GREENHOUSE GAS EMISSIONS AND LAND USE ISSUES RELATED TO THE USE OF BIOENERGY IN INDONESIA

Isu Emisi Gas Rumah Kaca dan Penggunaan Lahan Sehubungan dengan Pemanfaatan Bioenergi di Indonesia

Muhrizal Sarwani, Neneng Laela Nurida, and Fahmuddin Agus

Indonesian Centre for Agricultural Land Resources Research and Development,
Jalan Tentara Pelajar No. 12, Bogor 16114
Phone. (0251) 8323012, 83277215, Fax. (0251) 8311256
E-mail: bbsdlp@litbang.deptan.go.id; Muhrizal.sarwani@yahoo.co.id

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ABSTRACT

Biofuel use is intended to address the ever-increasing demand for and scarcer supply of fossil fuels. The recent Indonesia government policy of imposing 10% mixing of biodiesel into petroleum-based diesel affirms the more important biofuel role in the near future. Palm oil, methane from palm oil mill effluent (POME) and animal wastes are the most prospective agricultural-based biofuels. The production and use of palm oil is interlinked with land use and land use change (LULUC), while the use of methane from POME and animal wastes can contribute in reducing emissions. The current European Union (EU) and the potential United States (US) markets are imposing biodiesels' green house gas (GHG) emission reduction standards (ERS) of 35% and 20%, respectively relative to the emissions of petroleum-based diesel based on using the lifecycle analysis (LCA). EU market will increase the ERS to 50% starting 1 January 2017, which make it more challenging to reach. Despite controversies in the methods and assumptions of GHG emission reduction assessment using LCA, the probability of passing ERS increases as the development of oil palm plantation avoid as much as possible the use of peatland and natural forests. At present, there is no national ERS for bioenergy, but Indonesia should be cautious with the rapid expansion of oil palm plantation on existing agricultural lands, as it threatens food security. Focusing more on increasing palm oil yield, reducing pressure on existing agricultural lands for oil palm expansion and prioritizing the development on low carbon stock lands such as grass- and shrublands on mineral soils will be the way forward in addressing land scarcity, food security, GHG emissions and other environmental problems. Other forms of bioenergy source, such as biochar, promise to a lesser extent GHG emission reduction, and its versatility also requires consideration of its use as a soil ameliorant.

Keywords: Biofuel, greenhouse gas, land use, emission, food security

ABSTRAK

Penggunaan bahan bakar bio (BBB) ditujukan untuk menjawab tantangan meningkatnya permintaan dan menurunnya ketersediaan bahan bakar minyak (BBM). Kebijakan pemerintah yang mengharuskan pencampuran 10% solar nabati ke dalam minyak solar menunjukkan semakin pentingnya peran BBB. Minyak sawit, metana dari limbah cair pabrik minyak sawit dan kotoran hewan merupakan BBB dari pertanian dengan prospek tinggi. Sistem produksi dan pemanfaatan minyak sawit berkaitan dengan penggunaan dan perubahan penggunaan lahan (PPPL), sedangkan penggunaan metana dari limbah cair pabrik minyak sawit (LCMS) dan dari kotoran hewan dapat berkontribusi dalam menurunkan emisi berdasarkan analisis daur hidup (ADH). Pasar aktual Uni Eropa (UE) dan pasar potensial Amerika Serikat (AS) menetapkan standar penurunan emisi (SPE) gas rumah kaca (GRK) dari biodiesel berturut-turut 35% and 20% terhadap emisi BBM solar. UE akan meningkatkan SPE menjadi 50% mulai tahun 2017. Walaupun terdapat kontroversi dalam metode perhitungan dan asumsi dengan menggunakan teknik ADH, peluang untuk lolos SPE akan meningkat bila pengembangan perkebunan kelapa sawit sebisa mungkin menghindari lahan gambut dan hutan alam. Walaupun saat ini belum ada SPE nasional untuk bioenergi, Indonesia perlu mewaspadai perluasan kelapa sawit pada lahan pertanian eksisting, terutama area tanaman pangan karena dapat mengancam ketahanan pangan. Disarankan agar pengembangan kelapa sawit lebih fokus pada peningkatan produktivitas, pengurangan tekanan terhadap penggunaan lahan pertanian lainnya, dan memprioritaskan penggunaan lahan semak belukar berkarbon rendah pada tanah mineral demi mengatasi masalah keterbatasan lahan, ketahanan pangan, emisi GRK, dan masalah lingkungan lainnya. Bahan bioenergi lain seperti biochar, juga berpotensi menurunkan emisi GRK, namun karena bahan ini multiguna, maka penggunaannya untuk pembenah tanah juga perlu diperhatikan.

Kata kunci: Bahan bakar bio, gas rumah kaca, emisi, penggunaan lahan, ketahanan pangan

INTRODUCTION

The role of bioenergy is rapidly increasing with the decreasing availability of petroleum-based fuels and increasing energy consumption. Total annual energy consumption in Indonesia increased 2.9% annually from 300,147 GWh in 1980 to 1,490,892 in 2009 (Silitonga*et al.* 2011), suggesting that demand for land to plant fuel

feedstock is also increasing. The recent policy of the Government of Indonesia to impose 10% biodiesel mixture in petroleum-based diesel affirms the more important role of biodiesel.

The objectives of using biofuels are to decrease pressure on non-renewable fuels and reduce greenhouse gas (GHG) emissions through the replacement of non-renewable fuels. In their original fully-organic system, the production cycles (planting, weeding, harvesting) and the use of bioenergy produced from such system are near carbon neutral. The emissions of carbon dioxide (CO_2) from biodiesel or bioethanol are mostly compensated by the absorption of CO_2 from the atmosphere through photosynthesis. However, with the intensification of agriculture, oil and starch production systems are increasingly dependent on external inputs, most of which involve the use of petroleum-based fuels, while the use of man and animal powers are decreasing and replaced by machineries for soil tillage, farm transportation, harvesting, product processing and marketing. These add to GHG emissions in the production cycle.

In general, the emission assessment of biofuel uses is not limited only to farm gate emissions, but also includes emissions from land use change, fertilizer uses, farm transportation, and processing and refineries of oils, starches and sugars. This all-encompassing calculation procedure is known as the lifecycle analysis (LCA) (van Noordwijk *et al.* 2010; Chase *et al.* 2012).

