PalmGHG, RSPO greenhouse gas calculator, scientific background

Cécile Bessou*

* CIRAD, UPR Systèmes de pérennes, pôle ELSA, F-34398 Montpellier, France

ABSTRACT

GHG emissions from palm plantations are a major environmental issue in main producing countries. Through its working groups, RSPO developed a GHG calculator, PalmGHG, which can help the producers to monitor the GHG emissions from their supply areas and mill units and establish reduction plans. In 2013, the use of PalmGHG (or an RSPO endorsed equivalent) has been integrated in the revised Principles & Criteria for the Production of Sustainable Palm Oil (P&C 2013), which created an emulation to tackle this GHG issue. This paper provides an overview of the development of PalmGHG and its various versions as well as explains the main characteristics, calculation assumptions and features.

INTRODUCTION

Agriculture contributes roughly 13.5 percent to global GHG emissions (IPCC, 2007a). In particular, agriculture is the largest source of global anthropogenic emissions of methane (52 percent) and nitrous oxide (84 percent) (Smith et al., 2008). Moreover, part of the GHG emissions associated with the land use change and forestry sector that represent 17.4 percent of global GHG emissions, is related to agricultural activities. Hence growing attention is being paid to GHGs generated by agriculture and to ways by which they can be monitored and mitigated. There are, indeed, significant opportunities for GHG mitigation in agriculture, but numerous barriers need to be overcome (Smith et al., 2008). Tools are needed to quantify agricultural GHG emissions, to identify the major sources, and to design GHG reduction strategies.

Palm oil is now the most used vegetable oil worldwide, accounting for a third of the global oils and fats production. About 15% of global production is certified by RSPO (RSPO, 2015), which promotes the production and consumption of sustainable palm oil through a voluntary certification scheme. Palm oil has received increasing attention due to it being the main vegetable oil source, and also because of the deforestation that has been linked to oil palm plantation expansion. RSPO recognises the importance of addressing GHG emissions from palm oil production and requires that members monitor their sources of GHG emissions and implement measures to reduce them. In addition, RSPO organised two working groups on GHG emissions between 2009 and 2011, with the mandate to recommend ways of reducing GHG emissions across the whole palm oil supply chain and to provide producers with a tool to help them monitor GHG emissions and implement reduction plans. Existing GHG calculators that have been developed are both crop-generic (e.g. the Cool Farm Tool from Hillier et al., 2011) and crop-specific (e.g. the Bonsucro certification scheme for sugar cane). However, given the particular modelling needs of oil palm (i.e. a perennial crop with significant carbon fixation during its growth that undergoes continuous replanting), a crop-specific calculator was designed by the second working group. This calculator, named PalmGHG, is a development of a previous palm oil GHG balance calculator (GWAPP; Chase and Henson, 2010) and includes state-of-the-art information on palm oil GHG emissions as affected by present agricultural and industrial processes. PalmGHG was first developed as an Excel© spreadsheet using the life-cycle assessment approach and quantifying the major sources of emissions associated with the oil palm crop and palm oil mill, as well as carbon sequestration by the oil palm crop. PalmGHG was upgraded into a programmed user-friendly tool and the first updated version was released in 2014. The PalmGHG scientific background and features are regularly revised and updated by the RSPO Emission Reduction Working Group that has replaced the former GHG working group. This paper presents the scientific background to the current PalmGHG version 2 (of December 2015) with some insights on ongoing improvements and updates to be accounted for in the PalmGHG version 3 to come.

MATERIALS AND METHODS

A review of regulatory frameworks and GHG accounting standards was carried out by the second RSPO GHG working group (Bessou et al., 2010). It showed that all frameworks rely on the application of LCA standards (ISO 14040 and 14044, ISO, 2006), while taking advantage of some flexibility in their implementation. There is notably some variability in defining the system boundary (e.g. inclusion or otherwise of embodied emissions in capital goods; use of animal traction, allocation issues, accounting for indirect land use change, etc.). When focusing on GHG assessment, one of the LCA impact categories, all methodologies and tools are based on the IPCC guidelines (IPCC, 2006). However, these guidelines provide only a general framework with some degree of flexibility according to the level of detail needed for the assessment; hence differences in scope, emission factors and reporting units may hamper the comparison of results provided by different tools (Colomb et al., 2013). To harmonise GHG assessments, three main standards have been recently released: PAS2050 (2011), the GHG Protocol Product Standard (2011), and ISO 14067 (2012). As a result of a cross collaboration, the key methodological rules underpinning quantification in these standards are consistent. In particular, key topics such as i) sector or product rules, ii) inclusion of biogenic carbon, and ii) land use change, have been brought into alignment.

PalmGHG is based on a LCA approach, and is mostly in line with international GHG accounting standards, especially PAS2050-1 2012, a declination of PAS2050 for cradle-to-gate assessment of horticultural products and the only standard that specifically addresses issues related to horticulture and perennial crops. In exercising the degree of flexibility available for implementing those standards, attention was paid to clearly define the goal and scope of the tool with the diverse stakeholders and to ensure transparency of all assumptions behind the calculation choices. As a GHG calculator, PalmGHG does not encompass the comprehensive calculations of a full LCA such as calculations of eutrophication, ozone depletion or toxicity impacts. The results of PalmGHG should not be considered as an indicator of global environmental impacts, but only of global warming potential. Nevertheless, each step of the LCA methodology, where relevant to PalmGHG construction and GHG calculations, is carried out according to state of the art methodological development and knowledge of the palm oil supply chain. These steps cover the definitions of goal and scope, life cycle inventory, impact characterisation and interpretation of results.

Goal and scope

PalmGHG provides an estimate of the net GHG emissions produced during the palm oil supply chain up to the production of Crude Palm Oil (CPO) or Palm Kernel Oil (PKO) depending on the mill being assessed (i.e. whether it includes a palm kernel crushing plant or not). The main purposes of the tool are:

- Identification of critical points in the life cycle of palm oil products, with the aim of guiding GHG reduction opportunities;

- Internal monitoring of GHG emissions;

- Reporting to RSPO of the progress of GHG reduction plans.

To allow for a stepwise identification of main GHG sources and impacting practices along the supply chain, GHG emissions are expressed using several reference units. Hence, results are given as tonnes of CO_2 equivalents (tCO_{2eq}) either per hectare or per unit of intermediate or final product: i.e. per tonne of Fresh Fruit Bunches (FFB), per tonne CPO and per tonne PKO.

The system boundary is from cradle-to-gate (Figure 1), i.e. it includes the production of palm fruit and transformation into palm oil products up to the mill gate accounting for main background processes but does not include the distribution up to the consumer or the industrial or consumption stages of palm oil products. With the aim of identifying main sources and optimising reduction strategies, PalmGHG does not seek for an exhaustive accounting of all GHG emissions. A compromise was reached with the stakeholders to account for all relevant main sources recognised in the literature while minimising the data collection effort by excluding minor sources. GHG emission sources included are direct land use change and peat cultivation, manufacture, transport, spreading and field emissions related to fertilisers, fossil fuel use in the field and at the mill, and methane produced from Palm Oil Mill Effluent (POME). These emission sources account for about 99% of the total GHG balance (Chase and Henson, 2010), which exceeds the 95% cut-off in PAS2050. Excluded GHG emission sources are nursery palms, fuel used for land clearing, emissions embodied in capital goods, manufacture and transport of chemicals (other than fertilisers) to the storehouse, the sequestration of carbon in palm products and co-products, and emissions embodied in chemical use at the mill. Most of these items are generally negligible GHG sources or sinks (Schmidt, 2007; Choo et al., 2011). Moreover, short-lived biogenic carbon in food and feed should not be accounted for according to PAS2050. Carbon dioxide fixed in the oil palm trees, ground cover and plantation litter is considered as long-lived biogenic carbon and included as a carbon sink in the assessment. Finally, the system boundary does not include indirect land use change, also excluded in PAS2050 and not required in the GHG Protocol Product Standard.

