Indonesia issued Regulation PP 4/2001 on forbidding the use of fire in land preparation (Ministry of Forestry, 2007b).

The distance to road is considered as a factor because it can depict the accessibility of a forest area. It is assumed that the closer a forest area to a road, the higher the accessibility so that the human activities will be more intensive.

It is also assumed that increasing population in an area close to a forest will increase the pressure to the forest. Peat is included as a factor because there is information that in some part of the study area, since year 2000, plantations establishment has began focusing on peat lands and it becomes a major source of fires (Uryu *et al.*, 2008).

Forest fires tend to begin from the degraded forest areas (Langner *et al.*, 2007). MODIS NDVI which is known as one of the vegetation greenness indicators can be used as a factor that relates to the condition of forests (Huete *et al.*, 2006). Although the NDVI value is saturated in high biomass region, it still can depict the forest biophysical parameters such as biomass and canopy cover (Huete *et al.*, 2002). More dense forests will have higher NDVI values. Therefore, in this analysis NDVI was used as a factor related to the forest condition whether it is degraded or not. The MODIS NDVI 16 day composite with resolution of 1km (MOD13A2) of 1 April 2000 was chosen because it is assumed that this data will give closest real condition before the fire periods start.

1.7 Research Objectives

The general research objective of this study is to analyze the CO_2 emissions due to forest fires that occurred in Sumatra, Indonesia, in 2000 – 2007 and to analyze the probability of forest fire occurrence in Sumatra using the available data.

The specific Research Objectives of this study are:

1. To estimate CO_2 emission due to biomass burning caused by forest fires in Sumatra in 2000 – 2007
2. To estimate CO_2 emission due to peat land burning caused by forest fires in Sumatra in 2000 – 2007.
3. To assess the uncertainty of the CO_2 emission estimates.
4. To analyze the relation between some factors (distance to road, population, soil type, NDVI values) and forest fire occurrence using logistic regression.
5. To discuss the options to reduce the fire occurrence.

1.8 Research Questions

1. How much the CO_2 was emitted by forest fires in 2000 – 2007 from biomass burning?
2. How much the CO_2 was emitted by forest fires in 2000 – 2007 from peat land burning?
3. What is the uncertainty of the estimates?
4. Do any factors such as distance to roads, population, soil type and vegetation greenness (NDVI) have a correlation with forest fire occurrence?
5. What alternatives can be taken to reduce forest fire occurrence?

1.9 Hypotheses

- The CO_2 emission from peat land burning is much higher than the CO_2 emission from (above ground) biomass burning.
- There is a correlation between forest fire occurrence and distance to road, population, soil type, and vegetation greenness.

2. Materials and Methods

2.1 Study Area

This study was conducted for Sumatra island of Indonesia. This island lies between 6^o N to 6^o S latitude and 95^o E to 106^o E longitude. Sumatra is one of the largest islands in Indonesia. It has a total area of about 470.000 km^2. Based on the census by The Central Bureau of Statistics in 2000, the population of Sumatra island is 42,409,510 people (http://www.bps.go.id/sector/population/table1.shtml). Sumatra is the second most populous island in Indonesia after Java. The mainland of Sumatra is divided into 8 provinces i.e. Nanggroe Aceh Darussalam, Sumatra Utara (North Sumatra), Sumatra Barat (West Sumatra), Riau, Bengkulu, Jambi, Sumatra Selatan (South Sumatra), and Lampung.

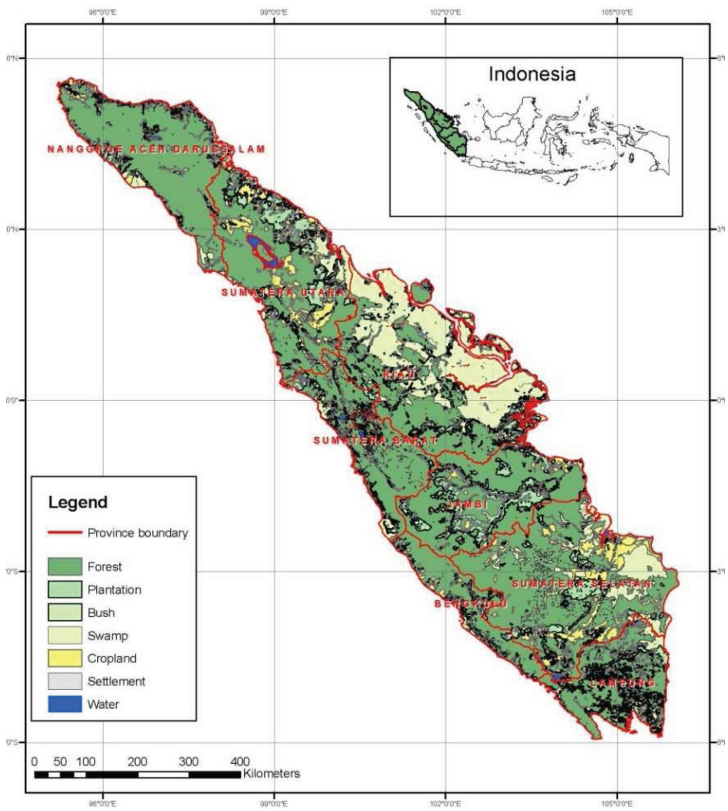

Figure 2.1. Map of Sumatra: the study Area

The Sumatra climate is tropical humid, 70% of its areas has an annual rainfall of over 2500 mm, ranging between 1,500 mm per year in the eastern part and 6,000 mm per year in areas to the west of the Barisan Range. The driest months are between May to September and the main rainy season is during December and March. The annual fluctuation in temperature is very small for almost all locations in Sumatra (Whitten *et al.*, 1987). Its daily temperatures vary between 23 ^{0}C and 34 ^{0}C with an average of 26^{0}C (Meteorology and Geophysics Board, 2008).

Fire has become a serious annual problem in Sumatra and Kalimantan especially in the dry season. Fire has not only an impact in these particular areas but also in Indonesia's neighboring countries e.g. Singapore, Malaysia, and Brunei Darussalam (Makarim *et al.*, 1998; Levine, 2000; Goldammer, 2007). Levine (2000) mentioned some of the impacts of the 1997-1998 fires: more than 200 million people were exposed to high levels of air pollution and particulates produced during the fires, more than 200 million smoke-related health problems, and fire-related damage in excess of US$ 4 billion spreading not only in Indonesia but also in Southeast Asia.

This research is a desktop study and no field work was conducted. Secondary data for the analysis was acquired from several sources. Global Burned Area 2000 – 2007 (referred as the L3JRC product to differentiate this product from other burned area data that have been produced before) was downloaded freely from the Joint Research Centre of the European Commission website (http://www-tem.jrc.it/Disturbance_by_fire/products/burnt_areas/GlobalBurntAreas2000-2007.htm). The South Sumatra Forest Fire Management Project (SSFFMP, http://www.ssffmp.or.id), a technical cooperation between the European Commission and the Government of Republic of Indonesia, has numerous data needed for the analysis. Several data, e.g. forest inventory data, was obtained from Ministry of Forestry of Indonesia. MODIS Vegetation Indices Monthly L3 Global 1km (MOD13A3) was downloaded freely from MODIS LAND website (http://modis-land.gsfc.nasa.gov/vi.htm).

2.2 Materials

To estimates the CO_2 emissions due to forest fires there are several data needed mainly: the location and the extent of burned areas, the available fuel load per unit area, burning efficiency (fraction of fuel that actually burned during fires), and emission factor (amount of CO_2 emitted per unit of fuel burned).

Besides those main data, land cover data is also required to distinguish fires that occurred in forest areas and the one that occurred in non forest areas. Since this study analyzed the CO_2 emissions for each province in Sumatra separately, province boundary map is used. A peat land map of Sumatra is used to analyze whether fires occurred in peat lands or non peat lands.

Information about fuel load is not available for Sumatra nor for Indonesia in general. For approximation, the available fuel load is calculated based on the forest inventory data which is available on Ministry of Forestry website (http://www.dephut.go.id). The forest inventory data is based on data from National Forest Inventory (NFI) conducted from 1989 to 1996. NFI 1989 – 1996 was not designed to include biomass and carbon stock measurement (Wardoyo and Forest Planning Agency - Ministry of Forestry, 2008).

Because of limited publications about peat land burning, the available fuel load for peat land burning is approximated using a value used by Page *et al*. (2002) when studying the emissions during forest fires in Indonesia in 1997.

Table 2.1. Summary of data used in this research

DATA	SOURCE	REMARK
Burned areas of Sumatra 2000 – 2007	Joint Research Centre of the European Commission	Subset from Global Burned Areas 2000 -2007, Raster data set, 1 km resolution
Forest inventory data	Ministry of Forestry	Forestry statistics, 2000 – 2006, tabular data in district/province level http://www.dephut.go.id
Land cover map of Sumatra	South Sumatra Forest Fire Management Project	Derived from Landsat images acquired in 2000 - 2003 http://www.ssffmp.or.id
Peat land map of Sumatra	South Sumatra Forest Fire Management Project	Shapefile, derived from Wetlands' peat lands map of Sumatra 2002
Road of Sumatra	South Sumatra Forest Fire Management Project	Shapefile, http://www.ssffmp.or.id
Population of Sumatra	South Sumatra Forest Fire Management Project	Shapefile, http://www.ssffmp.or.id
Administrative boundary	South Sumatra Forest Fire Management Project	Shapefile, http://www.ssffmp.or.id
MODIS NDVI	MODIS Land	Raster dataset, 1 km resolution, http://modis-land.gsfc.nasa.gov/vi.htm

2.3 Research Methods

In this study, a modelling methodology was used to estimate the CO_2 emissions due to forest fires. The amount of available fuel load that actually burned during a fire was calculated as the product of burned area, fuel load, and combustion completeness, integrated over the time and spatial scale of interest. This deterministic model which links the emissions to the amount and type of fuel consumed and to the combustion characteristics was proposed by Seiler and Crutzen (1980).

The total amount of biomass burned can be approximated using the following equation:

$$M = A * B * \beta \tag{1}$$

where *M* = the total amount of biomass burned annually [gram dry matter per year (g dm yr^{-1})], *A* =total land area burned annually [km^2 yr^{-1}], *B* = available fuel load per unit area [g dry matter km^{-2}], β = burning efficiency; fraction of the average above ground biomass actually burned (Seiler and Crutzen, 1980).

