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ABSTRACT

The Roundtable on Sustainable Palm Oil (RSPO) is a non-profit association promoting sustainable palm oil through a voluntary certification scheme. Two successive science-based working groups on greenhouse gas (GHG) have been active in RSPO between 2009-2011, with the aim of identifying ways leading to meaningful and verifiable reduction of GHG emissions. One of the outputs is PalmGHG, a GHG calculator using the LCA approach to quantify the major sources of emission and sequestration for a mill and its supply base. A pilot study was carried out in 2011 on nine RSPO companies. Results gave an average of 1.03 t CO_2e/t crude palm oil, with a wide range of -0.07 to +2.46 t CO_2e/t CPO. Previous land use and area under peat were the main causes of the variation. Further modifications to PalmGHG are being made, notably to amend default values and upgrade it to a user-friendly software.

Keywords: palm oil, biodiesel, GHG, calculator, RSPO, PalmGHG

1. Introduction

Nowadays, palm oil is the most used vegetable oil worldwide, representing more than 30% of total produced vegetable oils by mass (Omont, 2010). About 10 to 15% of global production is certified by RSPO (USDA, 2011; RSPO, 2011). RSPO is a non-profit association registered in 2004. It promotes the production and consumption of sustainable palm oil through a voluntary certification scheme. For the growers, this scheme relies on the compliance with 39 principles and criteria (P&Cs) of sustainability that were defined by consensus in 2007. During 2009-2011, the RSPO Executive Board (EB) has commissioned a science-based working group on greenhouse gas (GHG WG) with the aim of identifying ways leading to meaningful and verifiable reduction of GHG emissions. One of the outputs is PalmGHG, a greenhouse gas calculator that allows producers calculate the GHG balances of oil palm products. PalmGHG was developed by the GHG WG as an excel spreadsheet using the LCA approach and based on a previous tool by Chase & Henson (2010). PalmGHG quantifies the major sources of emission and sequestration for a palm oil mill and its supply base, and is compatible with standard international GHG accounting methodologies. It allows for identification of principal emission sources for management purposes; regular reporting, and monitoring. This paper presents the scientific background of PalmGHG Beta version (of April 2012) calculation as well as results from a pilot study carried out in 2011 on nine RSPO companies.

2. Methods

2.1. PalmGHG approach and boundaries

The PalmGHG calculator provides an estimate of the net GHG emissions produced during the palm oil and palm biodiesel production chains. Following the IPCC guidelines (2006), the GHGs considered are CO_2, N_2O, and CH_4, with 100-year timeframe conversion factors of N_2O and CH_4 into CO_2 equivalents (CO_2e) (IPCC, 2007). The conversion factor for biogenic CH_4 is calculated from the ratio of the molecular weights of CO_2 and CH_4 to account for the released CO_2 originating from photosynthesis fixation; i.e. a global warming potential of 22.25 kg CO_2e/kg CH_4 (Wicke et al., 2008). The calculator is based on an attributional LCA approach, i.e. the impacts are those linked to the production unit without considering marginal impacts on other productions or any feedback mechanisms, and without including indirect land use changes.

The emission sources included in the calculator are: i) Land clearing; ii) Manufacture and transport of fertilisers; iii) N_2O and CO_2 resulting from the field application of fertilisers and mill by-products; iv) Fossil fuel used in the field, mainly for harvesting and collection of Fresh Fruit Bunches (FFB); v) Fossil fuel used at the mill; vi) CH_4 produced from palm oil mill effluent (POME); and vii) N_2O and CO_2 resulting from the cultivation of peat soils. In addition, the following GHG sequestration and credits are also considered: i) CO_2 fixed by oil palm trees, ground cover and plantation litter; ii) CO_2 fixed by biomass in conservation areas (methodology still under development); iii) GHG avoided by the selling of mill energy by-products (electricity sold to the grid; palm kernel shell sold to industrial furnaces; etc.). These ten elements account for the bulk of the GHG emission and sequestration occurring during the oil palm crop cycle (Chase and Henson, 2010). Items that are not included in the budget are the nursery stage, pesticide treatments, fuel used for land clearing, emissions embedded in infrastructures and machines, and the sequestration of carbon in palm products and co-products. These items are generally negligible GHG sources (Schmidt, 2007; European Commission, 2009; Choo et al., 2011). Carbon sequestered in palm products and co-products is short-lived, while the other emissions are small when annualised over the crop cycle. Changes in soil organic matter in mineral soils might be significant in the long term but were not considered due to a lack of consensual and harmonised reliable data.