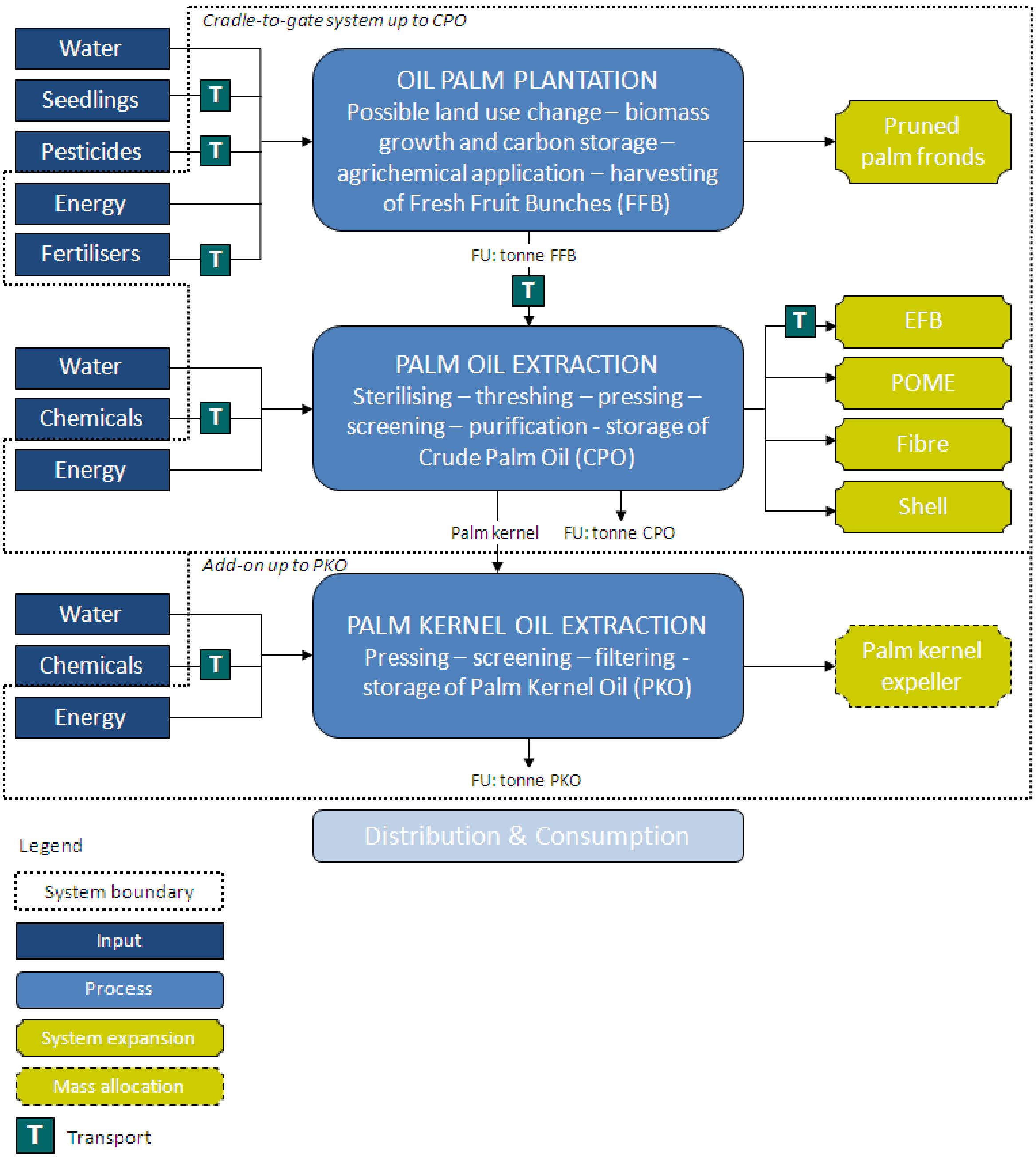


Figure 1: Cradle-to-gate system boundary of CPO and PKO GHG assessments (based on PAS2050 guidelines)

The palm oil supply chain ending at the mill gate provides one intermediary product (FFB) and two potential final products (CPO and PKO). Not all the mills process palm kernel. For palm oil and palm kernel, and for palm kernel oil and palm kernel expeller, emissions are partitioned according to their respective masses. Besides these major products, the process chain delivers numerous co-products. Here, for simplicity, we use "co-product" as a generic term for all other products, residues or wastes generated during palm oil production, which allows for their changing status over time. Thus, some co-products that were previously considered as waste materials are now finding new uses in line with the “Zero Waste” concept. The main co-products are pruned palm fronds, empty fruit bunches (EFB), palm oil mill effluent (POME), fibre, shell, and palm kernel expeller (PKE) or cake. Fronds, EFB and treated POME are commonly recycled as fertilisers. Methane, emitted during POME treatment, may be captured and converted to CO_2 (with a much lower global warming potential) or used to produce electricity. Options for three different POME treatments are provided in PalmGHG. Shell and fibre are usually burnt in the boiler to produce heat and power. When excess electricity production can be exported to the grid, emission credits are calculated according to the emissions avoided by producing an equivalent amount of electricity in the national grid (Malaysia/Indonesia). Another example is the sale of palm kernel shell for use by other manufactures as a coal substitute. Emissions related to the treatment and transport of internally used co-products are included within the system boundary.

Life Cycle Inventory

GHG emissions are calculated at the level of the RSPO certification unit, i.e. one mill and its supply base. A single mill can be supplied with fruits from diverse plantations including those owned by the company running the mill (“own crops”) and others independent of it (“out-growers” crops). Life cycle inventories are assembled separately for each plantation or entity (such as, e.g. smallholders cooperatives) supplying the mill. PalmGHG uses yearly emission and sequestration data to estimate the net GHG balance of the palm products from both own and out-grower crops at an individual mill. Land use history is recorded for each plantation with a breakdown into percentages of mineral and peat soils. Emissions from the biomass cleared at the beginning of the crop cycle are averaged over the crop cycle (25 years is set as a default parameter). PalmGHG estimates can be updated yearly to reflect changes in operating conditions at both plantation and mill levels.

Data sources

Primary data are provided by the producer (or PalmGHG user) while secondary data are taken from the literature. Primary data consist of inputs to the plantation and mill. The minimum primary data set needed to run PalmGHG includes on a yearly basis:

i) at the agricultural stage (needed for all supplying plantations): areas planted each year with a breakdown of previous land uses recorded separately for mineral and organic (peat) soils; total fruit production; fertiliser types, amounts applied, and transport distances; and fuel used in the field;

ii) at the mill stage: total CPO and kernel produced; fuel and electricity from the grid; POME treatment; amounts of exported co-products; kernel crusher added fuel and electricity used (if relevant).

Secondary data consist of emission factors and calculation parameters taken from the literature (scientific papers, technical reports, and methodological guidelines). Emission factors represent GHG emissions embodied in background processes (e.g. manufacturing of fertilisers, production of imported electricity), and GHG emissions or sequestration occurring at field and mill stages in proportion to inputs fed into the processes (fuel combustion, field emissions related to fertiliser use, carbon sequestration in biomass, emissions due to POME treatment). Calculation parameters encompass the rest of the numerous parameters needed to link process inputs with outputs where the links are not directly addressed by primary data or emission factors (e.g. ratio of POME/FFB, N-contents of diverse mineral and organic fertilisers, water table level etc.). The aim is to provide users with as many default values as possible to ease data collection. However, PalmGHG remains flexible and allows for changes in default values and keyed in own measurements once primary data become available. But, these changes must be sound and made transparent when reporting results.

Land clearing and crop sequestration

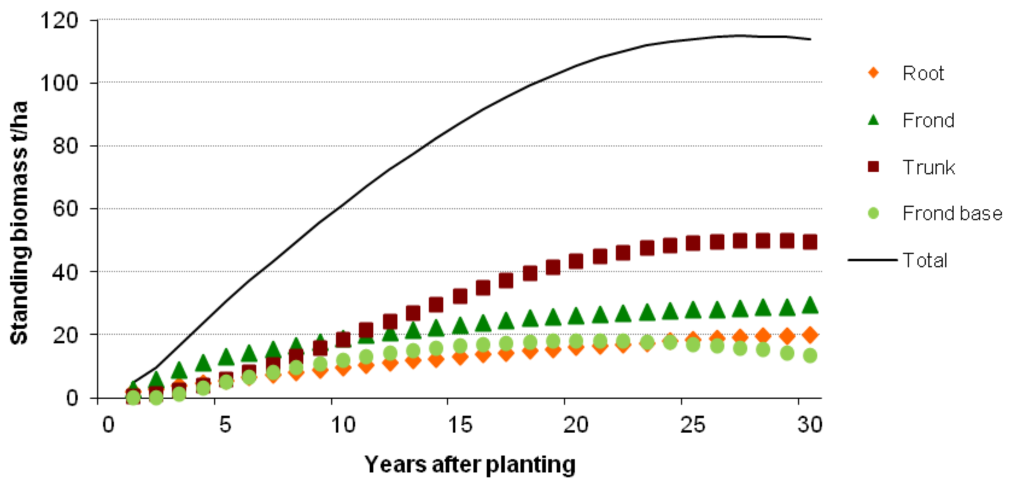
The approach used to evaluate the contribution of land use and land use change (LULUC) to net GHG emissions is based on the Stock-Difference Method of IPCC (2006) Tier 1. The time interval to assess the stock-difference corresponds to the average crop cycle length (i.e. 25 years). The calculator estimates the total emissions occurring each year due to land clearing for new plantings, adds them up, and finally divides by the number of years in the average crop cycle to obtain an average emission per ha per year. It must be noted that allocation of land clearing emissions is still a debated issue as to whether it should be based on a fixed amortisation period such as the 20 years recommended by IPCC (2006) and PAS2050 or on a discount rate (Fearnside, 2002; Brandão et al., 2012), and whether allowance should be made for a cut-off year such as 2008 as proposed in the European Directive on Renewables (European Union Commission, 2009). In PalmGHG, both calculations with or without considering the 2005 RSPO cut-off year are made available.