Then, the emission of CO_2 was calculated by using the equation provided by 2006 IPCC guidelines (IPCC, 2006):

$$M(CO_2) = M * e \tag{2}$$

where $M(CO_2)$ = the annual total amount of CO_2 emitted from biomass burning [g CO_2 yr^{-1}] and *e* = the emission factor; the amount of CO_2 released per unit of biomass burned.

Peat was the dominant fuel in some fires that occurred in South East Asia (Muraleedharan *et al.*, 2000). Several studies have found that the emission from peat is greater than that from forest during fires in Indonesia in 1997 (Levine, 2000; Boehm *et al.*, 2001). Therefore, it is important to include the CO_2 emission from these two types of ecosystems in Sumatra in this study: forests and peat lands. There are two types of processes which can lead to CO_2 emissions from peat i.e. fires and oxidation. However, this research will only estimate the CO_2 emissions caused by forest fires.

All of the spatial datasets were re-projected from their original projection system to geographic coordinate system (GCS) WGS 1984. In this analysis of CO_2 emission due to forest fires in Sumatra, the burned areas which exist on the plantations, croplands, paddy fields and settlements are excluded and only burned areas within forests and swamp forests are included. For this purpose, the burned areas of Sumatra were overlaid with the land cover data. This was done to make the forest land cover class consistent with the definition used in the 2006 IPCC Guidelines. There are six different land use classes for greenhouse gas inventory reporting, i.e. forest land, cropland, grassland, wetlands, settlement and other land. Forest land is defined as “Land with woody vegetation consistent with thresholds used to define Forest Land in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but *in situ* could potentially reach the threshold values used by a country to define the Forest Land category" (IPCC, 2006). The thresholds for the area, minimum height and crown cover can be determined within the following ranges: minimum forest area 0.05 to 1 ha, potential minimum height 2 – 5 m, canopy cover 10 – 30% (UNFCCC, 2001). It is assumed that plantations in the land cover map are not primarily used for forestry purpose for example coffee or oil palm plantations so that based on the guidelines by IPCC these were excluded from the analysis.

2.3.1 Input Data

Burned Area of Sumatra

In this study, the L3JRC product was used to analyze the extent and the location of fires. It needs to be overlaid with land cover data and peat lands data to detect fires occurred in peat land or non-peat land and in forest or non-forest areas.

For this purpose, a subset of the L3JRC which covers only the Sumatra Island was made. The L3JRC contains 7 datasets for 7 different fire periods starting from 2000 until 2007. Every dataset shows the burned areas for period between 1 April and 31 March (for example: Global Burned Area 2000-2001 shows the areas burned between 1 April 2000 and 31 March 2001). The validation process reported that the amount of burned area within a specified area and over a certain time period is correctly detected (Tansey *et al.*, 2008). The pixel value of the burned area shows the Julian date when a pixel was burned (The Joint Research Centre, 2005). However, the day-to-day accuracy of this product is not reported and this product is not a robust indicator that a fire has occurred on a given day (Tansey *et al.*, 2008).

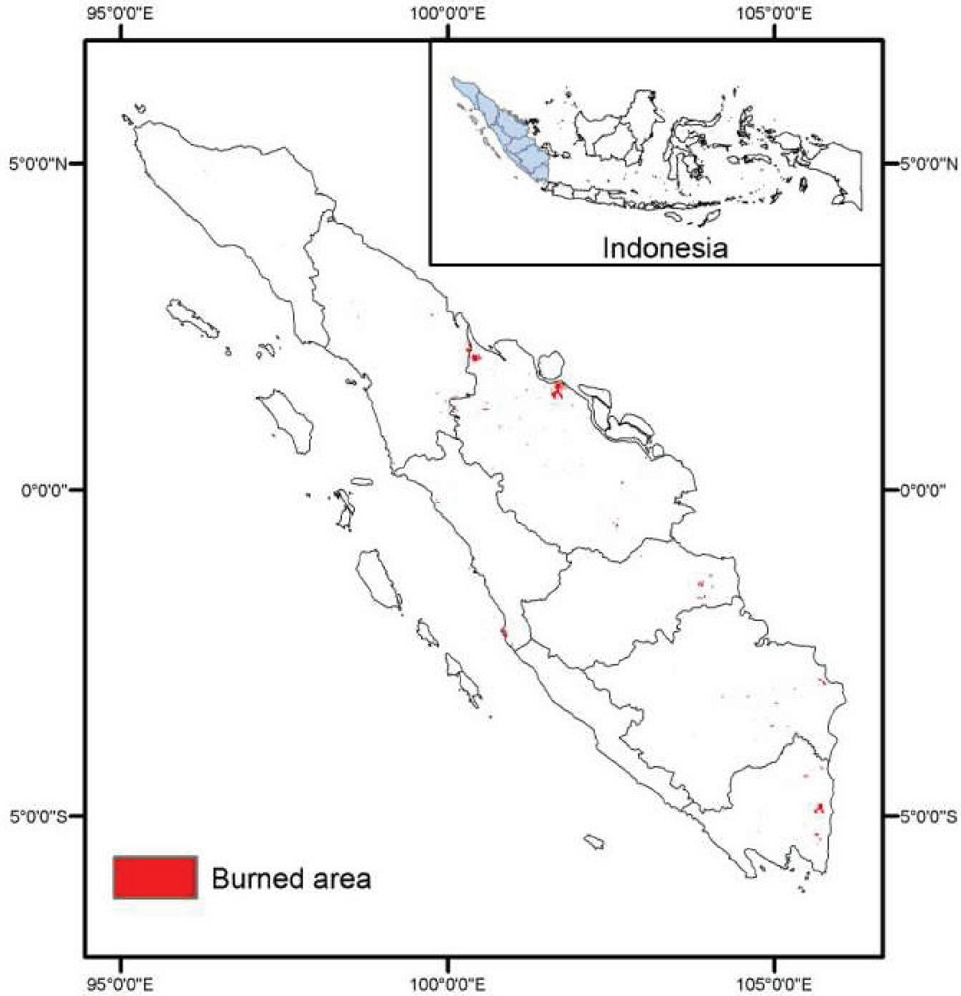

Figure 2.2. Sumatra subset of the L3JRC global data (2000 – 2007)

Available fuel load of above ground fires

The available fuel load for above ground fires was approximated using the above ground biomass available on a particular region calculated from the forest inventory data acquired from the Ministry of Forestry of Indonesia. The forest inventory data shows the average forest potential standing stock by district/province in volume (m^3 ha^{-1}) for trees with diameter at breast height of 20 cm or above. The data is available for year 2001 to 2006. All of the inventory data is still based on the result of National Forest Inventory (NFI) which is conducted in 1989 to 1995 with the support of FAO and the World Bank. Re-enumeration of permanent sample plots (PSP) is conducted starting in 1995 to recalculate the standing stock for the periods after 1996.

The biomass volume data was converted to biomass dry weight using Biomass Conversion and Expansion Factor (BCEF) provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). As defined in the guidelines, biomass conversion and expansion factors are multiplication factors that convert merchantable volume of growing stock, or merchantable volume of net annual increment, or merchantable volume of wood-removal and fuelwood removal to above ground biomass, above ground biomass growth, or biomass removals, respectively. The biomass dry weight as a result of this conversion will include non merchantable or non commercial biomass components, such as stump, branches, twigs, foliage and sometimes non commercial trees.

To be able to convert biomass volume to dry weight, the forest inventory data has to be consistent with the biomass volume defined by FAO (as it is used by IPCC in the guidelines). The standing stock volume in the Indonesian forest inventory data contains only trees with minimum diameter of 20 cm, while according to FAO the merchantable volume is for diameter 10 cm or above (Garzuglia and Saket, 2003). Therefore, it needs to be adjusted to allow the inclusion of trees with diameter 10 to 20 cm using volume expansion factor (VEF) equation provided in the GOFC-GOLD sourcebook (GOFC-GOLD, 2008):

$$VOB10 = VOB20 * VEF \qquad (3)$$

$$VEF = Exp(1.300 - 0.209 * Ln\ (VOB20)) \quad \text{for VOB20} < 250\ m^3/ha \qquad (4)$$
$$= 1.13 \quad \text{for VOB20} > 250\ m^3/ha$$

where: Exp = exponential function
Ln = natural logarithmic
VOB10 = volume over bark growing stock with minimum diameter 20 cm
VOB20 = volume over bark growing stock with minimum diameter 10 cm

Available fuel load of peat fires

The only literature we could find about the peat depth that was burned during forest and peat fires in Indonesia is a publication by Page *et al*. (2002). The average burned peat was calculated by multiplying the extent of the peat areas with the mean thickness of the burned peat soil and the peat density. This value was a result of field drilling conducted in peat land in Kalimantan, Indonesia (Page *et al.*, 2002). Not all the peat was burned during fires. From the average peat thickness of 2.3 m, it was estimated that the thickness of peat burned during fire in 1997 in Indonesia was 0.51 m (the range was between 0.25 m and 0.85 m). A peat density of 0.1 g cm^{-3} was used for the calculation of the peat dry weight from its volume. It resulted in a value of burned peat of 510 Mg dry matter per hectare. This value from Page *et al.* was also used by Heil *et al.* when conducting a similar research for Sumatra and Kalimantan (Heil *et al.*, 2007). The same value of burned peat is used in this research.

Burning Efficiency

Burning efficiency is related to the amount of available fuel load that is actually consumed during fire. Not all the biomass available will be burned if a fire occurs in an area. It depends on the ecosystem characteristics such as moisture content of the fuel and the type of fire. The IPCC default value is used in the analysis. Based on 2006 IPCC guidelines the burning efficiency for primary tropical forest is 0.32 (IPCC, 2006). There are two classes of forest in the land cover data, i.e. forest and swamp forest. It is assumed that the burning efficiency of forests and swamp forests is the same.

Burning efficiency for peat fires is not necessary since the CO_2 emission is calculated directly from the average amount of peat actually burned (not as a fraction of the total available fuel load). It is assumed that the average depth of peat being burned in Sumatra during 2000 – 2007 is 0.51 m, the same as that has been used by Page *et al.* (2002) when estimating the amount of carbon released to the atmosphere during 1997-1998 fires for the whole area of Indonesia.