Methane (CH_4) as a by-product of animal husbandry and crude palm oil (CPO) production processes also has a great potential as a biofuel. Wood biomass (Myllyviita *et al.* 2013) and biochar (char produced in oxygen depleted combustion known as pyrolysis) are also gaining higher attention as a potential renewable fuel although their use for other purposes such as soil ameliorant is also important (Tang *et al.* 2013).

There are controversies in the use of vegetable oils, starches and sugars as biofuel feedstock. On the one hand, the use of these kinds of bioenergy was expected to reduce significant amount of emissions, but on the other hand their production cycles may involves high amount of GHG emissions depending on the amount of petroleum based fuels used and the type of soil and land cover converted for their production. Biodiesels produced by crops planted on peatland or crops that replaces natural forests, may release high amount of GHG emissions. As a result, their use may not significantly reduce GHG emissions relative to those of petroleum-based diesel. Understanding of the hotspots of emission sources within the processing cycles is important for determining the emission reduction strategies.

This paper discusses (1) the development and environmental aspects of oil palm as the most prospective crop in Indonesia for producing biodiesel, (2) emission reduction standards of biofuel usage and (3) the prospects of other biofuel sources.

LAND USE COMPETITION BY BIOENERGY CROPS

There are two issues related to the development of bioenergy crops, i.e. competition for the use of land, and GHG emissions associated with land use change.

Land Use Competition

The most important oils as the feedstock of biodiesels are CPO from oil palm, soybean oil, corn oil, rapeseed oil and sunflower oil. Among these oil producing crops, palm oil is the most rapidly developing (Ditjenbun 2007; Gunarso *et al.* 2013). It is also the most controversial commodity. On the one hand, it is needed to supply vegetable oil for food and industrial uses. On the other hand, its rapid development is feared to undermine food security (Cornelissen *et al*. 2012; Maltsoglou *et al*. 2013) biodiversity (Killeen *et al.* 2011; Persson 2012; Kraxner *et al.* 2013; Pedroli *et al*. 2013) and increase GHG emissions (Reijnders and Huijbregts 2008; Wicke *et al.* 2008; Souza *et al.* 2010; Page *et al.* 2011).

Areas for soybean, maize, rapeseed and sunflower are changing much less rapidly. The use of other oils (corn oil, coconut oil), starches and sugars are mainly for food. The production of biodiesel from *Jatropha curcas* (under smallholder systems) offers many social, economical and environmental benefits as well as partially solves energy crisis in Indonesia (Silitonga *et al.* 2011). However, its planting areas are scattered (Mulyani *et al.* 2006) and thus problematic in its processing and marketing.

The global future demand for edible oil is around 240 Mt in 2050, nearly twice today's total. Most of the additional oil may be palm oil, which has the lowest production cost of the major oils. To meet the increasing demand for food, an additional 12 million ha of palm plantation area will be needed and this need not be at the expense of forest (Corley 2009) and peatlands (Page *et al.* 2011; Agus *et al.* 2013). Corley (2009) estimated that oil palm planted on anthropogenic grassland could supply all the oil required for edible purposes in 2050. However, biofuel demand might greatly exceed that for edible use which means that the demand for land for oil palm plantation will escalate. This may threaten the sustainability of other crop production, including food crops (Maltsoglou *et al.* 2013). Therefore, land use policy should integrate food security, energy sources and environmental consideration (Harvey and Pilgrim 2011).

With rising populations and projected consumption levels, there will not be enough land to simultaneously conserve natural areas completely, halt forest loss, and switch to 100% renewable energy, but it is very important to control conversion from unmanaged to sustainably managed forest as well as increased protection of areas for ecosystems services such as biodiversity (Cornelissen *et*

al. 2012; Agus *et al.* 2013; Gunarso *et al.* 2013; Kraxner *et al.* 2013).

Production of biofuel feedstock on the currently available cropland area increased the competition between food and fuel production. The exclusive consideration of LUC for bioenergy production minimizes direct LUC at the expense of increasing indirect LUC (Lange 2011), i.e. land use change for food crops because some areas of food crops are converted to bioenergy crops. These land conversion, in general, will cause an increase of GHG emissions and loss of environmental functions, unless strict regulations are in place to localize land conversion only on low carbon stock areas.

Greenhouse Gas Emissions Related to Land Use and Land Use Change for Bioenergy Crops

Oil palm is the most rapidly developing crop in Indonesia. Areas of oil palm plantation in Indonesia have been increasing dramatically at a rate of 12.3% annually from only 290,000 ha in 1980 to 6,075,000 ha in 2006 (Ditjenbun 2007; IPOB 2007). In 2010 oil palm area in Sumatra, Kalimantan and Papua was estimated to be 7.9 milion ha, about 1.7 milion ha of which were on peatland (Gunarso *et al.* 2013). For overall Indonesia, the estimated total area in 2010 was about 8.4 milion ha (Ditjenbun, unpub.).

The most widely cited estimate of deforestation attributed to oil palm plantations is based on a reinterpretation of the national reports provided by government ministries to the Forest Resource Assessment Program of the Food and Agriculture Organization (FAO 2006) covering the period between 1990 and 2005. This information has been reinterpreted to provide an estimate that approximately 55–59% of oil palm expansion in Malaysia and Indonesia has occurred at the expense of forests (Koh and Wilcove 2008). A recent study by Gunarso *et al.* (2013) for the period of 2000 to 2010, however, revealed that only 4.1% (397,000 ha) of oil palm plantations originated on land derived directly from undisturbed forests, while 32.3% (3.1 million ha) were established on land previously covered with disturbed forest. Conversion of low biomass shrub lands and grasslands was documented at 17.6% (1.7 million ha). For Malaysia, Hassan *et al.* (2011) predicted that if oil palm plantation development can keep the balance of forest and degraded land conversion, and palm oil diesel can replace 5% of petroleum-based diesel, then the country can reduce about 1 Mt CO_2 emissions annually or about 4.9% of the transportation sector's diesel emissions.