Default values of previous land uses currently available in PalmGHG consist in 6 land use types with carbon stock based on a literature review and harmonised calculations to consolidate above and below ground biomass stocks. The land cover values in PalmGHG are provided as guidance in the absence of site-specific measurements, which are generally not available. Further options can easily be incorporated and the choice of previous land uses will be expanded and updated regularly. Further guidance will be also required for the audit of PalmGHG input data, on how to link evidence for previous land uses (such as aerial photographs or maps) to specific land use classes and carbon stocks, especially in the case of user-defined land use options made available in the future based on on-site field measurements. Clearing of primary (i.e. undisturbed) forest is not accepted within the framework of RSPO Principles and Criteria after 2005; however, this option for previous land use has been included in case growers want to assess the effects of areas cleared prior to RSPO certification, which would provide a more accurate assessment of total embedded emissions.

Emissions arising from land clearing are calculated based on a 45% C content of the biomass dry weight (above-and below-ground) of previous vegetation. The emitted carbon is then converted to CO_2 by multiplying by 44/12. In PalmGHG changes in organic carbon in mineral soils due to land use changes are not accounted for due to a lack of consensual and reliable data on soil organic carbon stocks prior to and after oil palm establishment (Agus et al., 2013).

Data for carbon sequestration in the crop can be obtained from different sources. The preferred option is to base them on direct measurements, but where the resources for undertaking this are not available, modelled data may be used instead. The data needed include planting density and frond and trunk dry weights for palms of different ages. These can be obtained following the methods described by Corley et al. (1971) and Corley and Tinker (2003). Guidance from an experienced agronomist is usually required to analyse these data further before they are used to generate sequestration values.

Several models are available in the absence of measured data to estimate sequestration. Examples are the OPRODSIM and OPCABSIM models (Henson, 2005; Henson, 2009) which are specifically designed to estimate oil palm and other plantation biomass (e.g. litter and ground cover) throughout the life of the crop, largely based on Malaysian conditions. OPRODSIM and OPCABSIM produce annual values of standing biomass for the oil palms (above and below-ground), ground cover, frond piles and other plantation litter (shed frond bases and male inflorescences). The total amount of carbon sequestered in the reporting year is calculated by multiplying the area of each year of planting by the amount of carbon sequestered, adding these together, and dividing by the total area to give tC/ha/yr. Field observations revealed that biomass growth and yields are generally lower in the case of out-growers (Chase and Henson, 2010; Khasanah et al., 2012). To reflect this difference, contrasting simulation scenarios of crop sequestration can be used as default estimates within PalmGHG for mill own crops and out-growers. A "vigorous growth" simulation model is considered for own crops, and an "average growth" simulation is used for out-growers (Figures 2a,b).



a)

b)

Figure 2: Standing biomass in oil palm stands as simulated with OPRODSIM (Henson, 2005, 2009); a) Total standing biomass with a vigorous growth with the details of most important biomass components, b) Comparison of total standing biomass with a vigorous growth or an average growth.

Field emissions

Emissions due to fertilisers contribute significantly to the final GHG balance of palm oil (Yusoff and Hansen, 2007; Pleanjai et al., 2009; Arvidsson et al., 2011; Choo et al., 2011). For synthetic fertilisers, emissions consist of i) indirect upstream emissions during their manufacture and transport from production sites to the field; ii) direct field emissions linked to physical and microbial processes in the soil, and iii) indirect field emissions following re-deposition or re-mobilisation of previous direct N-losses after fertiliser application. Emissions during fertiliser production vary with the type and location of the product from 44 to 2,380 kgCO_{2eq}/t fertiliser (Jensson and Kongshaug, 2003). Provision is made in PalmGHG for use of nine widely available synthetic fertilisers and two organic ones (EFF and POME) but additional fertiliser types can be included by the user if required. Calculation parameters will be provided in PalmGHG version 3 for NPK compound fertilisers. Direct and indirect N_2O field emissions are calculated according to IPCC Tier 1 (IPCC, 2006). Nitrogen fertiliser emissions are converted to N_2O by multiplying by 44/28. Following the same guidelines (IPCC, 2006), CO_2 emissions from urea, which is subject to substantial volatilisation losses, are also accounted for. The emitted carbon is converted to CO_2 by multiplying by 44/12.

Emissions due to EFB and POME production are already accounted for intrinsically within the supply chain assessment. The amounts of EFB and POME, unless measured directly, are calculated from total FFB assuming 0.5 tPOME/tFFB (Yacob et al., 2005) and 0.22 tEFB/t FFB (Gurmit, 1995). Direct and indirect field emissions of N_2O are calculated according to IPCC Tier 1 based on N content, assumed to be 0.32% for EFB and 0.045% for POME (Gurmit, 1995). The default amounts of EFB and POME, as well as their N contents can be substituted with on-site measurements if these are available. Methane emissions due to POME are accounted for at the mill stage (cf. Mill emissions).

Other emissions due to field operations arise from fossil fuel consumed by machinery used for transport and other field operations, and are calculated based on an emission factor of 3.13 kg CO_{2eq}/L diesel (JEC, 2011). Total field fuel used includes fuel used for the transport of workers and materials, including the transport and spreading of fertilisers, the transport of FFB from the growing areas to the mill, and the maintenance of field infrastructure. Data on field fuel used in different operations is usually not disaggregated and only the overall fuel purchased is normally recorded. A pragmatic approach was hence adopted for calculating emissions by including fuel used by the whole plantation over a specific period of time.

Peat cultivation

Cultivation of oil palm on peat results in the continuous emission of CO_2 due to the oxidation of organic carbon in the peat that results from peat drainage and lowering of the water table. There are also smaller, but variable peat-related N_2O emissions. Release of both GHGs involves enhanced microbial activity. Research is still ongoing to determine more precisely the magnitude of these emissions, and how they are affected by such factors as drainage depth, peat subsidence and plantation age. The RSPO GHG WG2 intensively reviewed the effects of peat cultivation on GHG emissions and identified management options designed to reduce rates of subsidence and loss of carbon (RSPO, 2012). In its findings, the Working

Group placed emphasis on the importance of managing the water table depth to limit CO_2 emissions. CO_2 emissions due to peat cultivation are currently calculated using Eq. 1. This linear correlation is based on a meta-analysis on various published field measurements (Figure 3, Hooijer et al., 2010). Peat CO_2 emissions will thus vary with water table management, which gives incentive for the grower to improve practices and lower GHG emissions. In PalmGHG, a default drainage depth when water table is actively managed is set to 60 cm, considered, as good management practice (RSPO, 2012) to be the maximum water level to be maintained below the peat surface. From Eq. 1 this leads to an annual emission of 54.6 tCO_2/ha. The default water table depth is set to 80 cm (or 100 cm according to various PalmGHG versions 2) in cases where the water table is not actively managed. RSPO Emission Reduction Working Group is currently working on providing growers with guidance to measure peat drainability and water table levels.

Peat CO_2 emission (tCO_2/ha.year) = 0.91 x Drainage depth (cm) Eq. 1

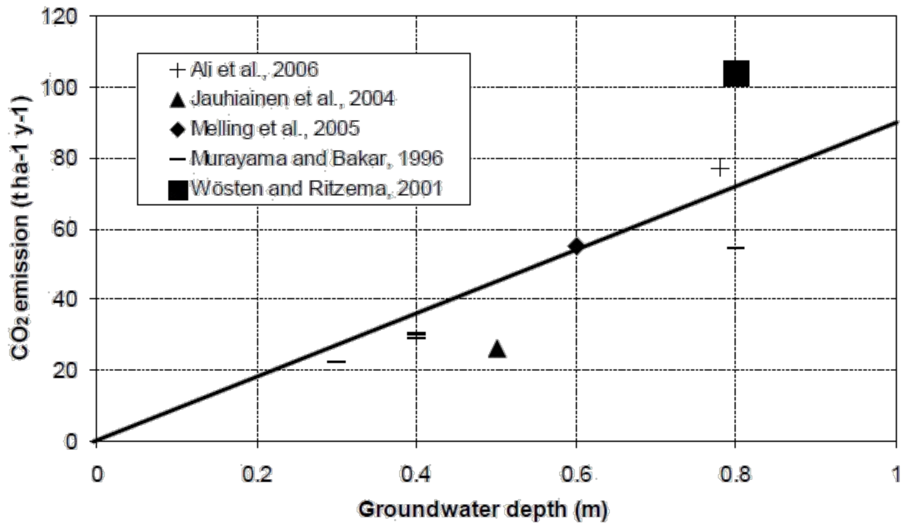


Figure 3: Correlation between emission rate and water table depth based on a field measurements meta-analysis (Hooijer et al. 2010)

For N_2O emissions, data relating emissions to drainage depth are presently inadequate. Therefore, the IPCC Tier 1 emission factor of 16 kgN-N_2O/ha.yr is used as a default (IPCC, 2006). Further research is needed to better define how agricultural management and in particular water table management and nitrogen use, affect the amount of CO_2 and N_2O emissions linked to peat cultivation. As more data become available, PalmGHG will need updating. In the meantime users have the option of using actual data measured in the field if these are available.