Emission Factor

Emission factors are defined as the amount of certain trace gas species released per amount of fuel consumed expressed in grams of a gas compound per kilogram of dry matter (Palacios-Orueta *et al.*, 2005). For this study, emission factors for both forests and peat land are needed. The value was acquired from a literature review. A list of emission factors for different types of ecosystem is found in an article by Andreae and Merlet (2001). The list of emission factors found in this article is the one that is used also as default emission factors in the 2006 IPCC guidelines. The emission factor of CO_2 for fires in tropical forest 1,580 g kg^{-1} is used in this research.

Three articles about emission factor from peat fires were found during this desktop study. All of those are derived from laboratory measurement (Muraleedharan *et al.*, 2000; Christian *et al.*, 2003; Rein *et al.*, 2008). Muraleedharan *et al*. reported CO_2 emission 300 – 360 g kg^{-1}. Christian *et al* reported 770 g kg^{-1} (Muraleedharan *et al.*, 2000; Christian *et al.*, 2003; cited in Rein *et al.*, 2008). Only Rein *et al* reported the result with standard deviation included that is 420 ± 134 g kg^{-1}. Rein suggest that the value should be adjusted to 320 g kg^{-1} if the CO_2 emission factor will be applied to estimate the emission in natural peat fire. Emission factor of 320 g kg^{-1} was used in this study.

The research approach flowchart to estimate the CO_2 emissions due to forest fires is shown in figure 2.2. Basically, there are two separated methods to estimate the CO_2 emissions from above ground fires and the CO_2 emissions from peat fires.

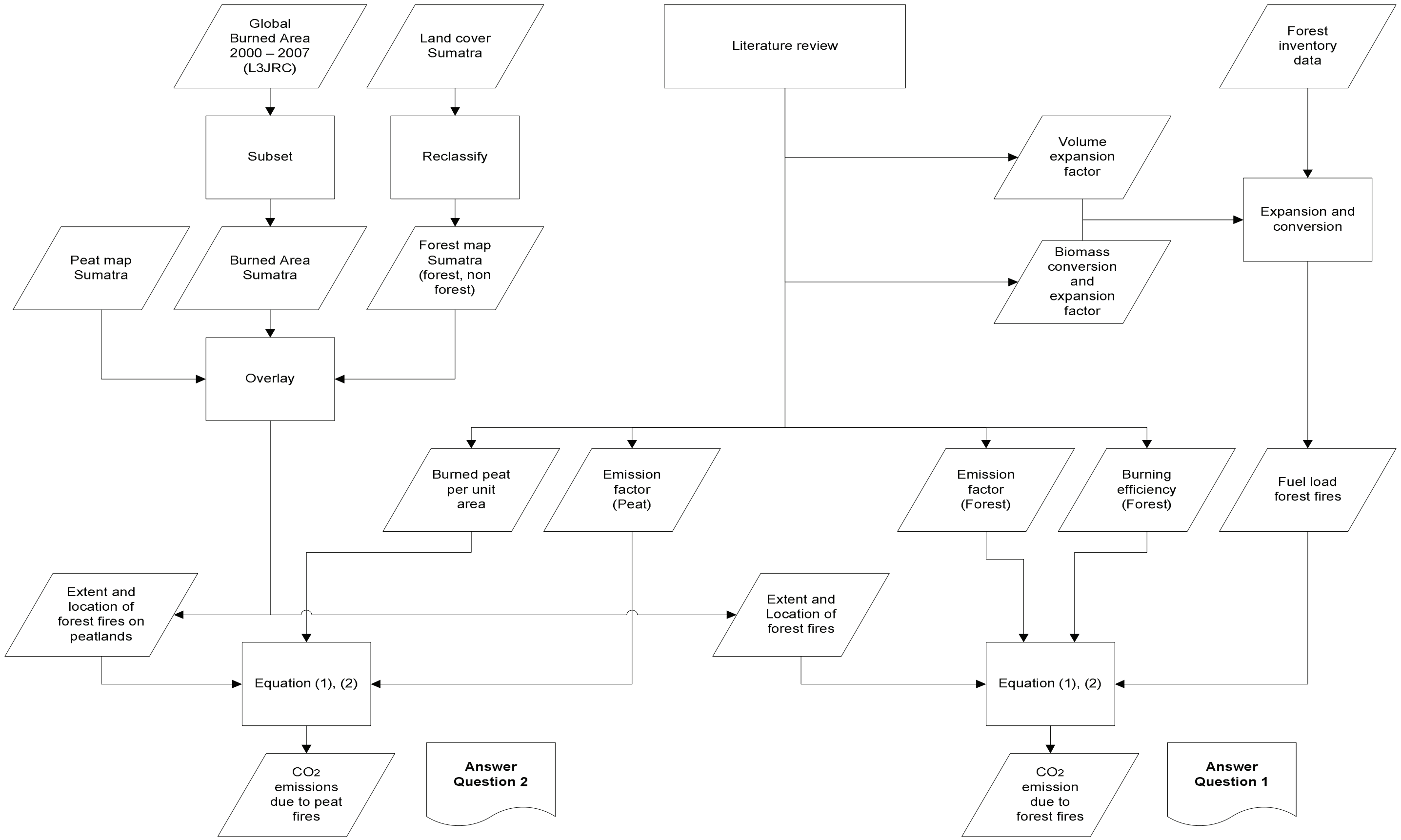

Figure 2.3. Research approach to estimate CO_2 emissions

2.3.1 Uncertainty Assessment

The estimation of CO_2 due to forest fires in this desktop study is based on several secondary published data. The uncertainty of emission estimates, where parameters or emission factors needed are acquired from published references, can be assessed from original research including country-specific data. The data from original measurements or experiments may enable an uncertainty assessment (IPCC, 2006). For most emission factors and other estimation parameters, the IPCC guidelines provide default uncertainty estimates that should be used in the absence of other information. Because this study is a desktop study which used published data for the analysis, the uncertainty for each parameter is acquired from the related publications.

Once the uncertainties in activity data, emissions factors or emissions have been determined, they may be combined to provide uncertainty for the whole emissions. There are two approaches to combine the uncertainty (IPCC, 2006): (1) using simple error propagation equation and (2) using Monte Carlo technique (IPCC, 2006). In this study, the simple equation from 2006 IPCC Guidelines for National Greenhouse Gas Inventories was used to combine the uncertainty of burned area, available fuel load, burning efficiency and emission factor (equation 5). Where uncertainties are to be combined by multiplication, like what was done in this research, the standard deviation of the sum will be the square root of the sum of the squares of the standard deviations of the quantities that are added, with the standard deviations all expressed as coefficients of variations, which are the ratios of the standard deviations to the appropriate mean values.

$$U_{total} = \sqrt{U_1^2 + U_2^2 + U_3^2 + U_4^2} \quad (5)$$

Where:

U_{total} = the percentage uncertainty in the CO_2 emission;

U_i = the percentage uncertainties associated with the quantities of burned area, available fuel load, burning efficiency and emission factor.

The research approach to calculate the uncertainties can be seen in figure 2.3.

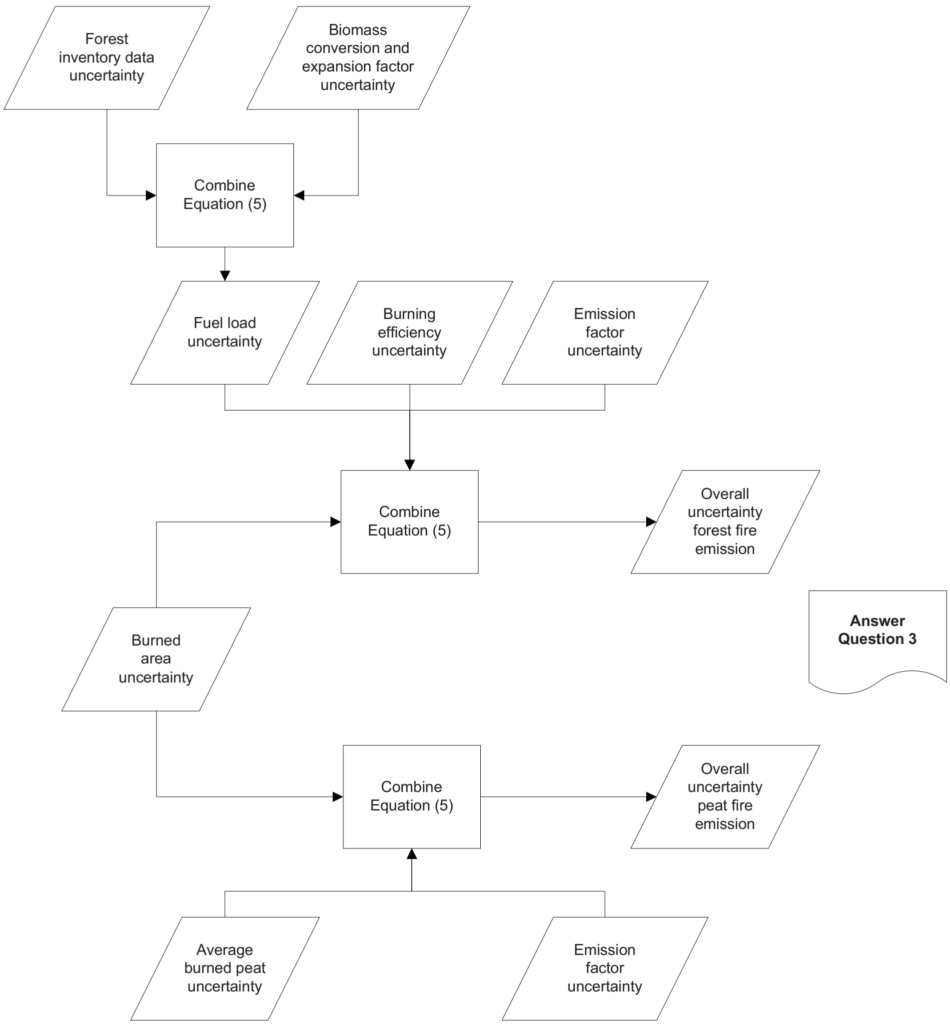

Figure 2.4. Research approach to analyze the uncertainties

2.3.1 The Relationship between Fire Occurrence and distance to road, population, soil type, NDVI values

Logistic regression was used to analyze the relation between fire occurrence and the mentioned factors. Logistic regression is a method to model the relationship between a response variable, which only has two possible values (presence or absence), and one or more explanatory variables (Moore and McCabe, 2006).

The statistical model for logistic regression is:

$$\log\left(\frac{p}{1-p}\right) = \beta 0 + \beta 1x \quad (6)$$

where p is a binomial proportion and x is the explanatory variable. The parameters of the logistic model are β0 and β1 (Moore and McCabe, 2006).