Compared to other oil producing crops, oil palm is the most efficient in the use of land as its yield is at least five times higher than those of other oil producing crops (Figure 1). Despite the high productivity and high efficiency in using land resources, its rapid expansion that partially replace forest (including peat forest) positions this commodity as an important driver of GHG emissions. Schmidt (2010) compared the environmental aspects of palm oil and rapeseed oil production for European market uses. He concluded that overall, palm oil tends to be environmentally preferable to rapeseed oil within all impact categories. For global warming, biodiversity and

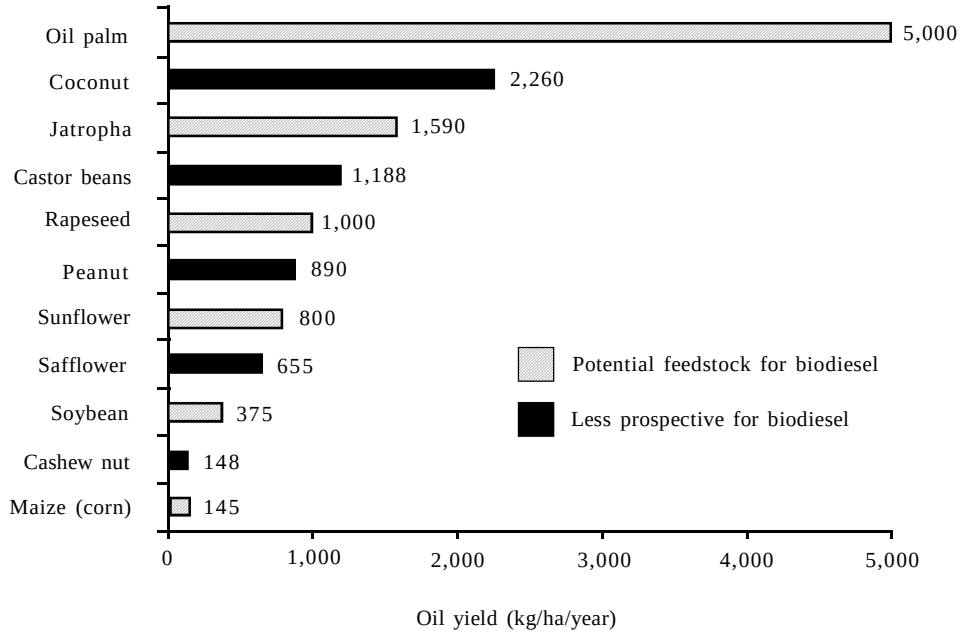

Figure 1. The yield of several oil producing crops (Source: recalculated from http://en.wikipedia.org/wiki/Table_of_biofuel_crop_yields, download March. 2013).

ecotoxicity, the difference is less pronounced and it is highly dependent on the assumptions regarding system delimitation in the agricultural stage.

Agus *et al.* (2009) analyzed CO_2 emissions from different land use change trajectories. If oil palm plantation with time averaged carbon (C) stock of about 40 t/ha replaces forest with the C stock of 132–300 t/ha, in one cycle of oil palm plantation production, it will emit C as much as 92–260 t/ha or CO_2 emissions of about 338–954. However, if shrub or Imperata grassland, with respective C stocks of 15 and 2 t/ha is rehabilitated to plantation, it results in a net C sequestration of about 25 and 38 t/ha, respectively or equivalent to 92 and 139 t CO_2/ha. The use of primary and secondary forests results in net CO_2 emissions, while the use of shrub or grassland, in general will result in the net C sequestration. Therefore, the use of low C stock land is recommended for oil palm plantation expansion as an attempt to reduce emissions.

Expansion of plantation on peatland involves emissions, not only from the change of C stock from plant biomass, but also from peat oxidation (Hooijer *et al.* 2006, 2010; Handayani 2010). The estimate of the amount of emissions from peat oxidation varies depending on the research sites and methods (Husnain *et al.* 2013).

If the land conversion involves fire, the emissions can increase dramatically if the layer of peat is combusted. Despite in general a high net positive emission from agriculture on drain peatland, the use of peat shrub and peat grassland is more acceptable compared to using peat forest (Agus *et al.* 2009, 2013).

EMISSION REDUCTION STANDARDS

Emission reduction standards, in general, use the lifecycle analysis (LCA). This section explain the principles of LCA, the USA and EU standards.

Lifecycle Analysis

Lifecycle analysis (LCA), in general includes the emissions from the below listed sources, although the detail of each component and methods of its calculation may vary to some extent from one model to another (van Noordwijk *et al.* 2010; Chase *et al.* 2012; US-EPA 2012) as follows:

- Emissions due to loss of stored carbon in plant biomass at land clearing.
- Carbon stored in oil palm biomass.
- Emissions due to cultivation of peatland .
- Emissions due to manufacture, transport and use of fertilizers, including nitrous oxide (N_2O).
- Emissions due to combustion of fossil fuels used in the field and in the mill.
- Net emissions of methane (CH_4) produced from palm oil mill effluent (POME).

US-EPA Biofuel Standard

In January 2012, US-EPA issued a notice of data availability (NODA) concerning renewable fuels produced from PO under the renewable fuel standard (RFS) program. The notice gave an opportunity for governments, companies, scientists and communities at large to comment especially on the method used and the scientific base. US-EPA's analysis shows that biodiesel and renewable diesel produced from palm oil have estimated lifecycle GHG emission reductions of only 17% and 11%, respectively, compared to the statutory baseline petroleum-based diesel fuel used in the RFS program. This analysis temporarily concluded that both palm oil-based biofuels would fail to meet the minimum 20% GHG performance threshold for renewable fuel under the RFS program.

The NODA provided a description of the analysis. Table 1 shows the summary of the analysis and our recalculation using alternative scenarios. Land use change, including emissions from peat, are among the highest contributor of the lifecycle GHG emissions with the contribution of 46 and 47 kg CO_2e/mmBtu, respectively for palm oil diesel and palm oil renewable diesel. Fuel production which includes the processing of fresh fruit bunch to CPO and emissions from POME contributed the second highest emissions. The tailpipe emissions for PO diesel and PO renewable diesel were negligibly small as the emitted carbon was generated from CO_2 absorption in the plant growth and production process. Meanwhile, tailpipe emissions were the highest contributor (79 kg CO_2e/mmBtu) of the diesel baseline as the emitted carbon was originated from petroleum that is non-renewable.

There are a few issues related to the US-EPA LCA and they are especially related to land use change and emissions from peat. Based on these issues we developed new Scenarios of LCA calculation and rerun the model.