Mill emissions

At the mill level, two main sources of GHG emissions are present, fossil fuel consumption and methane emission from POME. Fuel emissions are calculated as in the field using the conversion factor of 3.13 $kgCO_{2e}q$/L diesel (JEC, 2011). Diesel use is usually limited and is mostly needed to start the mill machinery following shut-downs (Pleanjai et al., 2009).

Methane emissions from POME vary according to the treatment applied. The amount of methane (CH_4) produced per unit of POME when conventionally digested in open ponds is taken to be 12.36 kgCH_4/tPOME (Yacob, et al. 2006). However, options are provided for the capture of methane which is then either flared or used as a fuel to generate electricity. Calculations of CH_4 production and losses during digestion, flaring, and electricity production are based on factors derived by Schmidt (2007) and the UK Environment Agency (2002). As CH_4 emissions may vary widely across mills, PalmGHG version 3 will include a new option to calculate CH_4 production according to on-site measurements of COD[1] reduction (Figure 4) and a calculation formula from UNFCCC[2].

Emissions involving CH_4 are calculated in terms of CO_{2eq} using a global warming potential of 22.25 kgCO_{2eq}/kgCH_4 instead of 25 kgCO_{2eq}/kgCH_4 (IPCC, 2007b) to allow for reduced emissions of biogenic CO_2 originally fixed by photosynthesis (Wicke et al., 2008; Muñoz et al., 2013). When CH_4 is flared and converted to CO_2 these emissions are not accounted for because of their biogenic origin. However, provision needs to be made for the small fraction of methane 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/kgCH_4 (Lower Heating Value assumed to be equivalent to that of EU natural gas mix (JEC, 2011). The corresponding emissions avoided (i.e. credit) by the exported excess electricity produced are calculated using the average of the emission factors for grid electricity reported for Indonesia and Malaysia (RFA, 2008).

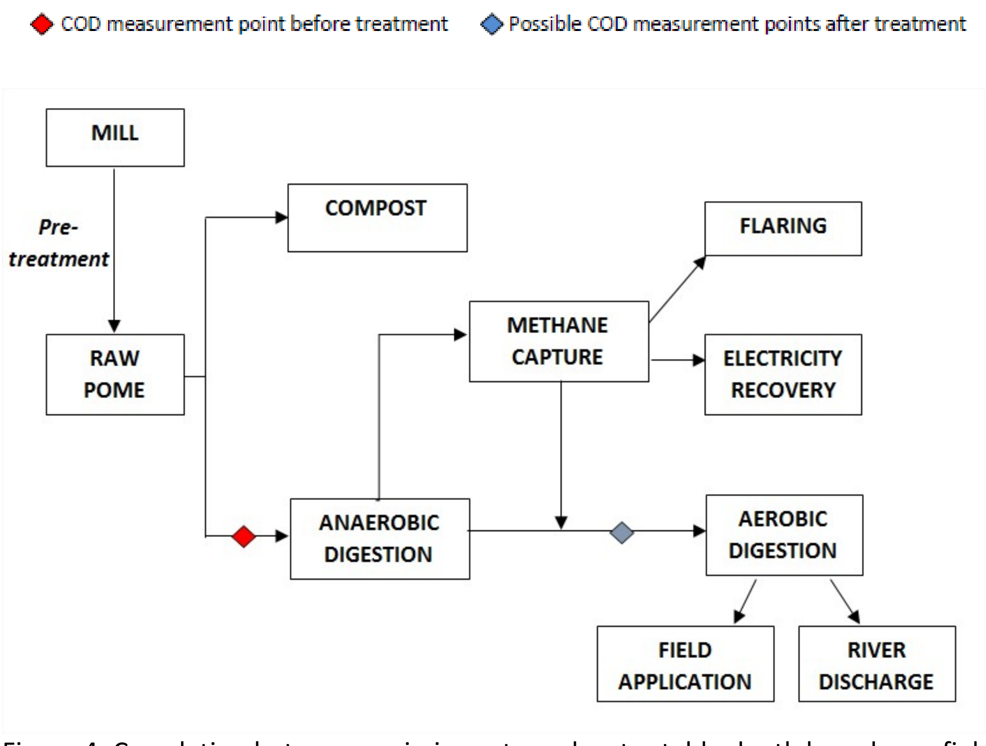


Figure 4: Correlation between emission rate and water table depth based on a field measurements meta-analysis (Hooijer et al. 2010)

A further credit is provided in case excess palm kernel shell is sold for use as a substitute for coal in industrial furnaces. If the palm oil mill is isolated from the electricity grid, it may not

[1] The chemical oxygen demand (COD) is an indicator of the particulate organic matter content of effluents; effluent treatments aim at reducing COD below legal thresholds.

[2] UNFCCC-CDM. AMS-III.H: Methane recovery in wastewater treatment. Version 18.0

be possible to sell surplus electricity, and a valid alternative to make the most of the mill co-products is to sell any solid waste to users of solid fuel. Palm kernel shells (PKS) are currently in high demand in Malaysia as they are used to substitute fossil fuels in cement works, plastic and chemical factories, and in brick and timber kilns. The most likely fuel to be replaced by PKS in those factories is coal, and thus the emissions displaced by not burning coal may be considered as a credit for the palm oil system . Assuming a gross calorific value of 28.2 MJ/kg for coal and 20.5 MJ/kg for PKS , each tonne of PKS sold by the mill would displace about 726 kg coal in an industrial kiln. The exact amount displaced depends on the quality of the coal, and ranges between 600 and 750 kg coal per tonne PKS. The GHG emissions related to the combustion of coal are about 105 gCO_{2eq}/MJ, or ca. 3 $kgCO_{2eq}$/kg coal. Thus, the approximate emission saving from PKS sold to industrial furnaces becomes -2,203 $kgCO_{2eq}$/t, and ranges from -1,820 to -2,276 $kgCO_{2eq}$/t. As the exact final use of exported shell is not guaranteed, another more conservative assumption will be implemented in PalmGHG version 3, i.e. a mass allocation ratio in order for the excess sold shell to leave the studied system with an embedded emission burden.

Impact assessment

Following IPCC guidelines (2006), the GHGs considered are CO_2, N_2O, and CH_4. Conversion factors (i.e. global warming potentials) of N_2O and CH_4 into CO_{2eq} are as given by IPCC (2007b), and correspond to a 100 year timeframe. The conversion factor for N_2O is 298 CO_{2eq}. For carbon-based GHG, in summary, a factor of 0 is used for CO_2 fixed in (or emitted from) short-lived biomass (such as the palm fruit or the emissions derived from it when palm oil is consumed); a factor of -1 is used for CO_2 fixed in biomass for a longer period (e.g. in palm trunks); and a factor of 22.25 CO_{2eq} is used for CH_4 emissions arising from biogenic carbon not previously accounted for as fixation (e.g. emissions from POME arising from carbon in the palm fruit).

RESULTS

GHG hotspots and contribution analysis

The GHG balance of a virtual mill was calculated with PalmGHG given a set of dummy but still representative data. This mill represents a base case with widespread characteristics for common mills in Indonesia and Malaysia, the main world producing countries. This base case was established by experts who have decades of experience in oil palm agronomy and data collection at field and mill levels. In this base case, the mill is supplied by both own crops (~9,800 ha) and outgrowers (~9,500 ha). Palm trees were planted on mixed previous land use (incl. oil palm, rubber, grassland and logged forest), and 3% of own crops were established on peat soil without any active water table management. Average yields are 20 tFFB/ha for own crops and 14 tFFB/ha for outgrowers. The average fruit throughput in the mill is 330,000 tFFB/yr with an average oil extraction rate of 21%. The calculated GHG balance for this virtual mill was 1.08 tCO_{2eq}/tCPO. Half of the total net emissions occurred at the field stage, and half at the mill stage. At the field stage net emissions from own crops (37.4% of the net GHG balance) were higher than from outgrowers' (12.6% of the net GHG balance). Higher emissions in own crops' estates were mostly due to peat emissions and to a lesser extent to higher fertiliser use.

Contributions of each source are detailed in Figure 5. Main emission sources were land clearing, methane from POME conventional digestion, peat cultivation and fertiliser-related emissions. In this base case, emissions due to the clearing of mixed previous land use were compensated by carbon sequestration in the plantations. If previous land uses would consist of only primary or logged forests, the net GHG would be significantly higher as showed in a scenario testing of PalmGHG on pilot data sets (Bessou et al., 2014). On the contrary, in the same pilot study, it was shown that grassland as single previous land use could lead to negative net GHG balance. At the mill stage, only one source of GHG emissions was significant, which was CH_4 from conventional POME digestion accounting for almost half of the net GHG balance. The importance of CH_4 emissions from POME treatment has been emphasised by several authors (Schmidt, 2007; Choo et al. 2011). Technical options exist that enable to capture the biogas emitted during POME treatment in order either to flare CH_4 and spare some additional GHG emissions, or to convert it to electricity when connection to the grid is feasible (Chavalparit et al. 2006; Chuchuoy et al. 2009; Choo et al. 2011). These options are provided in PalmGHG.