The fire occurrence (occurred or not occurred) is the response variable. Population density and distance to road were used as explanatory variables which have relation to human activities. Besides those factors, Soil type (peat or non-peat) and MODIS NDVI for the year 2000 were used (assumed that these factors have a close relation with the available fuel load – below and above ground biomass). Peat soils in Indonesia have an average below ground biomass 2.3 – 4.4 Gg dry matter ha^{-1} as the available fuel load for fires (Page *et al.*, 2002), which is higher than the available fuel load provided by above ground biomass. The vegetation indices especially NDVI has been frequently used as a parameter in the assessment of biomass. MODIS NDVI of 1 April 2000 was chosen because it can depict the initial condition of the area before the fire seasons of 2000 - 2007.

Random points were generated for the burned and unburned areas using the Hawth's analysis tool, an extension tool for the ArcGIS 9.x software ((Beyer, 2004). 198 sample points were established in the burned areas 2000 – 2007 (1 sample for each locations). The rest of the samples, 202 points were distributed randomly over the unburned areas throughout Sumatra Island.

The logistic regression analysis was done in the SPSS 16.0 software, using stepwise backward likelihood ratio method. The backward method starts the model with all predictors included and then tests whether any of these predictor variables can be removed without affecting on how well the model fits the data. The backward method is preferable than forward method because it has lower risk of missing a predictor that does in fact predict the outcome (Field, 2005). This study was aimed to know what is correlated and what is not correlated with fire occurrence. The backward method might be the better method and therefore it was chosen for this study.

The stepwise backward method (likelihood ratio) was applied in the analysis. This method begins by placing all the factors in the model, examines t-test for each predictor to assess individual contribution of each predictor, and compared its significance against a specific removal criterion (Field, 2005). The research approach to analyze the relationship between fire occurrence with those factors is shown in figure 2.4.

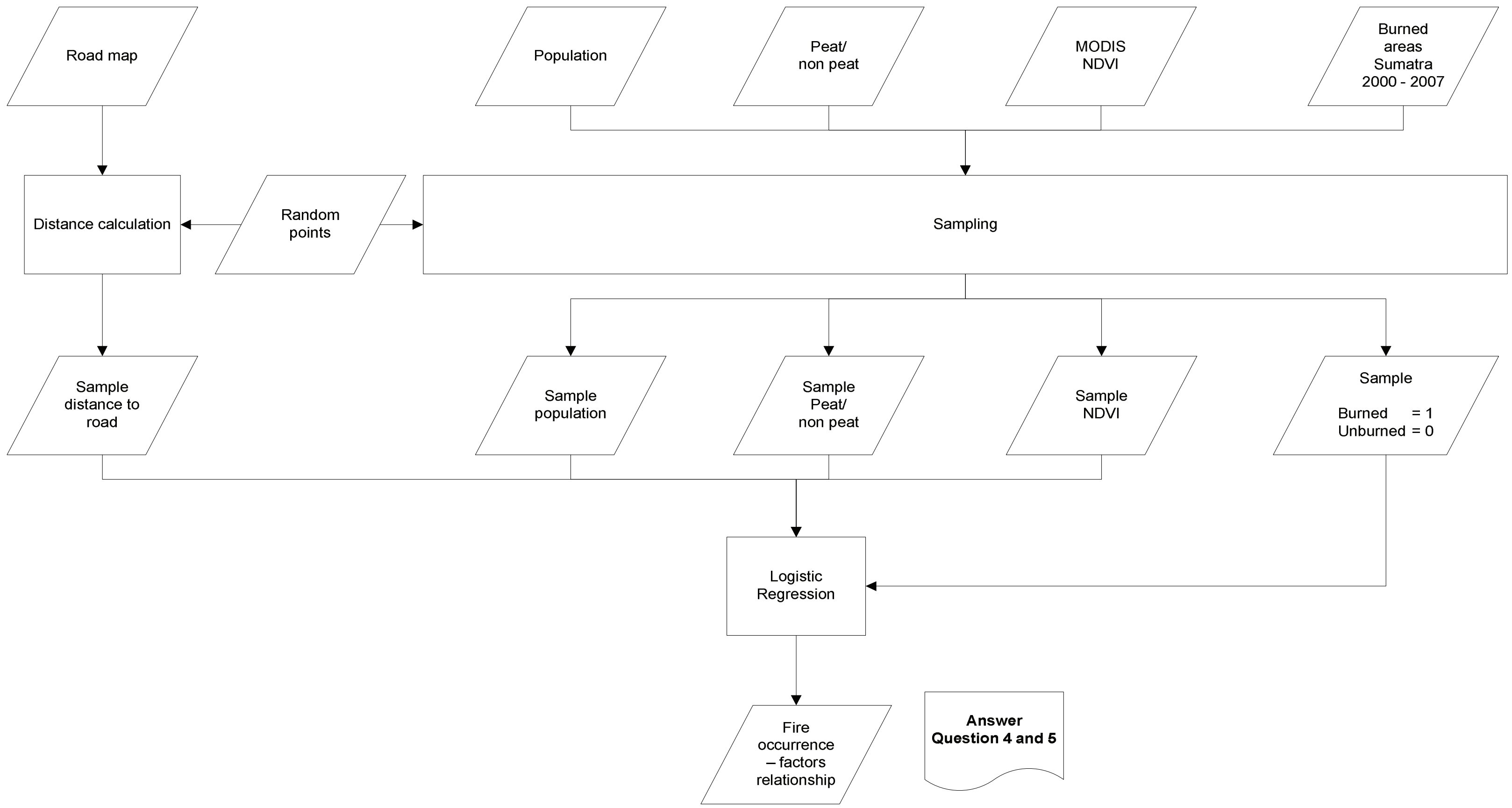

Figure 2.5. Research approach to analyze fires occurrences

3. Results

3.1 Activity data and other parameter to calculate the CO_2 emissions

3.1.1 The burned areas of Sumatra in 2000 - 2007

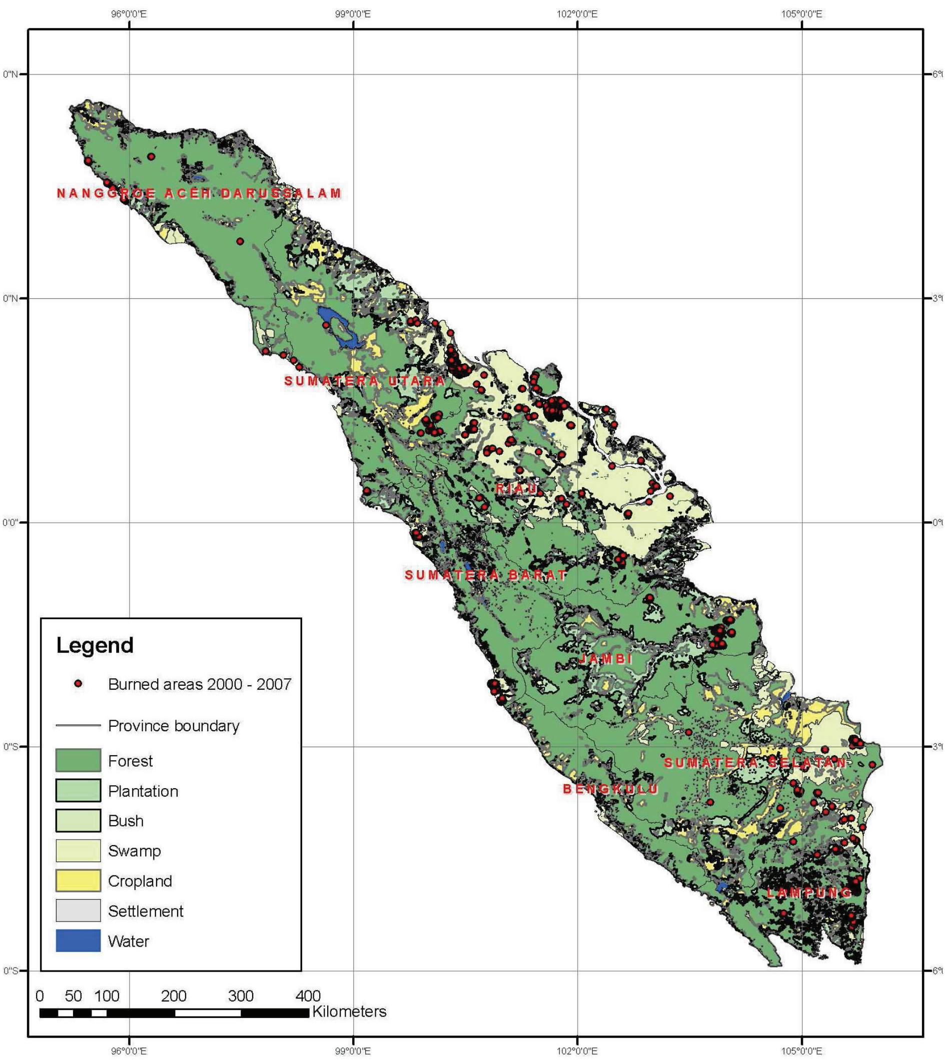

Figure 3.1. The burned areas of Sumatra 2000 – 2007. Land cover data was acquired from the South Sumatra Forest Fire Management Project . Burned area points derived from Global Burned Area 2000 – 2007 (L3JRC) from The Joint Research Centre of the European Commission.

During 2000 – 2007, the Sumatra Island experienced forest fires with extents between 46 – 523 km^2. Figure 3.1 shows the location of the forest fires during this period. The resolution of the Global Burned Area datasets which were used in this study is 1 km. Therefore in the analysis, the total burned area (in km2) within a period is equal to the number of burned pixels in those raster datasets. The datasets use an assumption that a global fire year starts on the 1st April of every year and that a surface cannot be burned more than once in the same fire season. For example, Global Burned Area 2000 – 2001 shows the areas burned between 1 April 2000 and 31 March 2001.