In the first step, net emissions are calculated as tonnes of CO_2e per hectare. From the yield in FFB and the extraction rates in the mill, results are then calculated per tonne of Crude Palm Oil (CPO) and per tonne of Palm Kernel (PK). Allocation of the net emissions of CO_2e between CPO and PK, then subsequently between Palm Kernel Oil (PKO) and Palm Kernel Expeller (PKE), is carried out according to either the relative masses of these co-products or to their relative energy contents. Mass allocation ratios are setup as default in PalmGHG. Finally, the net emissions of CO_2e are calculated per Mega Joules (MJ) of palm biodiesel including emissions from refinery and further biofuel steps according to the methodology and default coefficients provided by the European Renewable Energy Directive (European Commission, 2009). Biodiesel results are given as GHG emission savings compared to the diesel fossil equivalent.

Provision is made for separate budgets for a mill's own crop (usually produced on estates) and an out-grower crop (such as produced by smallholders). PalmGHG uses the annualised emission and sequestration data to estimate the net GHG balance for the palm products from both own and out-grower crops at an individual mill. Emissions from the biomass cleared at the beginning of the crop cycle are averaged over the cycle. Emissions from the other sources are averaged over the three years up to and including the reporting date, thus simplifying data collection and smoothing out short-term annual fluctuations.

2.2. Land clearing and crop sequestration

The approach used to evaluate the contribution of land clearing to GHG emissions in PalmGHG is to average the emissions over a full crop cycle. The calculator estimates the total emissions occurring each year of new planting, adds them all up, and finally divides by the number of years in the average crop cycle (the default is 25 years or 20 years in the case of biodiesel calculation) to obtain an average emission per ha per year. The crop cycle length is defined by users and can differ between "own crops" and "out-growers". It also differs between crops on mineral soils and those on peat soil, which are often shorter due to accentuated sensitivity to pest and diseases (Wetlands International, 2010).

Previous land uses and their respective carbon stocks were defined in consultation with the scientific panel of RSPO GHG WG who performed a thorough review of literature data and satellite images to identify land use changes associated with oil palm plantations in Indonesia and Malaysia. Considered carbon stocks include above- and below-ground biomass. Carbon stock values for eight previous land uses apart from oil palm stands are currently available in PalmGHG (logged forest, secondary regrowth forest, shrub, grassland, food crops, coconut, rubber, cocoa under shade). Further previous land uses should be implemented soon. However, within the framework of RSPO P&Cs, land use change after 2005 from primary forest to palm plantation will not be allowed. Emissions arising from land clearing are calculated based on measured carbon contents or in their absence an assumed carbon content of 45% in the biomass of the previous land use.

Data for carbon sequestration in the vegetation stand can be obtained from different sources. Field measurements may often be the most relevant data, should they be available and representative of a whole plantation cycle. Where the resources for obtaining these measurements are not available, modelled data may be used instead. Data from OPRODSIM and OPCABSIM models (Henson, 2005, 2009) are used as defaults in PalmGHG to calculate oil palm carbon stock depending on the crop cycle length. These models produce annual values of standing biomass for the oil palms (above and below-ground), ground cover, frond piles and other litter. Field observations revealed that biomass growth and yields are generally lower in the case of out-growers (Chase & Henson, 2010). To reflect this difference, contrasting simulation scenarios of crop sequestration are used as default estimates for mill own crops and out-growers: a 'vigorous growth' simulation is used for own crops, and an 'average growth' simulation is used for out-growers.