Whereas peat soils only represent 3% of the total supplying area, emissions related to peat cultivation accounted for roughly one fourth of the net GHG balance. This highlights that peat cultivation represents a serious challenge in terms of GHG mitigation. Some best management practices were stressed by the RSPO working group on peatland (RSPO, 2012). The authors showed that an active management of the water table to limit the drainage depth can reduce the peat subsidence rate and GHG emissions. In PalmGHG, default drainage depths are provided in both cases of active or no water table management. The user also has the possibility to enter the exact drainage depth when this one is measured. Finally, fertiliser-related emissions accounted also for almost one third of the net GHG balance. N_2O emissions due to fertiliser application in the field were twice as much as GHG emissions related to fertiliser manufacture and transport.

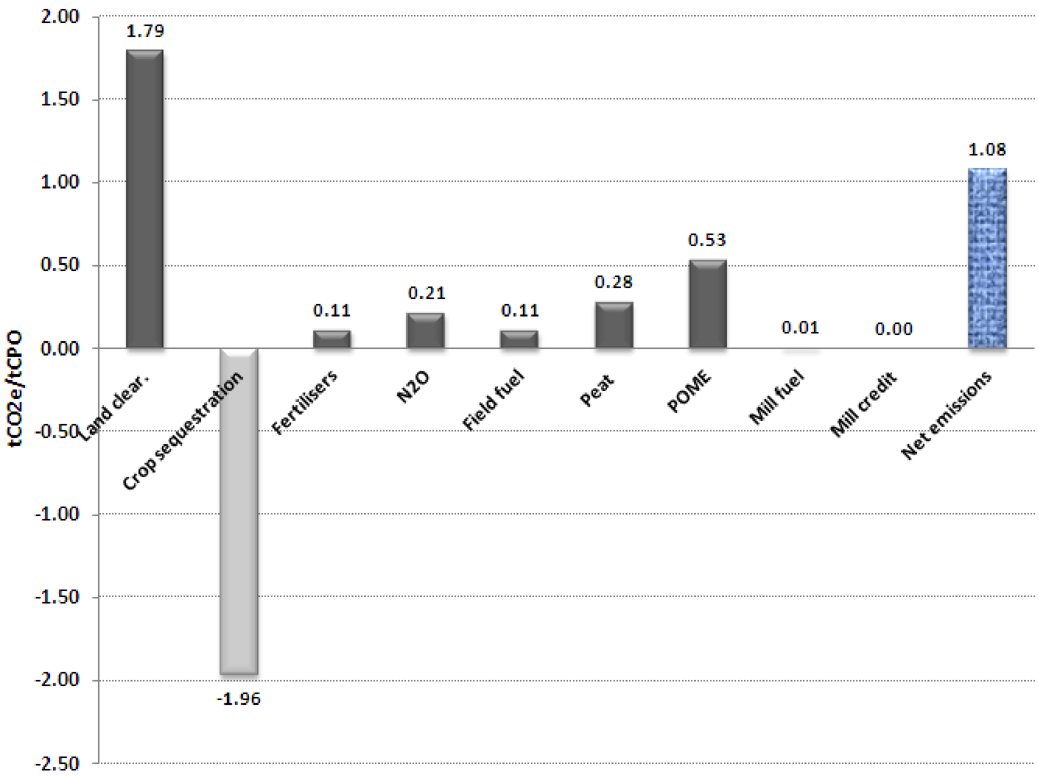


Figure 5: Contributions to GHG balance of a virtual mill assessed with PalmGHG. Base case for the virtual mill: mixed previous land uses, peat 3% of total area (no active water table management), conventional digestion of POME, OER 21%, own crops mean yield 20 t FFB/ha, outgrowers' mean yield 14 t FFB/ha.

Sensitivity analysis

A sensitivity analysis was conducted on the main parameters. The sensitivity of the calculator (PalmGHG version 1) was tested by looking at the variation of the final GHG balance of the virtual mill analysed above with a stepwise variation of individual parameter between ±80% of their default values. 22 parameters were tested with the same base case scenario as previously used (Figure 6). 5 other parameters were also tested in the case of flaring or converting to electricity CH_4 emissions from POME.

Parameters constituting the main contributing processes were logically among the most sensitive ones. Among the first 22 tested parameters (Figure 6), only 5 were remarkably influencing the final GHG balance. A single variation of the remaining 17 parameters between ±80% of their default values only led to a variation of ±2% of the final GHG balance. The main sensitive parameters are the couple tPOME/tFFB and $kgCH_4$/tPOME, closely correlated. A single variation of one of these 2 parameters led to a variation of up to ±40% of the final GHG balance. The extreme variation of both parameters individually affected POME emissions directly, resulting in up to a five-fold decrease (-80%) and to a roughly two-fold increase (+80%) of POME contribution to the total emissions. The parameter tPOME/tFFB also contributed to a smaller extent to an increase/decrease in field emissions (±2% of field N_2O emissions). A parallel variation of both parameters together would lead to a further 15% change in final GHG balance.

Default drainage depth (without active management of water table) and the CO_2 peat emission factor (tCO_2/ha.yr) were also among the most sensitive parameters. These parameters are equally affected by the multiplying factor (Eq. 1). A single variation of each of them led to a maximum decrease/increase of ±21% of the final GHG balance. In both cases, only peat emissions were affected, and increased/decreased proportionally (±80%).

The carbon stock in previous land uses was a very sensitive parameter given the major contribution of land clearing to total emissions. The relative sensitivity of the diverse land uses depended on both their proportions in the base case scenario and the relative importance of the baseline default values. Hence, for the tested virtual mill, the main sensitive previous stocks were rubber (~3,800ha, 62tC/ha), then logged forest (~1,400ha, 87tC/ha); leading to maximum variations of ±28% and ±15% of the final GHG balance; respectively. Grassland represented roughly the same surface area as rubber (~1,600ha) but was not a sensitive parameter due to very low carbon stocks (5tC/ha) notably compared to rubber.

The phenomenon was the same for the relative sensitivity of PalmGHG to the diverse fertiliser types. Emissions embodied in Urea production are lower than those in Ammonium Nitrate (AN), but, in the base case, the total amount of Urea used is much higher than that of AN especially in the outgrowers' plantations. The influence of fertilisers is, however, not limited to their embodied emissions in production and transport. The complete picture also includes their N-content and the field emissions. Numerous parameters are involved in determining field emissions. In particular, the direct N_2O emission factor appeared to greatly influence the final results with maximum variations of ±10% of the final GHG balance, due to variations of ±52% of the field emissions. Further parameters related to field emissions were less sensitive. A five-fold multiplication of "N lost through runoff and leaching", "N_2O indirect emission factors through runoff and leaching or volatilisation", as well as or "N_2O emissions from peat" led to an increase of merely 10% of the final GHG balance.