Assumption of Emission Factor (EF) from Peatland

EPA adopted EF of peat of 95 Mg CO_2/ha/year under oil palm plantation was based on a review paper by Page *et al.* (2011) who chose research results of Hooijer *et al.* (2012). Hooijer *et al.* (2012) used subsidence measurement approach for research in Riau and Jambi and came up with annualized emission rate from peat under oil palm plantation of 100 and 86 Mg CO_2 /ha/year for 25 and 50 year oil palm plantation cycles, respectively. Other research by Wösten *et al.* (1997) from 17 observation

Table 1. Summary of lifecycle analysis of greenhouse gas emissions (in kg CO_2e/mmBtu) by US-EPA and our recalculation using various input scenarios, including alternative peat emission factor, land use change data and percentage of peatland used for oil palm plantation expansion.

Emission category	2005 diesel baseline	PO biodiesel	PO renewable diesel
Net agriculture (without land use change)	–	5[1]	5[1]
Land use change	–	46[1]	47[1]
S1: Peat EF of 38 (max 57 and min. 20) Mg CO_2/ha/yr for Indonesia and Malaysia		32(28–37)[2]	33(29–38)[2]
S2: S1 + adjustment of affected forest area from 43% to 28% and affected shrubland from 0% to 15% for Indonesia		30(26–35)[2]	31(26–35)[2]
S3: S2 + (in Indonesia) peatland area impacted by OP is reduced 3% (13% under EPA estimate to 10% under our assumption). The 3% reduction is reallocated to shrubland		29(25–33)[2]	29(26–33)[2]
Fuel production	18[1]	25[1]	31[1]
Fuel and feedstock transport	–	4[1]	4[1]
Tailpipe emissions	79[1]	1[1]	
Net emissions	97[1]	81[1]	87[1]
% reduction relative to baseline (EPA)			
EPA estimate		17%[1]	11%[1]
S1		31% (26–35%)[2]	25% (20–29%)[2]
S2		33% (28-38%)[2]	27% (22–32%)[2]
S3		35% (31-38%)[2]	29% (25–32%)[2]

[1]Source: US-EPA (2012).
[2]Source: Own calculation based on selected scenarios. Numbers in brackets are mean (minimum and maximum) values.

points in Malaysia assuming the peat bulk density of 0.1 g/cm^3 and C^{org} of 60% found the subsidence rate to be 2 cm/year and estimated the emission as high as 27 Mg CO_2/ha/year; which is much lower than that of Hooijer *et al.* (2012).

The lack of bulk density and carbon stock data at the beginning (before the peatland is cleared) and the current year, for the calculation of oxidized peat, has lead researchers to use assumptions of peat oxidation/peat subsidence ratio. For example, Couwenberg *et al*. (2010) used the value of 40%, Wösten *et al*. (1997) 60% and Couwenberg *et al*. (2010) 60%, while Hooijer *et al.* (2012) 92%. On the contrary, Kool *et al.* (2006), based on the changes in peat ash content and subsidence from a research in Central Kalimantan, concluded that oxidation is only a small portion of subsidence. Thus, the oxidation/subsidence ratio is a source of uncertainty.

Research using closed chamber measurement techniques, representing a wide variation of peat areas and properties, came up with emission estimate ranging from 20.0 to 56.7 Mg CO_2/ha/year, or a mean of 38 Mg CO_2/ha/year (Murayama and Bakar 1996; Melling *et al.* 2005; Melling *et al*. 2007; Fargione *et al.* 2008; Reijnders and Huijbregts 2008; Wicke *et al.* 2008; Agus *et al.* 2010; Murdiyarso *et al.* 2010; Jauhiainen *et al.* 2012). More recent studies using closed chamber techniques on peatland in Jambi, found similar annualized emissions of 38 Mg CO_2/ha/year for 6-year old oil palm plantation (Dariah *et al*. 2012) and 46 Mg CO_2/ha/year for 15-year old plantation (Marwanto and Agus 2013). Using the mean annual emission value of 38 Mg CO_2/ha/year, we rerun Scenario 1 of the LCA and present the result in Table 1. Table 1 shows that introduction of Scenario 1 drastically decreased CO_2 emissions from land use change from 46 to 32 kg/mmBtu for PO biodiesel and from 47 to 33 kg/mmBtu for PO renewable diesel. This scenario alone results in emission reduction of 31 and 25% for the two respective types of biodiesels. The sensitivity analysis showed that even under the annual emission of 57 Mg CO_2/ha/year, the emission reduction would still be 26% and 25% for the two types of biofuels, respectively, meaning that they were well above the minimum standard of emission reductions as set out by the US Government. As the current database for peat emissions is still scares, it is very important to conduct research on this aspect to develop database for better representation of peat of different maturity and pedo-genesis.

Land Cover Change for Oil Palm Plantation Expansion

The US-EPA analysis projected that future oil palm expansion will be mostly on forest (43%), mixed (38%), savanna (10%) and croplands (7%) (Table 2). Shrubland

was not regarded as a potential land cover for oil palm expansion in the US-EPA analysis and this perhaps because of the wide definition of forest under EPA LCA. An analysis by Gunarso *et al.* (2013) shows a much lower reliance of oil palm expansion in the past on forest and an important role of shrubland. Oil palm expansion between 1990 and 2010 used only around 34% forest (about 6% undisturbed forest and 28% disturbed forest), around 26% shrubland and 40% other land uses including rubber plantation, timber plantation, and other low carbon biomass agricultural and grasslands. For 2000–2010, based on a recalculation of the same database as the 1990–2010, the reliance of forest for oil palm development was decreased to 28%, which is much lower than the 2000–2009 US-EPA figure (Table 2). The future use of shrubland will remain important as there are quite a significant areas of shrubland on mineral and peat soils (Figure 2). Therefore we adjusted the percentage value of oil palm plantation that replaces forest to 28% and the difference (43–28% = 15%; Table 2) is allocated for shrubland under Scenario 2. The recalculation of emissions under Scenario 2 plus Scenario 1 reduced the emission further to 30 kg CO_2e/mmBtu under palm oil biodiesel and 31 kg CO_2e/mmBtu for palm oil renewable diesel.