2.3 Emissions due to fertiliser use and field operations

Emissions due to fertilisers contribute significantly to total agricultural GHG emissions and so affect the final GHG balance of palm oil (Yusoff et Hansen, 2007; Pleanjai et al., 2009a; Arvidsson et al., 2011; Choo et al., 2011). Therefore, they have been accorded special attention in PalmGHG. Provision is given for nine widely used synthetic fertilisers and two organic ones (Empty Fruit Bunches (EFB) and POME).

For synthetic fertilisers, emissions consist of i) indirect upstream emissions due to their manufacture and transport from production sites to the mill; ii) direct field emissions linked to physical and microbial processes in the soil, and iii) indirect field emissions following re-deposition of previous direct field emissions. Emissions during fertiliser production vary with the type of product from 44 to 2,380 kg CO_2e/t fertiliser (Jensson and Kongshau, 2003). N_2O direct and indirect field emissions, as well as CO_2 emissions from urea application, are calculated according to IPCC Tier 1 (IPCC, 2006).

Emissions due to EFB and POME production are already accounted for intrinsically within the supply chain assessment. The amounts of EFB and POME are calculated using the following factors: 0.5 t POME/t FFB (Yacob et al., 2006), and 0.22 t EFB/t FFB (Gurmit, 1995). Direct and indirect field N_2O emissions are calculated according to IPCC Tier 1 based on their N content of 0.32% for EFB and 0.045% for POME (Gurmit, 1995). The amounts of EFB and POME, as well as their N contents can be substituted using on-site measurements if these are available.

Emissions due to field operations arise from fossil fuel consumed for transport and other field operations, based on the emission factor 3.13 kg CO_2e/L diesel (JEC, 2007). Total field fuel used encompasses the fuel used for the transport of workers (when managed by the mill) and materials, including the transport and spreading of fertilisers, the transport of FFB from the growing areas to the mill, and maintenance of field infrastructure. Data on fuel use is usually not disaggregated at mill level.

2.4 Emissions due to peat cultivation

Emissions from peat cultivation include CO_2 emissions due to the oxidation of organic carbon and associated N_2O emissions. Both involve enhanced microbial activity. RSPO GHG WG intensively reviewed the impacts of peat cultivation on GHG emissions and identified best management practices for oil palm cultivation on peat soils. In their findings, the authors put emphasis on the importance of managing the water table depth to limit CO_2 emissions from peat land. CO_2 emissions due to peat cultivation are hence calculated using the equation (Eq. 1) according to RSPO GHG WG (F. Agus, pers. com. 2012). Peat CO_2 emissions will vary depending on water table management and this is allowed for in PalmGHG.

$$\text{Peat } CO_2 \text{ emission (t } CO_2\text{/ha/year)} = 0.7 \times 0.91 \times \text{Drainage depth (cm)} \qquad \text{Eq. 1}$$

For N_2O emissions from peat soils, data relating emissions to drainage depth are presently inadequate. Therefore, the IPCC Tier 1 emission factor is used as a default, i.e. 16 kg N-N_2O/ha/yr (IPCC, 2006). Research is still ongoing to better determine the magnitude of peat emissions and how they are affected by and related to factors such as drainage depth, peat subsidence and plantation age.

2.5 Emissions due to oil extraction and transesterification

At the mill level, two main sources of GHG emissions are recorded, fossil fuel consumption and CH_4 emission from POME. Fuel emissions are calculated using the conversion factor of 3.13 kg CO_2e/L diesel (JEC, 2007). Diesel use is usually limited and mostly use to start the machines (Pleanjai et al., 2009a).