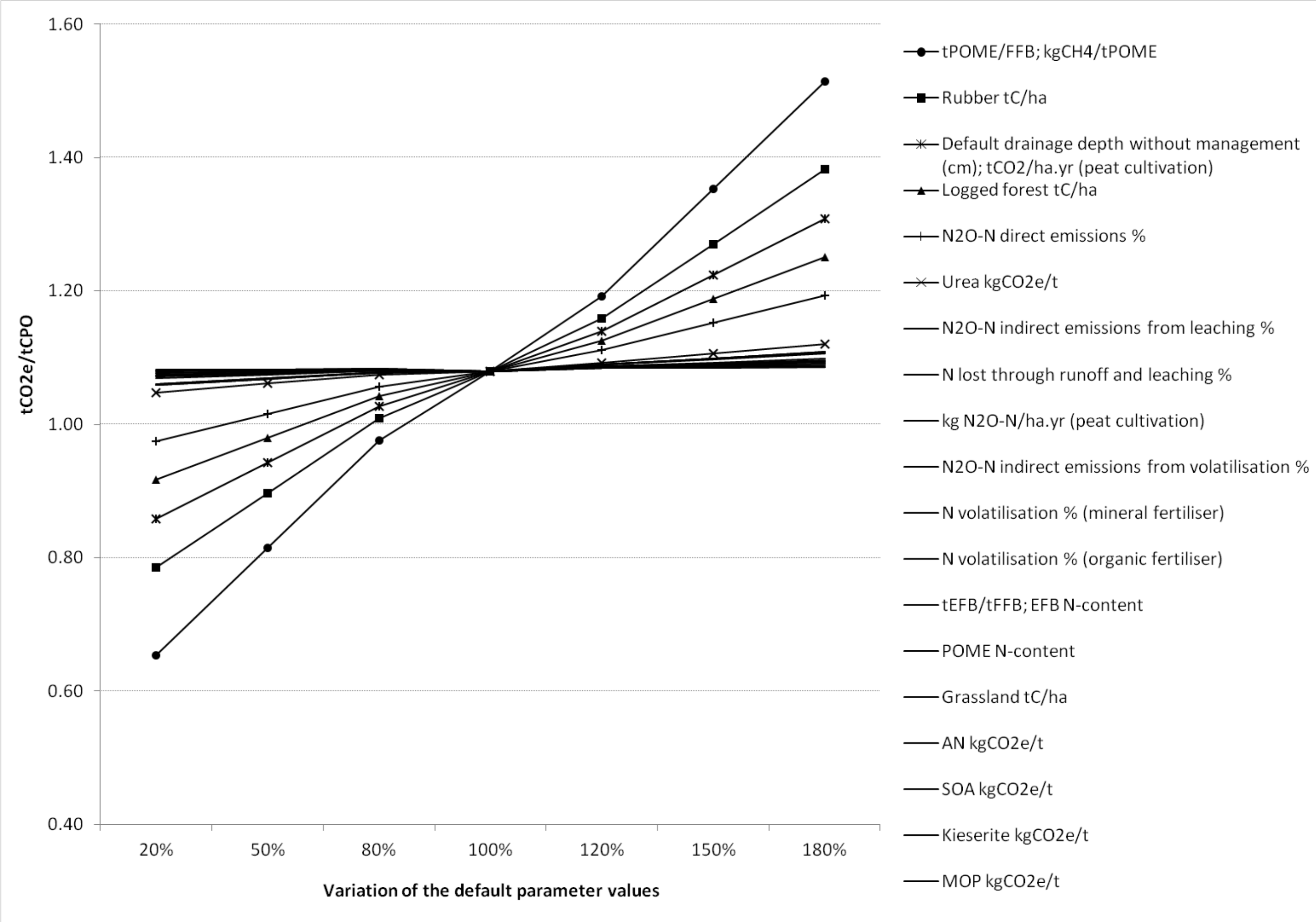


Figure 6: Sensitivity analysis of PalmGHG (version 1) main parameters

With the same data set, a scenario including methane capture, and flaring or conversion to electricity was tested. When methane is flared the GHG balance is reduced to 0.65 tCO_{2eq}/tCPO, with a drop in mill contribution from 50 to 17% of total emissions. The parameters tested, i.e. %CH_4 lost from digestion and %CH_4 lost in flare, were merely sensitive with a maximum GHG balance variation of ±4-7% with parameter variations of ±80%. When methane is converted to electricity the GHG balance is reduced to 0.55 tCO_{2eq}/tCPO, with a mill contribution merging to 1% of total emissions. In this context, the variations of the parameters could hardly influence the final results. Variations of ±80% of the gas motor efficiency and the proportion of total CH_4 converted to electricity would only lead to a minimum of 0.50 tCO_{2eq}/tCPO and a maximum of 0.59 tCO_{2eq}/tCPO. In terms of further improvement of PalmGHG, it is hence more interesting at the mill stage to focus on better modelling the influence of operations and treatments on POME production and CH_4 emissions.

PalmGHG pilot testing and training

A pilot study was carried out in 2011 with nine RSPO member companies that gave an average of 1.67 tCO_{2eq}/t crude palm oil (CPO) (Bessou et al., 2014). During this pilot testing it was shown that PalmGHG can help to identify GHG emission 'hot spots' and test management scenarios, hence helping to define GHG reduction strategies. Feedback from the pilot companies highlighted problems in data collection. However, it is expected that difficulties related to data recording will progressively diminish once the monitoring becomes routine. Data collection for outgrowers is a critical issue and PalmGHG version 2 allows for using default factors in the case of missing data from outgrowers' plantations. However, for the purpose of new plantings, RSPO Emission Reduction Working Group is presently working on a dedicated smallholders' guidance in order to assess their GHG emissions on their own plots.

Since the public release of PalmGHG two first versions, RSPO has already organised several training workshops in order to familiarise growers and auditors with the use of PalmGHG and to solicit feedback on future improvements to the calculator. Further information on future trainings can be found on the RSPO website www.rspo.org.

DISCUSSIONS

Comparison with published results

The order of magnitude of GHG balances calculated with PalmGHG is within the range of results found in the literature. These results vary from 0.6 to 19.8 tCO_{2eq}/tCPO (with a median value around 2 tCO_{2eq}/tCPO), depending on system boundaries and particularly on assumptions regarding land clearing and peat emissions (Schmidt, 2007; Reijnders and Huijbregts, 2008; Siangjaeo et al., 2011). Across published studies, land use change (LUC) is one of the most important factors affecting GHG emissions of palm oil and palm oil biodiesel, especially when primary forest is the previous land use (Wicke et al., 2008; Rejinders and Huijbregts, 2008; Zulkifli et al., 2009; Reinhardt and von Falkenstein, 2011). In this study, land clearing emissions were also one of the main contributors, although the relative contributions would depend on the distribution of the diverse previous land uses over the supply area. The sensitivity analysis highlighted the primary role played by carbon stocks in the diverse land uses. Besides land clearing, all studies agree that main GHG contributors are fertilisers and related field emissions at the farm stage, and POME emissions at the mill stage (Yusoff and Hansen 2007; Schmidt, 2007; Pleanjai et al. 2009; Arvidsson et al., 2011; Choo et al., 2011). This large contribution of the farm stage is not significantly reduced when including the refinery stage (Pleanjai et al., 2009; Choo et al. 2011). As shown with the methane capture from our base case, the impacts from POME can be drastically reduced if the biogas is captured at the mill (Chuchuoy et al. 2009; Choo et al. 2011) and the contribution of the mill stage becomes even smaller if this biogas is used to fuel the mill (Chavalparit et al. 2006). Finally, the drastic impact of peat emissions was also shown in Schmidt (2010), where cultivation on peat increased the contribution to global warming with a factor of 4–5 compared to cultivation on the current mix of soils types.

LULUC and carbon sequestration

Accounting for biogenic carbon in GHG assessments is not trivial. First, as highlighted by several authors (Brandão et al., 2012), biogenic carbon sequestration through biomass growth may only consist in a time delay between absorption and emission. Nevertheless, the human short-term visibility (compared to the geological time scale) has led to specific considerations regarding land clearing and carbon sequestration which tend to compromise between scientific and political rationales. PalmGHG relies on subsequent international agreements such as PAS2050 and IPCC (2006). Knowing that some of these considerations might be eventually revised, results of PalmGHG (as well as those from the majority of GHG assessments or LCA studies) cannot be taken as absolute but rather as relative ones that can suit comparative purposes.

In the year of land clearing the GHG emissions will contribute to an emission peak that will be largely absent in succeeding years. However, it is common practice in such circumstances to average (amortise) the loss over a time period (as one would amortise the cost of building a factory over a few years); such period could in theory be centuries-long when one knows that land will be used for human purposes almost indefinitely, but it tends to be fixed in a shorter length over which there is enough certainty; this emphasises the weight of immediate actions. In practice, the land use change amortisation period is set to the lifetime of the new crop or a 20-year period (IPCC, 2006; European Union Commission, 2009). This is the approach taken in PalmGHG which uses the intended crop cycle length (usually 25 years), as the amortisation period. The crop cycle length appeared to be a very sensitive parameter. With our base case, a variation of this length by ±80% led to a variation in the GHG balance by -70% to +400%; a 20-year crop cycle instead of 25 years would lead to an increase of the GHG balance by 37%. In PalmGHG version 1, the crop cycle length was keyed in by the grower and could vary across plantations. This factor could induce bias in the comparison of successive assessments and in case on unanticipated changes in the effective crop cycle length. The 25-year cycle was hence subsequently fixed. Biases remain possible. In the case of shorter crop cycles than expected for instance (e.g. in new plantations that have not completed a full cycle yet), care should be taken that all emissions from land clearing were "paid-back". In the same way, the use of the crop model to calculate crop sequestration in the year it occurs, thus depending on the age of the plantation, leads to variations in the balances from year to year and potential bias in case of short-term GHG monitoring (only a few years) of unevenly distributed plantations (Bessou et al., 2014). In future PalmGHG versions, a fix carbon stock for oil palm stand may be implemented. The evolutions along PalmGHG versions and perspectives are summarised in Figure 7.

Data and models are missing to assess properly the long-term dynamics of carbon pools in agro-ecosystems (Soussana et al., 2004; Seguin et al., 2007), especially in the tropics (Plassmann et al., 2010; Flynn et al., 2012). In PalmGHG, we could not account for a comprehensive dynamics of carbon within the agro-ecosystem. In particular, the decomposition of co-products applied in the field and the effect on soil carbon in mineral soils should be more deeply investigated and accounted for. Changes in soil organic matter in mineral soils might be significant in the long term in some circumstances and may have to be included in future versions of PalmGHG. It is a difficult area and in order to obtain meaningful data complex long-term studies will be needed.