As a comparison, for Brazilian condition, where oil palm plantation so far has not involve the use of peatland, lifecycle analysis shows that avoided emissions due to the use of biodiesel account for 80 g CO_2e/MJ (Souza *et al.* 2010) or 92% of emissions emitted by petroleum-based diesel of 87 g CO_2-e/MJ. For Malaysia, if oil palm plantation development does not solely convert intact forest, but also uses degraded lands, and palm oil diesel can replace 5% of petroleum- based diesel, the country can reduce about 1 million t CO_2 emissions or about 4.9% of the transportation sector's diesel emissions (Hassan *et al.* 2011).

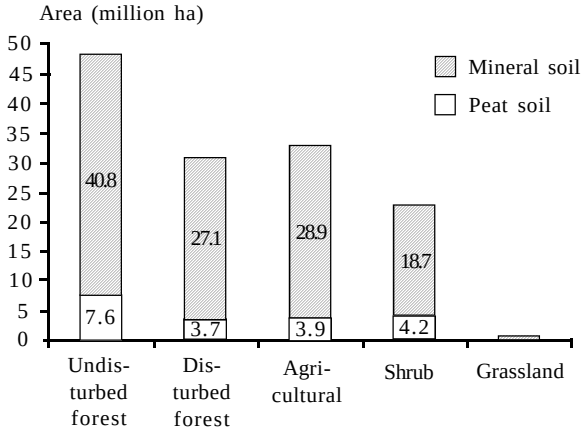

Figure 2. Land cover for Sumatra, Kalimantan and Papua in 2010 on mineral and peat soils (recalculated from Gunarso *et al.* 2013).

Peatland map issues

The peatland maps used by the US EPA were the one by Wahyunto *et al.* (2003, 2004, 2006) which were relied heavily on landsat TM imageries with a relatively limited ground truthing. Ritung *et al.* (2011) updated the maps of Wahyunto *et al.* (2003, 2004, 2006) using soil survey data conducted between 2001–2010. These new maps showed a 14% reduction in the estimate of peatland area in Sumatra and Kalimantan. Comparing between the two maps, there are cases where shallow peat (< 100 cm) has undergone subsidence until its thickness was less than 50 cm for which the area can no longer be classified as peatland. On the other hand, there are cases of areas depicted as peatland in the older map, but turned to be mineral soils based on the ground truth data. Furthermore, there are also cases in which the land was interpreted as mineral soil whereas it actually was peat. Comparison of peat area estimate in the three main islands of Indonesia is presented in Table 3. This new maps show a 14% reduction of peatland in Sumatra and Kalimantan. We estimate the future oil palm expansion on peatland of 10%

Table 2. Projected and historical land cover types impacted by oil palm plantation expansion in Indonesia.

Land cover types	Percentage of land cover type		
	US-EPA (2012) projection for 2022[2] based on 2000–2009 trend	Gunarso *et al.* (2013)	
		Historical 1990–2010	Historical 2000–2010[3]
Forest	43	34	28
Mixed[1]	38	34	26
Shrubland	0	26	23
Savanna	10		
Grassland and croplands	8	6	23
Wetland	1	n.a.	n.a.

[1]Rubber, timber plantations, agroforestry.
[2]Table II.5 NODA US-EPA 2012, based on 2000-2009 trend.
[3]For Sumatra and Kalimantan only (a recalculation).

Table 3. Revised estimate of peatland area in Indonesia based on soil survey data.

Island	Peatland area (ha)		
	Wahyunto *et al.* (2003, 2004, 2006)	Revised Wahyunto *et al.* (2003, 2004, 2006) by Ritung *et al.* (2011)	Difference (Column 2 – Column 3)
Sumatra	7,212,798	6,436,649	776,149
Kalimantan	5,830,228	4,778,004	1,052,224
Papua	7,759,372	3,690,921	4,868,451
Total	20,802,398	14,905,574	6,696,824

Note: Estimated peatland area in Sumatra and Kalimantan is 14% lower than the initial estimate.

maximum, relative to the total area of expansion, instead of 13% in the EPA estimate and reallocate the 3% difference to shrubland and used this assumption under Scenario 3 calculation. Scenario 3 showed only a slightly lower estimate of emission reduction compared to Scenario 2, because of relatively small area of oil palm expansion on peatland compared to the total expansion area.

The three scenarios show that the selection of emission factor of peat oxidation had the greatest influence on the overall average emissions according to this LCA approach. Therefore, the use of research-based reliable data of peat emission factor is very crucial in this internationally strategic decision. The support of more reliable data generated from research that meets the standard methodologies is necessary, especially on areas currently under-represented by the current research results.

European Union Directives on Biofuel Standard

The European Union (EU) has also issued earlier the EU Directives. The sustainability criteria for biofuels under Article 7b stated that the GHG emission saving from the use of biofuels shall be at least 35%. Starting on 1 January 2017, the GHG emission saving from the use of biofuels shall be at least 50%. The European market do not accept vegetable oil produced on wetlands for biofuel feedstock.

For various kinds of vegetable oils, the conversion of natural land, apart from grassy savannahs, impedes meeting the EU's 35% minimum emission reduction target for biofuels. Therefore to be qualified for biofuel, the production of oils such as CPO must be on land previously covered by low carbon stock vegetation such as grass or shrubs (Lange 2011).

THE PROSPECTS OF OTHER BIOFUELS

Apart from palm oil, the development of areas of starch, sugar and other oil producing crops is relatively slow. In some cases oil palm replaces areas; the trend that needs to be control to keep the balance between crops, especially of food crops to ensure the maintenance of a high level of food self-sufficiency. Two promising alternatives of biofuels, methane and biochar are mainly generated as byproducts of agriculture.

Methane from Agricultural Wastes

Methane (CH_4) as a point source by-product of agriculture, which otherwise an important GHG emission, can be captured and used as biogas. Animal waste is an important source of CH_4 and can be produced in small-scale digesters for household electricity and heat sources. The popularity of CH_4 generated by POME is also increasing and it is suitable for medium scale mills and the surrounding grids. Table 4 shows that each unit weight of CH_4 is comparable to petroleum-based diesel in terms of the amount of energy it generates, while the amount of emission it creates is lower than that of diesel. Furthermore, combustion of CH_4 and its conversion to CO_2 reduced emission significantly as the global warming potential of CH_4 is about 21 (IPCC 2006). Its use also replaces/reduces the use of non-renewable fuels.