Peat lands map of Sumatra (figure 3.2), which was a digitized map based on the published map by Wetland International Indonesia Programme (Wahyunto *et al.*, 2003), was used to identify the fires occurred on the peat lands. Amongst the

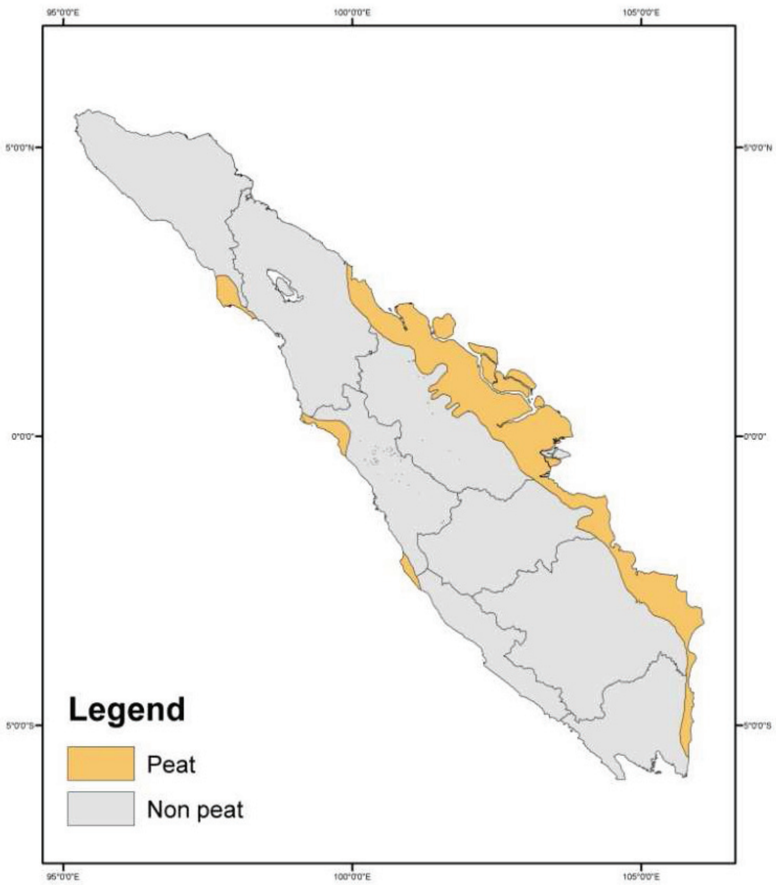

Figure 3.2. Peatlands map of Sumatra

burned areas of 2000 – 2007, 34 – 93% fires were occurred on peat lands. The extent of burned areas between 2000 and 2007 is shown in figure 3.3 below. In this calculation, only fires which occurred in forest and peat swamp forest were counted. Fires in settlements, cropland areas (included paddy fields), plantations, and bushes were not considered in this study.

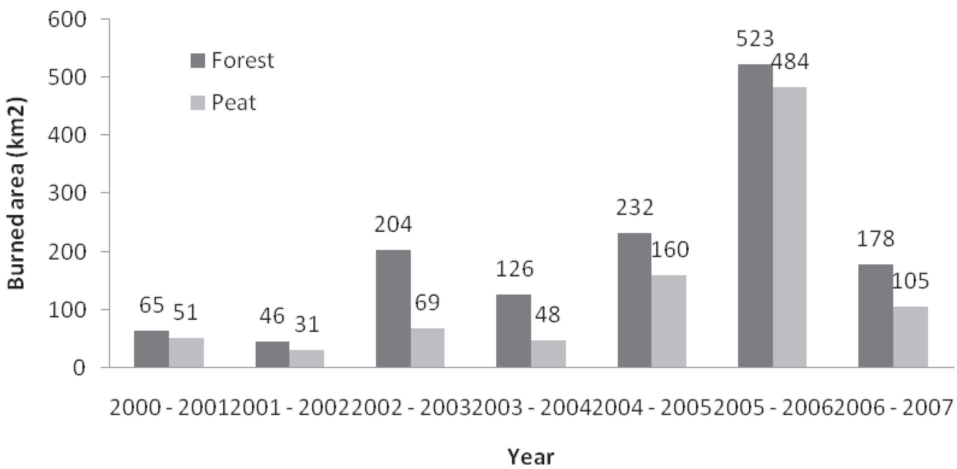

Figure 3.3. The extent of burned areas of Sumatra 2000 - 2007. The pixel resolution of the burned area datasets is 1 km^2 so that the total areas burned each year (in km^2) equal to the number of burned pixel in the datasets.

3.1.2 Available fuel load

The available fuel load of above ground fires in this study is assumed to be equal to the amount of above ground biomass in a particular area. No data about above ground biomass in the study area is available because the forest inventory only measures the volume of the standing stock in forest area. However, there is a method provided to convert the volume of above ground biomass to its dry weight. Table 3.1 shows the average volume of the standing stock (m^3 ha^{-1}) per province in the study area.

Table 3.1. Standing stock volume by province 2001 – 2006 (Source:Ministry of Forestry, 2002; 2003; 2004; 2005; 2006; 2007a)

No.	Province	Average standing stock (m^3/ha), all species +20 cm					
		2001	**2002**	**2003**	**2004**	**2005**	**2006**
1	Nanggroe Aceh D.	174.22	168.73	168.72	138.13	138.13	120.87
2	Sumatra Utara	105.56	98.04	98.04	117.41	117.41	119.75
3	Sumatra Barat	98.54	135.92	135.92	115.77	115.77	90.91
4	Riau	92.12	120.96	120.96	107.93	107.93	100.92
5	Jambi	136.66	125.88	125.88	118.61	118.61	118.97
6	Sumatra Selatan	65.53	57.10	57.10	41.30	41.30	29.23
7	Bengkulu	40.48	82.27	82.27	68.24	68.24	68.24
8	Lampung	44.01	44.01	44.01	74.12	74.12	74.12

Table 3.2. shows the result of calculation of the above ground biomass based on the volume inventory data using the volume expansion factor (VEF) and the biomass conversion and expansion factor. The amount of available fuel load varies amongst the eight provinces in Sumatra.

The standing stock volume data is only available for year 2001 until 2006. Since this study is for 2000 – 2007, it is necessary to acquired data for the year 2000. The IPCC guidelines provide several ways how to resolve data gaps i.e. overlap method, using surrogate data, interpolation/extrapolation. Trend extrapolation is used if data is not available at the beginning or the end of the time series (IPCC, 2006). To solve the problem of missing data in this study, data for the year 2000 is calculated by extrapolation from the data of 2001 and 2002.

Table 3.2. Above ground biomass by province 2000 – 2006.

No.	Province	Above ground biomass (Mg d.m. ha^{-1})						
		2000[a]	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
1	Nanggroe Aceh D.	289.70	282.64	275.57	275.56	235.24	235.24	211.66
2	Sumatra Utara	231.87	219.41	206.95	206.95	238.67	238.67	242.43
3	Sumatra Barat	183.34	207.80	232.25	232.25	236.03	236.03	194.96
4	Riau	182.21	197.00	211.79	211.79	223.29	223.29	211.75
5	Jambi	247.94	233.25	218.56	218.56	240.60	240.60	241.18
6	Sumatra Selatan	156.67	170.54	184.42	184.42	142.75	142.75	148.32
7	Bengkulu	203.65	191.90	180.15	180.15	176.11	176.11	176.10
8	Lampung	150.10	150.10	150.10	150.10	188.00	188.00	188.00

[a] extrapolation from year 2001 and 2002 value.

Previous study which estimated the emission from peat burning in Indonesia has given information about the amount of peat burned during forest fires. The peat depth in Indonesia varies between 2.3 m and 4.4 m (Page *et al.*, 2002). However, they did not calculate the burned peat as a fraction of available fuel load but used the average burned peat of 0.51 m. By using the same mean depth of peat burned during peat and forest fires in Indonesia during 1997 that was used by Page *et al.* (2002), which is 0.51 m and peat bulk density of 0.1 g cm^{-3} , the assumed of peat burned was calculated to be 510.0 Mg ha^{-1}.

3.2 CO_2 emission due to forest fires in Sumatra 2000 – 2007

After the extent of the burned areas, the available fuel load per hectare, the burning efficiency, and the emission factors are known, the CO_2 emission due to forest fires in Sumatra for every period can be calculated. The result is shown in table 3.3. The calculation was done on province level.

The amount of CO_2 emissions due to forest fires in 2000 – 2007 varied between 5.53 and 84.97 Tg CO_2 yr^{-1} mainly depending on the extent of the burned area per period. Although the extent of burned areas of peat lands is always smaller than that of the total burned forest areas, the CO_2 emissions from peat lands are much higher. The highest frequency of forest fires in Sumatra occurred in the Riau province (figure 3.4)