Indirect land use change is not covered by PalmGHG although it is recognised as an important aspect affecting land use planning that needs to be taken into account if the consequential effects of oil palm area expansion are to be fully accounted for. Such a consequential approach might also allow for a better allocation of land clearing emissions by taking into account the drivers for land clearing at the global level. Indirect land use change is a consequence of national and international level land use planning, though, and thus beyond the scope for a growers' management tool such as PalmGHG.

Finally sequestration of carbon in areas where vegetation is being conserved on land that would otherwise be used for oil palm may also be considered in each year's carbon budget. However, no default values are provided for this, as the amount that is being sequestered will depend on the type and maturity of the vegetation, as well as on climatic, management and soil factors. Growers reporting sequestration in their conservation areas will need to carefully assess the annual sequestration, preferably supported by field measurements. This is an aspect that is still under consideration by RSPO in the light of international mechanisms such as the UN's REDD+ (Reduction of Emissions from Deforestation and forest Degradation). The amount of sequestration in conservation areas could, alternatively, be reported separately from the palm oil GHG balance and the evidence carefully monitored in the audit process.

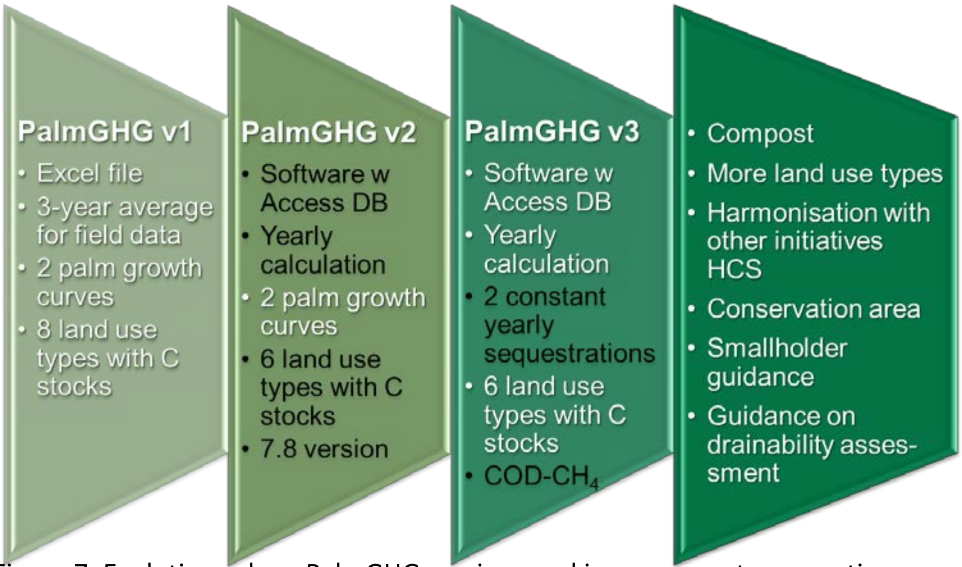


Figure 7: Evolutions along PalmGHG versions and improvement perspectives

CONCLUSIONS

PalmGHG was designed to be flexible in order to use field data and update default values easily. RSPO fosters the continuous improvement of the tool. In particular, knowledge improvement on the modelling of emissions from peat and co-product treatments and uses will allow for updating defaults and introducing new parameters in order to better mimic the causal-effect chain between practices and impacts.

The sensitivity analyses provides a very useful guidance to the research efforts that would significantly reduce the uncertainty linked to GHG assessment of palm oil products, by identifying those parameters that have a greatest effect on the results. In this sense, guiding data collection in mills to quantify the POME/FFB and CH_4/POME ratios could provide a significant reduction of the uncertainty in the results.

Despite its limitations, PalmGHG already provides useful information for the managers of plantations or mills towards reducing GHG emissions, and may be easily and regularly updated and improved.

Finally, a life-cycle cost analysis could be appended to the GHG balance to constitute an integrative management tool for the companies. It would imply a connection to database systems used by companies, such as SAP supply chain management software, and ease the use of PalmGHG on a routine basis.

ACKNOWLEDGEMENTS

All the members of the various RSPO working groups on GHG issues are gratefully acknowledged for their contributions to the fruitful discussions and the development of the tool; in particular main co-authors of PalmGHG are Chase L.D.C., Henson I.E., Abdul-Manan A.F.N., Milà i Canals L., Agus F., Sharma M., and Chin M. All PalmGHG co-authors thank the companies who took part in the pilot phase for supplying data and feedback on the tool, and are most grateful to members of the RSPO Executive Board for their continuing support; particular thanks being due to Dr Simon Lord for proposing the adoption of the GWAPP model, and to Dr Timothy Killeen, for guiding the development of the GHG tool.

REFERENCES

Agus, F., Henson, I. E., Sahardjo, B. H., Harris, N. van Noordwijk, M., Killeen, T. J., 2013. Review of emission factors for assessment of CO2 emission from land use change to oil palm in Southeast Asia.. In T. J. Killeen & J. Goon (eds.) Reports from the Science Panel of the Second RSPO GHG Work

Arvidsson, R., Persson, S., Fröling, M., Svanström, M., 2011. Life cycle assessment of hydrotreated vegetable oil from rape, oil palm and Jatropha. J Cleaner Prod. 19, (2-3) 129-137.

Asmara, D. H., Khasanah, N., Agus, F., van Noordwijk, M., 2012. Oil palm plantation carbon stock calculator. World Agroforestry Centre ICRAF-SEA Regional Programme and Indonesian Soil Research Institute.

Bessou, C., L.D.C. Chase, I.E. Henson, A.F.N. Abdul-Manan, L. Milà i Canals, F. Agus, M. Sharma, and M. Chin. 2014. Pilot application of PalmGHG, the Roundtable on Sustainable Palm Oil greenhouse gas calculator for oil palm products. Journal of Cleaner Production 73: 136–145.

Bessou, C., Abdul-Manan, A., Caliman, J-P., Chen, S.S., Gheewala, S., Milà-i-Canals, L., Saharjo, B.H., Sharma, M., Lord, S., Chase, L.D.C., Henson, I.E., Ramani, P., 2010. Framework for a GHG reporting tool within RSPO - Methodology - RSPO GHG WG2 Workstream 1: Operational emission accounting. 29p. (+ Appendices), available from RSPO secretariat upon request at rspo@rspo.org.

Brandão, M., Levasseur, A., Kirschbaum, M. U. F., Weidema, B. P., Cowie, A. L., Jørgensen, S. V., Hauschild, M. Z., Pennington, D. W., Chomkhamsri, K., 2012. Key Issues and Options in Accounting for Carbon Sequestration and Temporary Storage in Life Cycle Assessment and Carbon Footprinting. The International Journal of Life Cycle Assessment 18(1), 230–240.

Chase, L.D.C., Henson, I.E., 2010. A detailed greenhouse gas budget for palm oil production. Int. J. Agr. Sustain. 8(3), 199-214.

Chavalparit, O., Rulkens, W. H., Mol, A. P. J., Khaodhair, S., 2006. Options for environmental sustainability of the crude palm oil industry in Thailand through enhancement of industrial ecosystems. Environ. Dev. Sustain. 8, (2) 271-287.

Choo, Y.M., Muhamad, H., Hashim, Z., Subramaniam, V., Puah, C.W., 2011. Determination of GHG contributions by subsystems in the oil palm supply chain using the LCA approach. Int. J. Life Cycle Assess. 16,669-681.

Chuchuoy, K., Paengjuntuek, W., Usubharatana, P., Phungrassami, H., 2009. Preliminary study of Thailand carbon reduction label: A case study of crude palm oil production. Eur. J. Sci. Res. 34, (2) 252–259.

Colomb, V., Touchemoulin, O., Bockel, L., Chotte, J-L., Martin, S., Tinlot, M., Bernoux M., 2013, Selection of appropriate calculators for landscape-scale greenhouse gas assessment for agriculture and forestry. Environ. Res. Lett. 8:015029. doi: 10.1088/1748-9326/8/1/015029

Corley R.H.V; Tinker, P.B., 2003. The Oil Palm, 4th ed. Blackwell Science.

Corley, R.H.V.; Hardon, J.J.; Tan, G.Y., 1971. Analysis of growth of the oil palm (Elaeis guineensis Jacq.). Euphytica. 20,307-315.

Ecoinvent, 2010. Data Bases Ecoinvent 2.2. Swiss Centre for Life Cycle Inventories.

Environment Agency, 2002. Guidance on Landfill Gas Flaring. Bristol: Environment Agency. Available at: http://www.environment-agency.gov.uk/static/documents/Business/lfg_flaring_guidance_1101730.pdf

European Union Commission, 2009. Directive 2009/28/EC Draft Annex V. Draft Commission Decision (of 31 December 2009) on guidelines for the calculation of land carbon stocks for the purpose of Annex V of Directive 2009/28/EC. European Commission, Brussels. 26 p.