CH_4 emissions from POME vary according to the type of treatment. The amount of CH_4 produced per unit of POME is 12.36 kg CH_4/t POME (Yacob et al., 2005). This is the amount released by untreated POME, but options are provided for the capture of CH_4 which is then either flared or used as a fuel to generate electricity. Calculations of CH_4 production and amounts and losses during digestion, flaring, or electricity production are based on factors from Schmidt (2007) and the Environment Agency (2002). When CH_4 is flared and converted to CO_2 these emissions are not accounted for because of their biogenic origin, except for a small fraction of CH_4 that escapes conversion. When CH_4 is used to generate electricity then the amount of substituted electricity is calculated based on an energy content of 45.1 MJ/kg CH_4 (JEC, 2007). The corresponding emissions avoided by the use of the electricity are calculated using the average emission factor for Indonesia and Malaysia (RFA, 2008). A further option is given to the user in case excess palm kernel shell is sold as substitute for coal in industrial furnaces (pers. com. L. Milà i Canals, 2011).

The GHG calculation in PalmGHG was completed with excel spreadsheets from the BioGrace calculator in order to enable GHG calculation up to palm biodiesel output (BioGrace, 2010). The user does not need to provide further data apart from field and mill data.

3. Results of PalmGHG pilot

3.1. The pilot process

A pilot study was carried out in 2011 on nine RSPO companies, to determine the ease of use, and suitability of PalmGHG as a management tool. In June 2011, a preliminary questionnaire was sent to correspondents from the pilot companies. This questionnaire was the starting point of correspondences between these companies and the authors, who were responsible for guiding company correspondents with the use of PalmGHG. Mail exchanges, as well as field visit, allowed for the compilation of input data and calculation of GHG balances.

3.2. Pilot results

Results from eight mills are presented in this paper (Table 1). The average GHG balance is 1.03 t CO_2e/t CPO, with a wide range from -0.07 to +2.46t CO_2e/t CPO. Previous land use and the percentage of the area under peat were the main causes of the variation. Main emission hot spots are land clearing, peat cultivation, and CH_4 from POME. Emissions from N-fertiliser production and N-related field emissions also are an important source of GHG. For the mill C1 (Table 1), main contributors for the mill's own crop plantations are peat emissions (43%), CH_4 from POME (28%), land clearing emissions (14%) and N_2O field emissions (8%). For the same mill, main contributors for the out-grower plantations are CH_4 from POME (52%), land clearing emissions (26%), and N_2O field emissions (12%). In this case, the absence of peat area in out-grower's plantation makes a clear difference between two cropping systems supplying the same mill.

Table 1. Pilot mills, their main characteristics and GHG balances assessed with PalmGHG

Mills	Mean yield t FFB/ha	Out-growers included	Peat soil proportions (own-growers only)	Previous land uses	t CO_2e/t CPO
A1	23	no	0%	Shrub	0.05
A2	24	no	0%	Shrub	-0.07
B	26	no	0%	Cocoa, oil palm	0.79
C1	23	yes	25%	Grassland, shrub	0.73
C2	19	yes	80%	Grassland, shrub	2.46
F	19	no	0%	Logged forest, oil palm	1.85
G	26	yes	0%	Range from logged forest to food crops	1.15
H	17	yes	0%	Logged forest	1.35