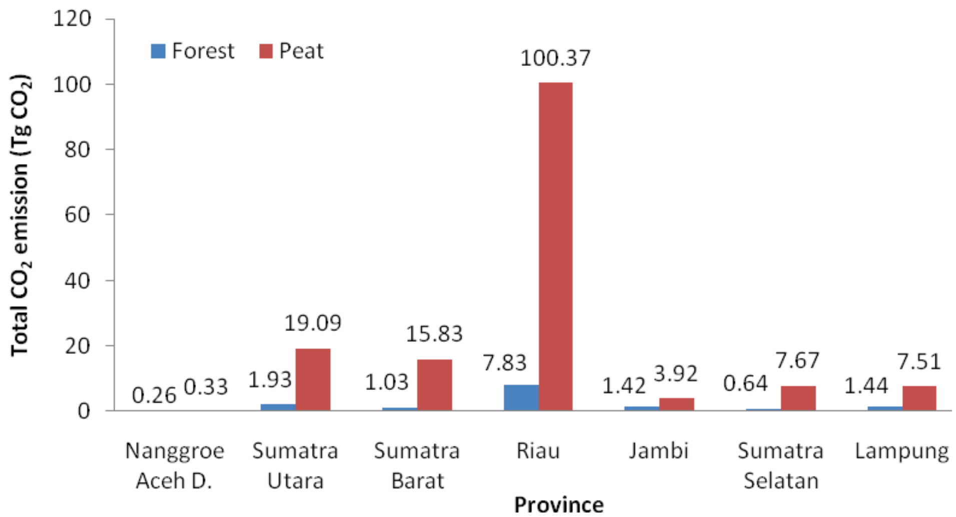

Figure 3.4. Total CO_2 emissions per province during 2000 - 2007

Table 3.3. CO_2 emissions from forest and peat fires of Sumatra 2000 - 2007

Period	Province	Burned area (*100 ha)		Fuel load (Mg dm ha^{-1})		Emission (Tg CO_2 yr^{-1})		
		Forest	Peat	Forest	Peat	Forest	Peat	Total
2000 - 2001		**65**	**51**			**0.673**	**8.323**	**8.996**
	Nanggroe Aceh D.	3	1	289.70	510.00	0.044	0.163	0.207
	Sumatra Utara	24	17	231.87	510.00	0.281	2.774	3.056
	Sumatra Barat	18	18	183.34	510.00	0.167	2.938	3.104
	Riau	17	12	182.21	510.00	0.157	1.958	2.115
	Sumatra Selatan	3	3	156.67	510.00	0.024	0.490	0.513
2001 - 2002		**46**	**31**			**0.474**	**5.059**	**5.533**
	Nanggroe Aceh D.	1	0	282.64	510.00	0.014	0.000	0.014
	Sumatra Utara	19	10	219.41	510.00	0.211	1.632	1.843
	Sumatra Barat	1	1	207.80	510.00	0.011	0.163	0.174
	Riau	18	18	197.00	510.00	0.179	2.938	3.117
	Sumatra Selatan	6	1	170.54	510.00	0.052	0.163	0.215
	Lampung	1	1	150.10	510.00	0.008	0.163	0.171
2002 - 2003		**204**	**69**			**1.719**	**11.261**	**12.980**
	Sumatra Utara	22	22	206.95	510.00	0.230	3.590	3.821
	Sumatra Barat	3	3	232.25	510.00	0.035	0.490	0.525
	Riau	4	4	211.79	510.00	0.043	0.653	0.696
	Jambi	24	17	218.56	510.00	0.265	2.774	3.040
	Lampung	151	23	150.10	510.00	1.146	3.754	4.900
2003 - 2004		**126**	**48**			**1.342**	**7.834**	**9.175**
	Sumatra Utara	9	1	206.95	510.00	0.094	0.163	0.257
	Sumatra Barat	9	8	232.25	510.00	0.106	1.306	1.411
	Riau	55	20	211.79	510.00	0.589	3.264	3.853
	Jambi	34	0	218.56	510.00	0.376	0.000	0.376
	Sumatra Selatan	19	19	184.42	510.00	0.177	3.101	3.278
2004 - 2005		**232**	**160**			**2.568**	**26.112**	**28.680**
	Nanggroe Aceh D.	17	1	235.24	510.00	0.202	0.163	0.365
	Sumatra Utara	12	1	238.67	510.00	0.145	0.163	0.308
	Sumatra Barat	22	22	236.03	510.00	0.263	3.590	3.853
	Riau	119	107	223.29	510.00	1.343	17.462	18.806
	Jambi	33	5	240.60	510.00	0.401	0.816	1.217
	Sumatra Selatan	27	24	142.75	510.00	0.195	3.917	4.112
	Lampung	2	0	188.00	510.00	0.019	0.000	0.019
2005 - 2006		**523**	**484**			**5.985**	**78.989**	**84.974**
	Sumatra Utara	67	59	238.67	510.00	0.809	9.629	10.437
	Sumatra Barat	2	2	236.03	510.00	0.024	0.326	0.350
	Riau	423	421	223.29	510.00	4.776	68.707	73.483
	Jambi	31	2	240.60	510.00	0.377	0.326	0.704
2006 - 2007		**178**	**105**			**1.776**	**17.136**	**18.912**
	Sumatra Utara	13	7	242.43	510.00	0.159	1.142	1.302
	Sumatra Barat	43	43	194.96	510.00	0.424	7.018	7.441
	Riau	69	33	211.75	510.00	0.739	5.386	6.124
	Sumatra Selatan	25	0	148.32	510.00	0.187	0.000	0.187
	Lampung	28	22	188.00	510.00	0.266	3.590	3.857

3.3 Uncertainty of the CO_2 estimates

The calculation of the uncertainties related to the CO_2 estimation in this study is based on the published articles or data where the parameters were acquired. All the data is secondary data and there is no primary data collected during this study.

The L3JRC product has been validated using a large number of burned area maps derived from higher resolution images such as LANDSAT TM images and other remotely sensed data. In general the accuracy of this dataset is good in a number of different vegetation types. The standard deviation from the best fit line is not more than 7%. However, this dataset has not been validated yet for the study area. It also is not able to recognize small burned areas less than 50 hectares and the detail boundary of the burned area (Tansey *et al.*, 2008). To compensate for this limitation, for the analysis we assume that the uncertainty comes from the burned areas data is 10%.

The available fuel load of the forest fires 2000 – 2007 was estimated from the forest inventory data. The growing stock data is available in Forestry Statistics of Indonesia 2001 – 2006 that can be downloaded from the Ministry of Forestry website. Because the data for 2000 is not available, the available fuel load (above ground biomass) was generated by extrapolating data of year 2001 and 2002. For the assessment of woody biomass purpose, this data is considered as has high class reliability since the data was collected using remote sensing analysis with ground checking and field sampling (Garzuglia and Saket, 2003). Re-enumeration of the permanent sample plots (PSP) is conducted within 3 – 5 year interval starting in 1995 (Wardoyo and Forest Planning Agency - Ministry of Forestry, 2008). Data presented in the annual forest statistics book published by the Ministry of Forestry is based on NFI data and adjusted using the results of re-enumeration of the permanent sample plots.

The forest inventory data has an uncertainty that vary between 5 – 17% depending on the regions in Indonesia (Wardoyo, personal communication). In calculating the CO_2 estimation uncertainty, an uncertainty of 17% is assumed for the forest inventory data. Another uncertainty related to the available fuel load was introduced when converting volume to weight using biomass conversion and expansion factor (using default IPCC data) is 30% (IPCC, 2006). Thus, the combined uncertainty related to available fuel load based on equation (5) is 34%. The uncertainty due to expansion using volume expansion factor (VEF) was not found in the referred publication so that it was not included in the calculation.

A published article about peat burning which also covered the study area is an article by Page *et al.* who studied the emission during fire season of 1997-1998 in Indonesia. They used value of 0.51 m as the average depth of the peat burned during the fire. Information about the uncertainty is also included in this article. The amount of peat burned during forest fire has an uncertainty of 10% (at 95% confidence limit) (Page *et al.*, 2002).

Information about specific burning efficiency for forest fires in the study area is not available. Therefore, the burning efficiency to estimate the CO_2 emission due to forest fires in Sumatra for this study is taken from the default value for primary tropical forest in the IPCC guidelines. The uncertainty of burning efficiency for primary tropical forest is 37% (IPCC, 2006).

The emission factor of forest burning related to above ground fuel load is taken from an article by Andreae and Merlet. They have established a database of emission factors from biomass burning for various species of gases for different ecological types based on intensive literature review over a large number of available publications. The emission factor of CO_2 for tropical forest uncertainty is 6% (Andreae and Merlet, 2001). This value is used in this study.

Publication about emission factor of peat burning is not as many as that of forest and other types of land burning. The uncertainty of the emission factor of CO_2 used in this analysis which is taken literature by Rein *et al.* is 31% (Rein *et al.*, 2008).

The overall uncertainty as a result of combining those uncertainties related to each parameter can be seen in table 3.4. The uncertainty of CO_2 emission estimates from forest fires is 52%, higher than the uncertainty of CO_2 emission from peat fires.

Table 3.4. The overall uncertainties of the CO_2 emission estimates due to forest fires and uncertainties related to each parameter

	Uncertainty (%)				
	Burned Area	Fuel Load	Burning efficiency	Emission factor	Overall
Forest	10	34	37	6	52
Peat	10	10		31	34

3.4 The relationship between fire occurrence and human activities

A total of 4 factors were used to develop a logistic regression model, i.e. distance to road, population density, soil type (peat, non-peat), and the NDVI (normalized difference vegetation index) of the year 2000 from MODIS data.

Table 3.5. The summary of logistic regression to predict fire occurrence

		B	Wald	Sig.	Exp(B)
Step 3[a]	PEAT(1)	-1.540	37.117	.000	.214
	NDVI	-5.054	25.949	.000	.006
	Constant	4.992	35.689	.000	147.200

a. Variable(s) entered on step 1: DIST2ROAD_KM, POP, PEAT, NDVI

b. Nagelkerke R square for step 3 is 0.196.

The result summary of the logistic regression is shown in table 3.5. The analysis came up with two significant factors related to fire occurrence i.e. soil types (peat, non-peat) and NDVI values. The distances to road and population variables were removed from the model in the second and third step respectively. The final model that resulted from the stepwise backward likelihood ratio method can predict correctly 69.5% the fire occurrence based on the soil type and the NDVI. Compared with the null model that does not considered those factors which already can predict 50.8% of the fire occurrence, this model increases the correct prediction by 19%.

The exp (B) for both of the significant factors, the soil type and the NDVI is less than 1. It means that the probability of fire occurrence in non-peat soil is higher that that in peat soils and the probability of fire occurrence will increase as the NDVI values decreases. The detailed SPSS result can be seen in appendix 1.

4. Discussion

4.1 CO_2 emission due to forest fires in Sumatra 2000 - 2007

The Indonesia's first National Communication to the UNFCCC shows that forest fires had significant contribution to the total CO_2 emission. Forest fires including those used for land clearing or land preparation for plantation establishment contribute about 75% of the total CO_2 emissions of Indonesia. Based on this information, the IPCC guidelines require that the CO_2 emissions from forest fires is one of the important greenhouse gas emission and therefore a higher tier method should be applied to estimates the CO_2 emission due to forest fires. However, because of the available data was limited, this study tried to estimate the CO_2 emission due to forest fires in Sumatra using tier 1 method of the IPCC guidelines.

The CO_2 emission due to forest fires in Sumatra occurred in 2000 – 2007 could be calculated using secondary data that are available from several resources. The annual CO_2 emission due to forest fires in Sumatra varies between 5.53 and 84.97 Tg CO_2 yr^{-1} depending on the extent of the burned area per year and the available fuel load on a particular area. The highest frequency of forest fires in Sumatra occurred in the Riau province (figure 3.4). Compared with the CO_2 emissions of forest fires in 1997 reported by Levine (2000), which was about 702.11 Tg CO_2 (in Kalimantan and Sumatra), the results found by this study are much lower. The 1997 fires have burned 1.5 million hectares of forests in Sumatra. Based on the L3JRC products (Tansey *et al.* 2008), there were only 4,600 – 52,300 hectares of forests burned during 2000 – 2007. The significant difference on the extent of burned areas in 1997 and 2000 – 2007 was caused by abnormal drought conditions and the number of land clearing fires exceeded the normal annual dry season's burning experienced by Indonesia in 1997 (Heil *et al.,* 2007). This abnormal situation was caused by el Niño, a global coupled ocean-atmosphere phenomenon which is associated with floods, droughts, and other disturbances in a range of locations around the world (http://en.wikipedia.org/wiki/El_Niño-Southern_Oscillation). The el Niño phenomenon occurred again in year 2005-2006 causing extended drought in Sumatra (Uryu *et al.*, 2008). That made the fire occurrence in that year (2005-2006) has the highest frequency compared with the other periods (figure 4.1).