With the current level of Indonesia's CPO production of more than 20 million tonnes (Mt) of CPO annually (www.RSPO.org), about 50 Mt of POME is poured to the waste ponds and releases about 620,000 t CH_4 annually. If just 50% of this CH_4 is captured, there will be 310,000 t CH_4 that can be used as a replacement of about 304,830 t diesel annually (1 t of POME releases about 12.4 kg of CH_4; Chase *et al*. 2012). In addition, emission of about 2.8 t CO_2/t CH_4 * 20 {(CH_4 - CO_2) GWP} * 304,830 t CH_4/year = 17,050,000 t CO_2-e/year is also reduced.

The problem in the adoption of CH_4 capture technology in oil palm plantation is the high initial cost, but in the long run the adoption of this technology is economically and environmentally rewarding (Dr. Tony Liwang, PT SMART, pers. comm.). Apart from CH_4 from POME, there is also a great potential of CH_4 digestion from

Table 4. Specific carbon content, specific energy content, specific CO_2 emission of different fuels.

Fuel	Specific carbon content (kg_C/kg_{fuel})	Specific energy content (kWh/kg_{fuel})	Specific CO_2 emission (kg_{CO2}/kg_{fuel})	Specific CO_2 emission (kg_{CO2}/kWh)
Coal	0.75	7.5	2.3	0.37
Gasoline	0.90	12.5	3.3	0.27
Kerosene	3.20		3.2	
Diesel	0.86	11.8	3.2	0.24
LPG	0.82	12.3	3.0	0.24
Methane	0.75	12.0	2.8	0.23

Source: http://www.engineeringtoolbox.com/CO_2-emission-fuels-d_1085.html [10 March 2013].

Table 5. Estimated annual by-products of agricultural biomass by-products and their potential use as raw materials for producing biochar (data analyzed from agricultural statistics).

Agricultural biomass	Amount[1] (t/year)	Assumption of convertible biomass (%)	Assumed amount of biomass convertible for biochar (t/year)	Biochar/ biomass ratio	Amount of potential biochar
Rice husk	13,612,343	50	6,806,172	0.26	1,769,605
Coconut shell	539,644	50	269,822	0.25	67,456
Palm kernel shell	6,400,000	30	1,920,000	0.50	960,000
Cocoa fruit shell	1,208,553	50	604,277	0.33	199,411
Corn stalk	3,652,372	30	1,095,712	0.13	142,443
Total	25,412,912		10,695,983		3,138,915

Source: [1]Biro Pusat Statistik (2011); [2]Nurida *et al.* (2008).

animal manure, but this topic is not discussed in this paper.

Biochar

Biochar is a fine material made from the combustion of plant biomass under depleted oxygen environment in a process known as pyrolysis. Recently its potential utilization as a soil ameliorant has been investigated. Not only its recalcitrant that can store carbon for hundreds of years, it also provides habitat for soil microorganisms, without being decomposed. These properties made it ideal as a soil ameliorant (Steiner *et al.* 2007; Tang *et al.* 2013). However, like charcoal, it can also be used as a renewable fuel (Okimori *et al.* 2003) and thus a balance must be made between the two potential utilizations.

Table 5 shows the estimated amount of agricultural by-products that can be used for various purposes, including biochar. Assuming a portion of the biomass is convertible to biochar (column 3, Table 5), roughly 3.1 Mt of biochar should be available annually as fuel and this amount can substitute the use of about 2.3 million liters of diesel or the equivalent of other petroleum based non-renewable fuels (Table 6).

CONCLUSIONS AND RECOMMENDATIONS

Indonesia has a great potential of using and exporting bioenergy sources especially palm oil. Under the current trend of land use and land use change, meeting the criteria of greenhouse gas emission reduction as set out by the US and EU markets is very challenging. However apart from settling uncertainties in the emission factors, those standards can be met by prioritizing the development of new oil palm planting areas on low carbon stock lands such as shrub and Imperata grassland and avoiding as much as possible the conversion of forest and peatland for new plantations.

The expansion of oil palm areas need to be controlled such that it is in balance with other crops development, especially food crops to ensure a high level of Indonesian food self-sufficiency and food sovereignty. Efforts on increasing palm oil production must focus on intensification (higher yield per unit area), especially under smallholder plantations with a relatively high yield gaps. This will cause minimal impact to the conversion of areas of other commodities and forests, contribute to the decrease of GHG emissions and improve smallholder livelihood.

Table 6. Energy potential generated from biochar and the estimated diesel substitution.

Agricultural biomass	Amount of potential biochar (t/year)	Energy potential (kcal/year)[1]	Diesel equivalent (liter)
Rice husk	1,769,605	12,247,433,367	1,324,699
Coconut shell	67,456	466,859,516	50,496
Palm kernel shell	960,000	6,644,160,000	718,641
Cocoa fruit shell	199,411	1,380,125,227	149,276
Corn stalk	142,443	985,844,598	106,630
Total	3,138,915	21,724,422,708	2,349,742

[1)]Calculated from Gaunt and Lehmann (2008).

Methane from palm oil mill effluent (POME) as well as animal manure has a great potential as a bioenergy source. The use of methane not only provides alternative renewable energy source, but also significantly reduces emissions due to conversion of CH_4 (with a global warming potential of 21) to CO_2 and reduction of the use of non-renewable diesel because of substitution with biogas.

Biochar also provides another bioenergy alternative, although its raw material (plant biomass) and the biochar itself are also important for other uses such as soil ameliorant. Keeping the balance of various uses will be the way forward.

REFERENCES

Agus, F., P. Gunarso, B.H. Sahardjo, N. Harris, M. van Noordwijk, and T.J. Killeen. 2013. Historical CO_2 emissions from land use and land cover change from the oil palm industry in Indonesia, Malaysia and Papua New Guinea. Roundtable on Sustainable Palm Oil, Kuala Lumpur, Malaysia.

Agus, F., E. Handayani, van Noordwijk, M., K. Idris, and S. Sabiham. 2010. Root respiration interferes with peat CO_2 emission measurement. pp. 50–53 *In* Proceedings of 19th World Congress of Soil Science, Brisbane, Australia, 1–6 August 2010. Published on DVD.

Agus, F., E. Runtunuwu, T. June, E. Susanti, H. Komara, H. Syahbuddin, I. Las. and M. van Noordwijk. 2009. Carbon budget in land use transitions to plantation. Indones. Agric. Res. Dev. J. 29(4): 119–126.

Badan Pusat Statistik. 2011. Statistik Indonesia. Badan Pusat Statistik, Jakarta.