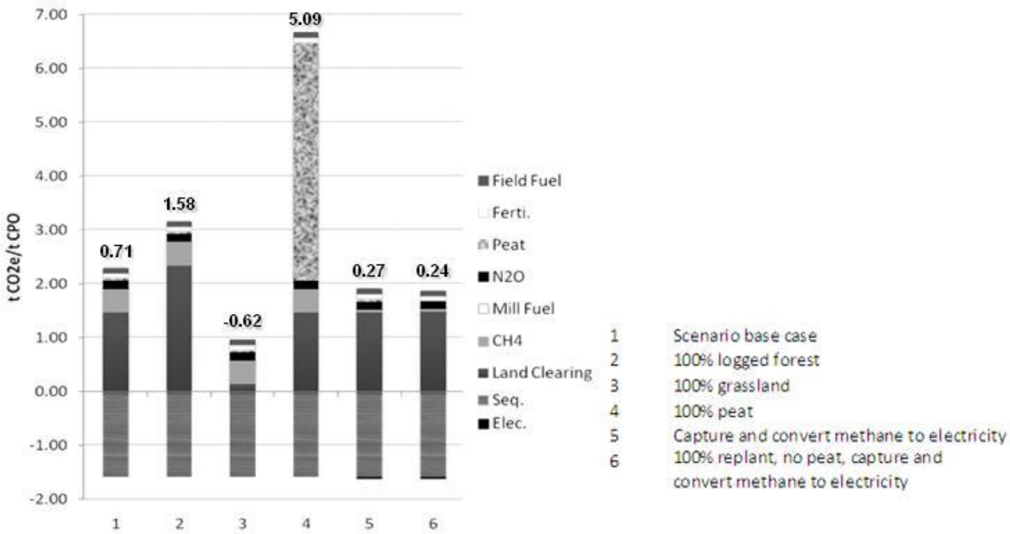

Figure 1. Scenario testing with PalmGHG: Base case (1) = mixed previous land uses, peat 3%, no POME treatment, OER 20%, mill 's own crop mean yield 20.2 t FFB/ha, out-growers' mean yield 14.2 t FFB/ha

PalmGHG readily allows manipulation of input data to test management interventions. Results of scenario testing are given for a set of dummy data for a base case (scenario 1 in Figure 1). The results show that high emissions result from clearing logged forest and peat cultivation, and conversely that very low (negative) emissions result from clearing low biomass land such as grass land. Fertiliser emissions are a non negligible contributor especially in scenario 3, where net sequestration (sequestration less land clearing emissions) is high, or in scenarios 5 and 6, where net sequestration is almost null and CH_4 is captured. The contribution of mill fuel is negligible and not visible on the graph. Net emissions below 0.5 t CO2e/t CPO can be obtained from a mature industry that is replanting palms and capturing and generating electricity from captured CH_4 (Fig. 1). This was highlighted in the recommendations to the RSPO EB.

4. Discussion

GHG balances calculated with PalmGHG are within the range of those found in the literature. However, depending on the system boundaries and particularly on assumptions regarding land clearing and peat emissions, GHG balances greatly vary around 2.3 t CO_2e/t CPO (Schmidt, 2007), 0.6-1 t CO_2e/t CPO (Siangjaeo et al., 2011), or 2.8-19.8 t CO_2e/t CPO (Reijnders et Huijbregts, 2008). Carbon stocks and peat emissions are notably very sensitive parameters. Research efforts are still needed to better quantify carbon stocks and the impacts of agricultural practices on these stocks, especially in the case of peat cultivation. PalmGHG should be updated regularly to introduce newly harmonised carbon stocks for diverse land uses with added impacts on soil organic contents, and to better model the emissions due to peat cultivation or restoration. This is of paramount importance in Southeast Asia where peat land area accounts for 57% of total tropical peat area, i.e. 10-14% of global peat carbon pool, mostly located in Indonesia and Malaysia (Page et al., 2011).

Integrating the spatial and temporal dimensions of the palm perennial crop cycle within a snapshot assessment is not immediate. In PalmGHG, this difficulty is somehow by-passed by embracing data from several plantations units from mill's own crop and out-growers at several ages. Despite large considered areas, ages of oil palms may however not be evenly distributed inducing some bias by displacing age distribution. In particular, plantation with short turn-over may displace the distribution towards young palm trees that sequester carbon more quickly.