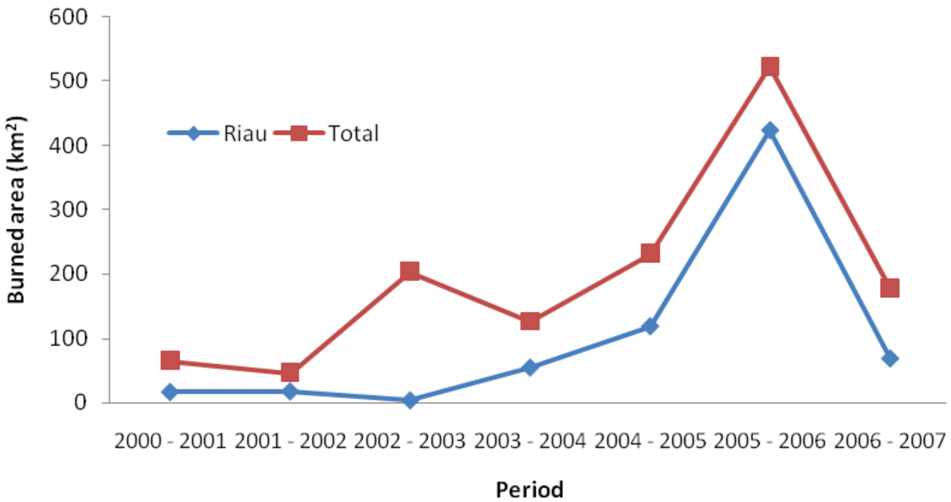

Figure 4.1. The Riau Province had a highest contribution to the total burned areas of Sumatra during 2000 - 2007

This study shows that the CO_2 emissions from peat burning is much higher than the CO_2 emissions from forest burning The results of this study agree with those of Levine (2000), Page *et al.* (2002) and Heil *et al.* (2007) which have similar conclusions. This finding is reasonable because the carbon contain of peat is higher than that of above ground biomass. On average, the CO_2 emissions from peat burning are about 86% of the total CO_2 emission caused by forest fires even though these values can be considered conservative since this study used the lowest level of emission factor and did not include the emissions from oxidation.

Amongst the eight provinces in the Sumatra Island, the Riau province has emitted the highest amount of CO_2 due to forest fires during 2000 – 2007. The main source of the CO_2 emission in the Riau province was from peat burning (see figure 4.2). This result might be related to the fact that since year 2000, conversion from forests to plantations has started focusing on Riau's peat lands (Uryu *et al.*, 2008). Canals that were built in peat land areas during plantations establishment has drained the soils causing peat lands become more susceptible to fires (figure 4.2). Fires are rarely occurred in non-degraded and non-drained peat lands (Hooijer *et al.*, 2006).

Figure 4.2. Drainage canals have been established over peatland areas during conversion of forests to plantations in Riau (source: Uryu et al., 2008)

Indonesia is interested with the REDD mechanism offered by the UNFCCC. If this mechanism is agreed by Parties of the UNFCCC as one of the options to reduce emissions in post 2012 commitment period, it will give opportunity generating funds which can be used to improve the quality of forests in Indonesia. The CO_2 emissions due to forest fires, especially which come from peat burning, are very important and therefore they can not be neglected when setting up the emission baseline and calculating the emission reduction by a proposed REDD project.

As many parties has concerned, the emission reduction estimation by a REDD project has to be conservative. In the REDD context, conservativeness means that – when completeness or accuracy of estimates can not be achieved – the reduction of emissions should not be overestimated, or at least the risk of overestimation should be minimized (GOFC-GOLD, 2008). If the emission due to forest fires reporting does not consider the emissions come from peat burning, it will underestimate the emission reduction (because of underestimating in estimating the emission from forest fires). This should be considered especially when establishing a REDD project in areas with large extent of peat lands e.g. in Sumatra, Kalimantan or Papua of Indonesia.

4.2 Uncertainty of the CO_2 emission estimates

The CO_2 emission estimates from forest fires in Sumatra during 2000 – 2007 still have high uncertainty. The overall uncertainty of the CO_2 emission estimates from vegetation burning and peat burning is 52% and 34% respectively. The highest contributor to the uncertainty of the CO_2 emissions from vegetation burning is the burning efficiency which is taken from the IPCC guidelines. The burning efficiency has uncertainty of 37%. The second significant uncertainty in the CO_2 emission estimates came from the available fuel load which is 34%. Compared with those parameters, burned area data and emission factor have relatively low uncertainty. The uncertainty of the emission factor of peat burning contributes to 31% of the overall peat burning CO_2 emission estimates uncertainty.

To reduce the overall uncertainty of the CO_2 emission estimates, we can reduce the uncertainty related to each parameter used in the calculation. In general, the uncertainties can be minimized by using the most rigorous methods in estimating the CO_2 emissions. However, the available resources are limited. It may not be feasible to use these methods because they usually need more extensive resources. Therefore, the parameters that have the most impact on the overall uncertainty should be prioritized. Based on the results of this study, to reduce the uncertainty we can focus on the parameters: burning efficiency, the available fuel load and the emission factor of peat burning. More research about the burning efficiency of the forest fires specific for the study area is needed to improve the quality of the CO_2 emission estimates. The information about emission factors from peat land burning is scarce compared with emission factors from vegetation burning. Therefore, more research in emission factors of peat land burning is also needed.

The available fuel load parameter related to forest fires also significantly influence the uncertainty of the CO_2 emission estimates. In this study, the available fuel load for vegetation burning was calculated based on the volume data of the standing stock provided in the forest inventory data. Besides the uncertainty related to the original forest inventory data, the expansion and conversion of volume data to dry weight has introduced other uncertainty. Since forest inventory is conducted periodically, it is important to include the biomass weight as a parameter assessed during future forest inventory activity. It will reduce the uncertainty related to the available fuel load of forest fires.

Due to limitation of the available data and because there was no fieldwork conducted for this study, the uncertainty related to the land cover data can not be estimated. Information about the accuracy of the land cover map is not available. A better uncertainty estimates can be obtained if we have information about the map's accuracy.

4.3 The relationship between fire occurrence and distance to road, population, soil type, NDVI values

The logistic regression analysis has resulted in two significant factors that correlated with the probability of fire occurrence in Sumatra, i.e. soil type (peat, non-peat) and NDVI. However, the model can only predict correctly 19% of the fire occurrence based on the two factors. Both factors have the exp (B) values less than 1, which mean that they have negative correlation with the fire occurrence. Based on the model, we expect that forest fires are more likely to occur in areas with non-peat soil type. This might be related to the fact that pristine peat soils actually are not prone to forest fires (Hooijer *et al.*, 2006). Only if peat soils are drained, for example because of canal establishment when converting peat forests to plantations, peat land areas become more susceptible to forest fires (Hooijer *et al.*, 2006).

The NDVI values also have a negative relation to the fire occurrence. If we assume that more dense forests have higher value of NDVI than degraded forests, this relation can be justified. Based on a study by Kumar *et al*, forest density has a positive correlation with NDVI values (Kumar *et al.*, 2007). The probability of fire to occur in degraded forests is higher than in intact forests as confirmed by the results of research by Langner *et al.* (2007) and Uryu *et al.* (2008) who concluded that most forest fires were detected in degraded forests.

The logistic regression analysis has removed the distance to roads and population from the significant factors related to fire occurrence. Instead of concluding that both factors are not related to fire occurrence, this result may be caused by limitation of the available data. The road of Sumatra map only shows national class and province class of roads. On the other hand, the access to a forest area in Sumatra usually is facilitated by lower class roads or even by footpaths made by indigenous people which are not covered by the map. The available map does not have the level of detail required to depict the accessibility of a forest area in the study area. The population map shows the number of people per municipality. There is no information, however about how many people live depending on forests. If population of a municipality is high but only few people live depending on forests, their pressure to forest is still low and hence the probability of fire occurrence is low. That is why the population data was excluded from the model to analyze the relation of human activities with forests and hence with forest fire occurrence.

After we know the factors related to forest fire occurrence, we can discuss what actions can be taken to reduce the fire occurrence especially in the study area (Sumatra, Indonesia). Peat swamp forests when in good condition can store huge amounts of carbon. This carbon stored in peat can be released through two mechanisms (Hooijer *et al.*, 2006): drainage of peat lands which leads to oxidation resulting in CO_2 emissions, and fires in degraded peat lands result in further CO_2 emissions. The first mechanism (drainage of peat lands) will increase the probability of fire occurrence. Fires are rare in non-degraded and non-drained peat lands (Hooijer *et al.*, 2006). Therefore, conservation of peat swamp forests can reduce the fire occurrence in Sumatra and hence reduce the CO_2 emissions. The natural water table regime of peat lands should be restored through improved water management.

Since the probability of forest fire occurrence is higher in degraded forests, the other option to reduce the fire occurrence is to apply sustainable forest management so that the extent of degraded forests can be minimized. Reforestation of degraded lands will increase the forest density and hence will reduce the probability of fire occurrence.

Land clearing and land preparation using fire has become usual way when convert forest to other land uses such as to agricultural lands or plantations in Indonesia. The Indonesian government has released the regulation PP 4/2001 which forbids the use of fire in land preparation. However, because it offers an easier and cheaper way for land clearing, this practice of using fire in land preparation still continues to be used by large scale plantations. For one hectare of land, mechanical land clearing (without burning) can be US$150 more expensive than using fire to clear lands (Ministry of Forestry, 2007b). Law enforcement still needs to be improved to reduce the use of fire in land clearing.

5. Conclusions and recommendations

5.1 Conclusions

Based on the results of this study, forest fires emitted a huge amount of CO_2 during 2000 – 2007 in Sumatra, Indonesia. The CO_2 emissions coming from peat land burning are higher than the CO_2 emissions from above ground biomass burning.