Chase L.D.C., I.E. Henson, A.F.N. Abdul-Manan, F. Agus, C. Bessou L. Milà. I. Canals, and M. Sharma. 2012. The PalmGHG Calculator: The RSPO greenhouse gas calculator for oil palm products, Beta-version. The Roundtable for Sustainable Palm Oil – RSPO. Kuala Lumpur, Malaysia.

Corley, R.H.V. 2009. How much palm oil do we need? Environ. Sci. Policy 12: 134-139.

Cornelissen, S., M. Koper, and Y.Y. Deng. 2012. The role of bioenergy in a fully sustainable global energy system. Biomass and Bioenergy 41: 21–33.

Couwenberg, J., R. Dommain, and H. Joosten. 2010. Greenhouse gas fluxes from tropical peatlands in South-east Asia. Global Change Biology 16: 1715–1732.

Dariah A., S. Marwanto, and F. Agus. 2013. Root and peat based CO_2 emissions from oil palm plantations. Mitigation and Adaptation Strategies for Global Change. DOI 10.1007/s11027-013-9515-6.

Ditjenbun (Direktorat Jenderal Perkebunan). 2007. Road Map Kelapa Sawit. Ditjenbun, Departemen Pertanian, Jakarta.

European Union. 2011. Official Journal of the European Union: Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009, European Union, Strasbourg. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0088:0113:EN:PDF. [download 4 Sept. 2013].

FAO (Food and Agriculture Organization). 2006. Global Forest Resources Assessment 2005: Progress towards sustainable forest management. FAO Forestry Paper, 147. FAO, Rome, Italy.

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. Land clearing and the biofuel carbon debt. Science 319: 1235–1238.

Gaunt, J.L. and J. Lehmann. 2008. Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production. Environ. Sci. Technol. 42: 4152–4158.

Gunarso, P., M.E. Hartoyo, F. Agus, and T.J. Killeen. 2013. Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea. Roundtable on Sustainable Palm Oil, Kuala Lumpur, Malaysia.

Handayani, E. 2010. Emisi karbon dioksida (CO^2) dan metan (CH_4) pada perkebunan kelapa sawit di lahan gambut yang memiliki keragaman dalam ketebalan gambut dan umur tanaman (CO_2 and CH_4 emissions from oil palm plantations on peatland with various levels of peat maturity and depths and palm ages). Ph.D dissertation, Bogor Agricultural University, Bogor, Indonesia. (In Indonesian).

Harvey, M. and S. Pilgrim. 2011. The new competition for land: Food, energy, and climate change. Food Policy 36(2011): S40–S51

Hassan, M.N.A., P. Jaramillo, and W. Mi. Griffin. 2011. Life cycle GHG emissions from Malaysian oil palm bioenergy development: The impact on transportation sector's energy security. Energy Policy 39(5): 2615–2625.

Hooijer, A., S.E. Page, J. Jauhiainen, W.A. Lee, X.X. Lu, A. Idris, and G. Anshari. 2012. Subsidence and carbon loss in drained tropical peatlands. Biogeosciences 9: 1053–1071.

Hooijer, A., S. Page, J.G. Canadell, M. Silvius, J. Kwadijk, H. Wösten, and J. Jauhiainen. 2010. Current and future CO_2 emissions from

drained peatlands in Southeast Asia. Biogeosciences 7: 1505–1514.

Hooijer, A., M. Silvius, H. Wösten, and S. Page. 2006. PEAT-CO_2, Assessment of CO_2 emissions from drained peatlands in SE Asia (Report Q3943). Delft, the Netherlands.

Husnain, H., IG P. Wigena, A. Dariah, S. Marwanto, P. Setyanto, and F. Agus. 2013. Emissions from tropical drained peat in Sumatra, Indonesia. Mitigation and Adaptation Strategies for Global Change (In Press).

IPCC (Intergovernmental Panel on Climate Change). 2006. IPCC Guidelines for National Greenhouse Gas Inventories. *In* H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe. (Eds.). IGES, Japan.

IPOB (Indonesian Palm Oil Board). 2007. Indonesian Palm Oil in Numbers. IPOB, Jakarta, Indonesia. 25 pp.

Jauhiainen, J., A. Hooijer, and S.E. Page. 2012. Carbon dioxide emissions from an Acacia plantation on peatland in Sumatra, Indonesia, Biogeosciences 9: 617–630.

Killeen, T.J., G. Schroth, W. Turner, C. A. Harvey, M.K. Steininger, C. Dragisic, and R.A. Mittermeier. 2011. Stabilizing the agricultural frontier: Leveraging REDD with biofuels for sustainable development. Biomass and Bioenergy 35: 4815–4823.

Koh, L.P. and D.S. Wilcove. 2008. Is oil palm agriculture really destroying tropical biodiversity? Conserv. Lett. 1: 60–64.

Kool, D.M., P. Buurman, and D.H. Hoekman. 2006. Oxidation and compaction of a collapsed peat dome in Central Kalimantan. Geoderma 137: 217–225.

Kraxner, F., E. Nordstr?m, P. Havl?k, M. Gusti, A. Mosnier, S. Frank, H. Valin, S. Fritz, S. Fuss, G. Kindermann, I. McCallum, N. Khabarov, H. B?ttcher, L. See, K. Aoki, E Schmid, L. Mäthë, and M. Obersteiner. 2013. Global bioenergy scenarios: Future forest development, land-use implications, and trade-offs. Biomass and Bioenergy. http://dx.doi.org/10.1016/j.biombioe.2013.02.003 (download 24 August 2013).

Lange, M. 2011. The GHG balance of biofuels taking into account land use change. Energy Policy 5(5): 2373–2385.

Maltsoglou I., T. Koizumi, and E. Felix. 2013. The status of bioenergy development in developing countries. Global Food Security 2: 104–109.

Marwanto, S. and F. Agus. 2013. Is CO_2 flux from oil palm plantations on peatlands controlled by soil moisture and/or soil and air temperatures? Mitigation and Adaptation Strategies for Global Change.

Melling, L., K.J. Goh, C. Beauvais, and R. Hatano. 2007. Carbon flow and budget in a young mature oil palm agroecosystem on deep tropical peat. *In* J.O. Rieley, C.J. Banks, and B. Radjagukguk (Eds.) Proceedings of the International Symposium and Workshop on Tropical Peatland, Yogyakarta, Indonesia. http://www.geog.le.ac.uk/carbopeat/media/pdf/yogyapapers/yogyaproceedings.pdf (downloaded 1 March 2012).