Across the published studies, the relative importance of the diverse contributors is in agreement. Land clearing is the most important contributor together with peat emissions (Germer and Sauerborn, 2008; Reijnders and Huijbregts, 2008; Wicke et al., 2008). Some studies that do not directly address this issue still mention the primary importance of this contributor (Yusoff et Hansen, 2007; Pleanjai et al., 2009; Stichnothe et Schuchardt, 2011). In all studies also CH_4 from POME emissions and fertiliser production and use are important contributors (Choo et al., 2011; Pleanjai et al., 2009; Siangjaeo et al., 2011), although their relative total importance depends on whether land use change and peat emissions are included or not. As shown in PalmGHG scenario testing, it is often emphasised that CH_4 capture can allow for significant GHG reductions, between 30 to 50% (Vijaya et al., 2008; Chuchuoy et al., 2009).A wide range of studies focused on treatment and uses of residues and co-products (Yacob et al., 2005; Chavalparit et al., 2006; Vijaya et al., 2008; Stichnothe et Schuchardt, 2011). However, emphasis should be put on the high costs and limited options in the field to actually implement the technologies to harness the best benefits from residues, notably when grid connection is not possible. Such technologies can be implemented through clean development mechanisms provided that attention is paid to avoid double-counting of GHG savings, such as credits for coal substitution by shells both at the palm oil mill and cement factory for instance. Moreover, research effort is also needed notably to better assess fertilising efficiency of land filled residues and environmental emissions of down-stream processes related to residues treatment and transport.

The GHG balance only is one potential impact on the environment. PalmGHG is a very useful tool that can help demonstrate potentials for GHG savings at the plantation and mill levels. Together with the other RSPO P&Cs that define a broader view for sustainability criteria, it can help improve oil palm production towards sustainability. However, more complete LCA must also be considered to quantify other impacts such as eutrophication or toxicities for instance. In this case, other stages of palm oil production might also play an important role such as pesticides for ecosystem toxicity or boiler emissions for human toxicity (Schmidt, 2007; Choo et al., 2011; Bessou et al., 2012). Compared to other vegetable oils, palm oil usually performs better due to high yields (5-17 t CO_2e/t Rapeseed oil *In* Schmidt, 2007; 39-88 g CO_2e/MJ Palm Methyl Ester compared to 62 and 124-159 g CO_2e/MJ of Rapeseed Methyl Ester and *Jatropha* Methyl Ester; respectively *In* Thamsiriroj and Murphy, 2009; Achten et al., 2010a,b), but comparison on a unique criterion may induced trade-offs in environmental impacts. In particular, consideration of impacts on soil fertility and biodiversity is paramount. In this case, a more comprehensive LCA approach is needed, such as in Milà i Canals et al., (2012), to allow for a sound and harmonised comparison between agricultural products considering land transformation and land occupation compared to restored vegetation stands or other common reference land uses.

5. Conclusion

PalmGHG is a comprehensive GHG calculator representative of the state of the art in terms of available data and international methodologies for GHG accounting. Emphasis has been placed on information directly relevant to palm oil production that should be easily available at the mill level. However, default data are also provided for data which might not be available. Flexibility is also an important feature of PalmGHG, with options that allow for alternative calculations and methodology; the main example being assessment of net emissions per MJ for palm oil biodiesel.

During pilot testing it was shown that PalmGHG can identify GHG emission 'hot spots', and so help to define GHG reduction strategies. Feedback from the pilot companies highlighted problems in collecting data, especially those for for three consequent years. It should however, be noted that difficulties related to data recording should progressively diminish once the monitoring of GHG emissions becomes routine. On the other hand, difficulties encountered when collecting data for out-growers are not so easily resolved and indicate a need for a specific strategy to help out-growers record and collect data on a routine basis.

The results of the pilot and scenario testing provided an important information basis to design some of the recommendations to RSPO EB and communicate to a large audience on the work of RSPO GHG WG and the use of PalmGHG. Further recommendations of the GHG WG to RSPO EB refer e.g. to the characteristics that should be met by new plantations in order to ensure low GHG emissions.

Further modifications to PalmGHG are still being made, notably to amend default values. Moreover, PalmGHG needs reprogramming to make it more user-friendly. The current spreadsheet is rather complex and not easy to follow. Software would allow users to quickly generate results, but at the same time provide means to readily change default parameters and undertake tests of alternative scenarios.

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