Fearnside, P.M., 2002. Time preference in global warming calculations: a proposal for a unified index. Ecol. Econ. 41,21–31. doi: 10.1016/S0921-8009(02)00004-6

Flynn, H.C., Milà i Canals, L., Keller, E., King, H., Sim, S., Hastings, A., Wang, S., Smith, P., 2012. Quantifying global greenhouse gas emissions from land use change for crop production. Glob. Change Biol. 18(5), 1622–1635

Gunarso P., Hartoyo M.E., Agus, F., 2013. Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea. In T.J. Killeen & J. Goon (Eds.) Reports from the Technical Panels of the Second RSPO GHG Working Group, Roundtable for Sustainable Palm Oil – RSPO, Kuala Lumpur.

Gurmit S., 1995. Management and utilisation of oil palm co-products. Planter. 71, 361-386.

Harris, N., Grimland, S., Brown, S., 2009. Land Use Change and Emission Factors: Updates Since the RFS Proposed Rule. Winrock International. Report submitted to EPA. Available at: http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2005-0161-3163

Henson, I. E., 2005a. An assessment of changes in biomass carbon stocks in tree crops and forests in Malaysia. J. Trop. Forest Sci. 17, 279-296.

Henson, I.E., 2005b. OPRODSIM, a versatile, mechanistic simulation model of oil palm dry matter production and yield. In: Proceedings of PIPOC 2005 International Palm Oil

Congress, Agriculture, Biotechnology and Sustainability Conference, 801-832. Kuala Lumpur: Malaysian Palm Oil Board.

Henson, I.E., 2009. Modelling carbon sequestration and greenhouse gas emissions associated with oil palm cultivation and land-use change in Malaysia. A re-evaluation and a computer model. MPOB Technology, 31, 116 pp.

Hillier, J., Walter, C., Malin, D., Garcia-Suarez, T., Mila-i-Canals, L., Smith, P., 2011. A farm-focused calculator for emissions from crop and livestock production. Environ. Modell. Softw. 26: 1070-1078.

Hooijer, A., S. Page, J. G. Canadell, M. Silvius, J. Kwadijk, H. Wosten, J. Jauhiainen, 2010. Current and future CO2 emissions from drained peatlands in Southeast Asia. Biogeosciences. 7, 1505-1514

International Standard Organization (ISO). 2006. Environmental management—Life cycle assessment—Requirements and guidelines. ISO 14044, 2006.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories. Vol 4 Agriculture, Forestry and Other Land Use. WMO/UNEP. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

IPCC. 2007a. Technical Summary. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

IPCC. 2007b. Fourth Assessment Report. Climate Change 2007 - Synthesis Report. WMO/UNEP. http://www.ipcc.ch/ipccreports/ar4-syr.htm.

JEC (JRC, EUCAR, CONCAWE), 2011. Well-to-wheels analysis of future automotive fuels and powertrains in the European context. http://ies.jrc.ec.europa.eu/WTW.

Jensson, T.K., Kongshaug, G., 2003. Energy consumption and greenhouse gas emissions in fertiliser production. Proceedings No 509, Int. Fertiliser Society, York, UK 28pp.

Khasanah, N., van Noordwijk, M., Ekadinata, A., Dewi, S., Rahayu, S., Ningsih, H., Setiawan, A., Dwiyanti, E., Octaviani, R., 2012. The carbon footprint of Indonesian palm oil production. Technical Brief No 25: palm oil series. Bogor, Indonesia. World Agroforestry Centre - ICRAF, SEA Regional Office. 10p.

Lasco, R.D., Sales, R.F., Estrella, R., Saplaco, S.R., Castillo, L.S.A., Cruz, R.V.O., Pulhin, F.B., 2001. Carbon stocks assessment of two agroforestry systems in the Makiling Forest Reserve, Philippines. Philippine Agri. Scientist. 84, 401-407.

Muñoz, I., Rigarlsford, G., Milà-i-Canals, L., King, H., 2013. Accounting for greenhouse-gas emissions from the degradation of chemicals in the environment. Int. J. Life Cycle Assess. 18(1), 252-262. DOI:10.1007/s11367-012-0453-4

Oil World. Oil World Annual 2012. Hamburg, Germany: ISTA Mielke GmbH; 2012.

Plassmann, K., Norton, A., Attarzadeh, N., Jensen, M.P., Brenton, P., Edwards-Jones, G., 2010. Methodological complexities of product carbon footprinting: a sensitivity analysis of key variables in a developing country context. Environ. Sci. Policy. 13, 393–404.

Pleanjai, S., Gheewala, S. H., Garivait, S., 2009. Greenhouse gas emissions from the production and use of palm methyl ester in Thailand. Int. J. Glob. Warming. 1, (4) 418–431.

Reijnders, L., Huijbregts, M. A. J., 2008. Palm oil and the emission of carbon-based greenhouse gases. J. Cleaner Prod. 16(4), 477-482.

Reinhardt, G.A., von Falkenstein, E., 2011. Environmental assessment of biofuels for transport and the aspects of land use Competition. Biomass Bioenerg. 35,2315–2322. doi:10.1016/j.biombioe.2010.10.036

RFA, 2008. Carbon and Sustainability Reporting Within the Renewable Transport Fuel Obligation. Technical Guidance Part 2 Carbon Reporting – Default Values and Fuel Chains. London: Renewable Fuels Agency. http://www.renewablefuelsagency.org/db/documents/RFA_ C&S Technical Guidance Part 2 v1 200809194658.pdf.

RSPO, 2012. RSPO Manual on Best Management Practices (BMP) for Existing Oil Palm Cultivation on Peat. Peat Land Working Group. Version 12.6 Draft (Final), 29th Feb 2012, 142p.

Schmidt, J.H., 2007. Life cycle inventory of rapeseed oil and palm oil. PhD Thesis: Life cycle inventory report. Department of Development and Planning, Aalborg University, Aalborg, Denmark.

Schmidt, J.H., 2010. Comparative life cycle assessment of rapeseed oil and palm oil. Int. J. Life Cycle Assess. 15,183-197.

Seguin B., Arrouays D., Balesdent J., Soussana J.F., Bondeau A., Smith P., Zaehle S., de Noblet N., Viovy N. (2007) Moderating the impact of agriculture on climate, Agr. Forest Meteorol. 142, 278-287.

Siangjaeo, S., Gheewala, S. H., Unnanon, K., Chidthaisong, A., 2011. Implications of land use change on the life cycle greenhouse gas emissions from palm biodiesel production in Thailand. Energ. Sust. Dev. 15(1), 1-7.

Smith P, Martino D, Cai Z, Gwary D, Janzen H. (+15)., 2008. Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society, B. 363:789–813.

Soussana, J.F., Loiseau P., Vuichard N., Ceschia E., Balesdent J., Chevallier T., Arrouays A. (2004) Carbon cycling and sequestration opportunities in temperate grasslands, Soil Use Manage. 20, 219-230.

van Noordwijk, M., Dewi, S., Khasanah, N., Ekadinata, A., Rahayu, S., Caliman, J-P., Sharma, M., Suharto, S., 2010. Estimating the carbon footprint of biofuel production from oil palm: Methodology and results from two pilot areas in Indonesia. Paper presented at: 2nd International Conference on Oil Palm and Environment (ICOPE) 2010, Bali, Indonesia.

Wicke, B., Dornburg, V., Junginger, M., Faaij, A., 2008. Different palm oil production systems for energy purposes and their greenhouse gas implications. Biomass Bioenerg. 32(12), 1322-1337.

Yacob S., Hassan M.A., Shirai Y., Wakisaka M., Subash S., 2006. Baseline study of methane emission from anaerobic ponds of palm oil mill effluent treatment. Sci. Total Environ. 366: 187-196.

Yacob, S., Hassan, M. A., Shirai, Y., Wakisaka, M., Subash, S.,2005. Baseline study of methane emission from open digesting tanks of palm oil mill effluent treatment. Chemosphere. 59, (11) 1575-1581.

Yew, F.K., 2000. Impact of zero burning on biomass and nutrient turnover in rubber replanting. Paper presented at International Symposium on Sustainable Land Management.

Yew, F.K., Nasaruddin, M., 2002. Biomass and carbon sequestration determinations in rubber. Methodologies and case studies. Seminar on Climate Change and Carbon Accounting. Department of Standards, Malaysia and SIRIM Sdn Bhd, Shah Alam, Malaysia. 13 pp.

Yusoff, S., Hansen, S., 2007. Feasibility Study of Performing a Life Cycle Assessment on Crude Palm Oil Production in Malaysia. Int. J. Life Cycle Assess. 12, (1) 50-58.

Zulkifli, H., Halimah, M., Mohd Basri, W., Choo, Y.M., 2009. Life cycle assessment for FFB production. Proceedings from PIPOC Conference 2009 Palm oil - Balancing Ecologies with Economics.