Melling, L., R. Hatano, and K.J. Goh. 2005. Soil CO_2 flux from three ecosystems in tropical peatland of Sarawak, Malaysia. Tellus 57B: 1–11.

Mulyani, A., F. Agus, dan D. Allelorung. 2006. Potensi sumber daya lahan untuk pengembangan jarak pagar (*Jatropha curcas* L.) di Indonesia. Jurnal Litbang Pertanian 25(4): 130–138.

Murayama, S. and Z.A. Bakar. 1996. Decomposition of tropical peat soils. Japan Agric. Res. Quart. 30: 153–158.

Murdiyarso, D., K. Hergoualc'h, and L.V. Verchot. 2010. Opportunities for reducing greenhouse gas emissions in tropical peatlands. PNAS 107: 19655–19660.

Myllyviita T., P. Leskinen, K. Lähtinen, K. Pasanen, S. Sironen, T. Kähknen, and L. Sikanen. 2013. Sustainability assessment of wood-based bioenergy - A methodological framework and a case-study. Biomass and Bioenergy. http://dx.doi.org/10.1016/j.biombioe.2013.07.010 (download 23 Marth 2013).

Nurida, N.L, A. Dariah, dan A. Rachman. 2008. Kualitas limbah pertanian sebagai bahan baku pembenah tanah berupa biochar untuk rehabilitasi lahan. Prosiding Nasional dan Dialog Sumberdaya Lahan Pertanian. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Bogor. hlm. 27–37.

Okimori, Y., M. Ogawa, and F. Takahashi. 2003. Potential of CO_2 emission reductions by carbonizing biomass waste from industrial tree plantation in South Sumatra, Indonesia. Mitigation and Adaptation Strategies for Global Change 8: 261–280.

Page, S., E.R. Morrison, C. Malins, A. Hooijer, J.O Rieley, and J. Jauhiainen. 2011. Review of peat surface greenhouse gas emissions from oil palm plantations in Southeast Asia. International Council on Clean Transportation, Washington, DC.

Pedroli, B., B. Elbersen, P. Frederiksen, U. Grandin, R. Heikkilä, P. H. Krogh, Z. Izakovicová, A. Johansen, L. Meiresonne, and J. Spijker. 2013. Is energy cropping in Europe compatible with biodiversity? Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes. Biomass and Bioenergy 55: 73–86.

Persson, U.M. 2012. Conserve or convert? Pan-tropical modeling of REDD–bioenergy competition. Biol. Conserv. 146: 81–88.

Reijnders, L. and M.A.J. Huijbregts. 2008. Palm oil and the emission of carbon-based greenhouse gases. J. Cleaner Prod. 16: 477–482.

Ritung, S., Wahyunto, K. Nugroho, Sukarman, Hikmatullah, Suparto, dan C. Tafakresnanto. 2011. Peta Lahan Gambut Indonesia Skala 1:250.000 (Indonesian Peatland Map at the Scale 1:250,000). Indonesian Center for Agricultural Land Resources Research and Development, Bogor, Indonesia.

Silitonga, A.S., A.E. Atabani, T.M.I. Mahlia, H.H. Masjuki, I.A. Badruddin, and S. Mekhilef. 2011. A review on prospect of *Jatropha curcas* for biodiesel in Indonesia. Renewable and Sustainable Energy 15(8): 3733-3756.

Schmidt, J.H. 2010. Comparative life cycle assessment of rapeseed oil and palm oil. Int. J. Life Cycle Assess. 15(2): 183–197.

Steiner, C., W.G. Teixeira, J. Lehmann, T. Nehls, J.L.V. de Macêdo, W.E.H. Blum, and W. Zech. 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant Soil 291: 275–290.

Souza, S.P., S. Pacca, M. T. de Ávila, and J.L.B. Borges. 2010. Greenhouse gas emissions and energy balance of palm oil biofuel. Renewable Energy 35(11): 2552–2561. http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,163182&_dad=portal&_schema=PORTAL [downloaded 25 Aug. 2013].

Tang, J., W. Zhu, R. Kookana, and A. Katayama. 2013. Characteristics of biochar and its application in remediation of contaminated soil. J. Biosci. Bioengin. (In Press).

US-EPA (United States Environmental Protection Agency). 2012. Notice of Data Availability Concerning Renewable Fuels Produced from Palm Oil under the RFS Program; Extension of Comment Period. Federal Register 77(30) 14 February 2012.

Van Noordwijk, M., S. Dewi, N. Khasanah, A. Ekadinata, S. Rahayu, J.P. Caliman, M. Sharma, and R. Suharto. 2010. Estimating the carbon foot print of biofuel production from oil palm: Methodology and results from two sites in Indonesia. International Conference on Oil Palm and Environment, Bali, Indonesia, 23-25 February 2010.

Wahyunto, S. Ritung, and H. Subagjo. 2003. Map of Peatland Distribution Area and Carbon Content in Sumatera 1990–2002. Wetlands International - Indonesia Programme, Bogor & Wildlife Habitat, Canada.

Wahyunto, B. Heryanto, H. Bekti, and F. Widiastuti. 2006. Maps of peatland distribution, area and carbon content in Papua 2000–

2001. Wetlands International - Indonesia Programme, Bogor & Wildlife Habitat, Canada.

Wahyunto, S. Ritung, Suparto, and H. Subagjo. 2004. Map of Peatland Distribution Area and Carbon Content in Kalimantan 2000–2002. Wetlands International - Indonesia Programme, Bogor & Wildlife Habitat, Canada.

Wicke, B., V. Dornburg, M. Junginger, and A. Faaij. 2008. Different palm oil production systems for energy purposes and their greenhouse gas implications. Biomass and Bioenergy 32: 1322–1337.

Wösten, J.H.M., E. Clymans, S. Page, J. Rieley, and S. Limin. 2008. Peat-water interrelationships in a tropical peatland ecosystem in Southeast Asia. Catena 73: 212–224.

Wösten, J.M.H., A.B. Ismail, and A.L.M. van Wijk. 1997. Peat subsidence and its practical implications: A case study in Malaysia. Geoderma 78: 25–36.