The CO_2 emission due to forest fires in Sumatra still has high uncertainty because the available information about the parameters to calculate the emissions is still limited. The uncertainty of the emission from forest fires and peat land fires is 52% and 34% respectively. Several default values provided by the 2006 IPCC guidelines were used in this study. Generally, those default values introduce relatively high uncertainty.

Soil types (peat, non-peat) and the NDVI have a correlation with the fire occurrence in Sumatra. The NDVI can be used to depict to the forest greenness condition. The logistic regression results have shown that those factors negatively correlate with fire occurrence. It means that forest fires are more likely to occur in the non-peat areas and degraded forests (which have lower NDVI values).

Research question 1: *How much the CO_2 was emitted by forest fires in 2000 – 2007 from biomass burning?*
Answer: The CO_2 emission due to forest fires from biomass burning in Sumatra in 2000 – 2007 was 0.47 – 5.99 Tg CO_2 yr^{-1}

Research question 2: *How much the CO_2 was emitted by forest fires in 2000 – 2007 from peat land burning?*
Answer: The CO_2 emission due to forest fires from peat land burning in Sumatra in 2000 -2007 was 5.06 – 78.99 Tg CO_2 yr^{-1}

Research question 3: *What is the uncertainty of the estimates?*
Answer: The CO_2 emission estimates of biomass burning and peat land burning is 52% and 34% respectively

Research question 4: *Do any factors such as distance to roads, population, soil type and vegetation greenness (NDVI) have a correlation with forest fire occurrence?*
Answer: Soil types and NDVI have a significant negative correlation with forest fire occurrence. It means that we can expect forest fires are more likely to occur in non-peat soil and in degraded forests.

Research question 5: *What alternatives can be taken to reduce forest fire occurrence?*
Answer: Conservation of peat land and and improvement of forest quality can reduce the forest fire occurrence since most fires are happened in degraded peat land and forests.

5.2 Recommendations

- To improve the accuracy of the CO_2 estimates, research is needed: to generate a specific burning efficiency for the study area, to analyze the specific emission factor from the peat burning.
- Inclusion of the biomass dry weight assessment in the future forest inventory will reduce the uncertainty related to the available fuel load of forest fires.
- A regulation to avoid/reduce the forest fire occurrence is already released by the Government of Indonesia. However, law enforcement still needs to be strengthened in order to significantly reduce forest fire occurrence.
- Most of data used to estimate the CO_2 emissions from peat lands is based on one single study on Kalimantan. It is necessary to start collecting better baseline data on peat depth, burning depth, and emission factor of peat burning.

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Appendix. The SPSS outputs of the logistic regression to predict the relation of fire occurrence with human activities

```
LOGISTIC REGRESSION VARIABLES BURNED
  /METHOD=BSTEP(LR) DIST2ROAD_KM POP PEAT NDVI
  /CONTRAST (PEAT)=Indicator
  /SAVE=PRED SRESID
  /CLASSPLOT
  /CASEWISE OUTLIER(2)
  /PRINT=GOODFIT CORR ITER(1) CI(95)
  /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

Logistic Regression

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	400	100.0
	Missing Cases	0	.0
	Total	400	100.0
Unselected Cases		0	.0
Total		400	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
0	0
1	1

Categorical Variables Codings

		Frequency	Parameter coding
			(1)
PEAT	0	286	1.000
	1	114	.000

Appendix (continued)

Block 0: Beginning Block

Iteration History[a,b,c]

Iteration		-2 Log likelihood	Coefficients
			Constant
Step 0	1	554.428	-.030
	2	554.428	-.030

a. Constant is included in the model.

b. Initial -2 Log Likelihood: 554.428

c. Estimation terminated at iteration number 2 because parameter estimates changed by less than .001.

Classification Table[a,b]

Observed			Predicted		
			BURNED		Percentage Correct
			0	1	
Step 0	BURNED	0	203	0	100.0
		1	197	0	.0
	Overall Percentage				50.8

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-.030	.100	.090	1	.764	.970

Variables not in the Equation[a]

			Score	df	Sig.
Step 0	Variables	DIST2ROAD_KM	1.005	1	.316
		POP	.001	1	.981
		PEAT(1)	32.812	1	.000
		NDVI	21.504	1	.000

a. Residual Chi-Squares are not computed because of redundancies.

Block 1: Method = Backward Stepwise (Likelihood Ratio)

Iteration History[a,b,c,d]

Iteration		-2 Log likelihood	Coefficients				
			Constant	DIST2ROAD _KM	POP	PEAT(1)	NDVI
Step 1	1	488.505	4.718	-.010	.000	-1.465	-4.499
	2	487.189	5.664	-.012	.000	-1.662	-5.442
	3	487.184	5.727	-.013	.000	-1.673	-5.506
	4	487.184	5.728	-.013	.000	-1.673	-5.506
Step 2	1	489.906	4.515		.000	-1.381	-4.458
	2	488.708	5.388		.000	-1.556	-5.357
	3	488.705	5.442		.000	-1.565	-5.413
	4	488.705	5.442		.000	-1.565	-5.413
Step 3	1	491.774	4.223			-1.368	-4.248
	2	490.787	4.955			-1.533	-5.015
	3	490.785	4.992			-1.540	-5.054
	4	490.785	4.992			-1.540	-5.054

a. Method: Backward Stepwise (Likelihood Ratio)

b. Constant is included in the model.

c. Initial -2 Log Likelihood: 554.428

d. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	67.244	4	.000
	Block	67.244	4	.000
	Model	67.244	4	.000
Step 2[a]	Step	-1.520	1	.218
	Block	65.723	3	.000
	Model	65.723	3	.000
Step 3[a]	Step	-2.080	1	.149
	Block	63.643	2	.000
	Model	63.643	2	.000

a. A negative Chi-squares value indicates that the Chi-squares value has decreased from the previous step.

Appendix (continued)

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	487.184[a]	.155	.206
2	488.705[a]	.152	.202
3	490.785[a]	.147	.196

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Classification Table[a]

Observed			Predicted		
			BURNED		Percentage Correct
			0	1	
Step 1	BURNED	0	153	50	75.4
		1	70	127	64.5
	Overall Percentage				70.0
Step 2	BURNED	0	152	51	74.9
		1	71	126	64.0
	Overall Percentage				69.5
Step 3	BURNED	0	151	52	74.4
		1	70	127	64.5
	Overall Percentage				69.5

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	DIST2ROAD_KM	-.013	.010	1.524	1	.217	.988	.968	1.007
	POP	.000	.000	1.837	1	.175	1.000	1.000	1.000
	PEAT(1)	-1.673	.272	37.973	1	.000	.188	.110	.319
	NDVI	-5.506	1.052	27.397	1	.000	.004	.001	.032
	Constant	5.728	.948	36.482	1	.000	307.275		
Step 2[a]	POP	.000	.000	1.872	1	.171	1.000	1.000	1.000
	PEAT(1)	-1.565	.254	37.885	1	.000	.209	.127	.344
	NDVI	-5.413	1.040	27.078	1	.000	.004	.001	.034
	Constant	5.442	.910	35.794	1	.000	230.832		
Step 3[a]	PEAT(1)	-1.540	.253	37.117	1	.000	.214	.131	.352
	NDVI	-5.054	.992	25.949	1	.000	.006	.001	.045
	Constant	4.992	.836	35.689	1	.000	147.200		

a. Variable(s) entered on step 1: DIST2ROAD_KM, POP, PEAT, NDVI.

Appendix (continued)

Model if Term Removed

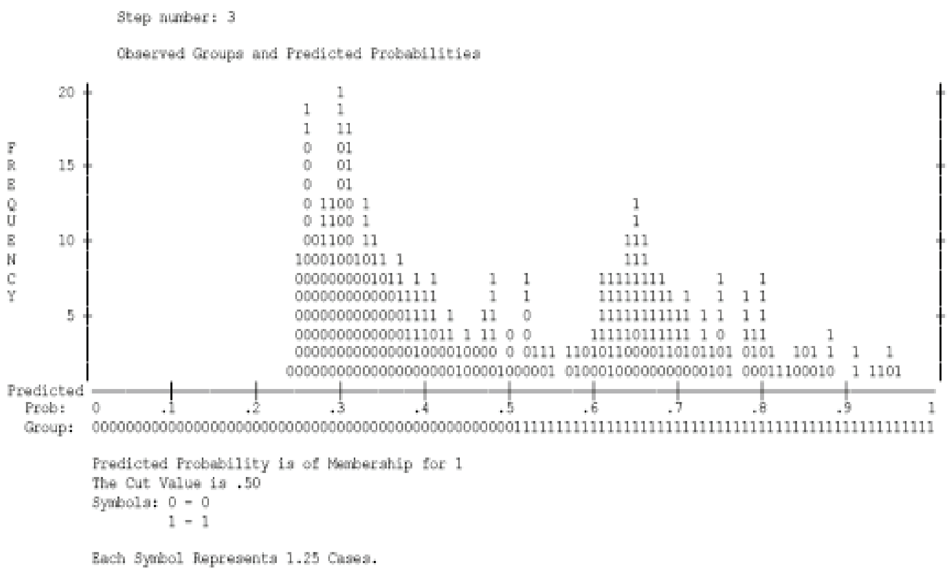
Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	DIST2ROAD_KM	-244.352	1.520	1	.218
	POP	-244.595	2.005	1	.157
	PEAT	-264.972	42.761	1	.000
	NDVI	-259.945	32.707	1	.000
Step 2	POP	-245.392	2.080	1	.149
	PEAT	-265.429	42.153	1	.000
	NDVI	-260.376	32.048	1	.000
Step 3	PEAT	-265.988	41.192	1	.000
	NDVI	-260.394	30.003	1	.000

Variables not in the Equation

			Score	df	Sig.
Step 2[a]	Variables	DIST2ROAD_KM	1.536	1	.215
	Overall Statistics		1.536	1	.215
Step 3[b]	Variables	DIST2ROAD_KM	1.614	1	.204
		POP	2.102	1	.147
	Overall Statistics		3.633	2	.163

a. Variable(s) removed on step 2: DIST2ROAD_KM.

b. Variable(s) removed on step 3: POP.



Appendix (continued)

Casewise List[b]

Case	Selected Status[a]	Observed	Predicted	Predicted Group	Temporary Variable	
		BURNED			Resid	ZResid
228	S	0**	.878	1	-.878	-2.688
392	S	0**	.941	1	-.941	-3.998

a. S = Selected, U = Unselected cases, and ** = Misclassified cases.

b. Cases with studentized residuals greater than 2.000 are listed.