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FLAG SCIENCE BASED TARGETS METHODS ADDENDUM FOR COMMODITY PATHWAYS

DRAFT FOR PUBLIC CONSULTATION

January 2022

This addendum provides detailed information on the methods and data used to develop the SBTi FLAG *Commodity* pathways as a complement to the overall description provided in the main FLAG Guidance document (Section 4.2.2).

Additional information on the data and models used in the *FLAG Commodity pathways* can be found in:

> Smith, P., Dali N., Giel, L., Daan, P., Coraline, B., Detlef, V., Elke, S., Mathijs, H., Lidewij van den B. (2016). 'Science-Based GHG Emissions Targets for Agriculture and Forest Commodities.' University of Aberdeen, Ecofys, and PBL.

Please note that this document does not include information on the SBTi *FLAG Sector pathway*. Detailed information on the methods and data used in the *FLAG Sector pathway* – described in the main Guidance document (section 4.2.1) – can be found in:

> Roe S, Streck C, Obersteiner M, et al (2019) Contribution of the land sector to a 1.5 °C world. Nat Clim Chang 9:817–828. doi: 10.1038/s41558-019-0591-9

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1. PROJECT CONTEXT & SCOPE

The WWF and SBTi Forest, Land and Agriculture work (FLAG) aims to address gaps in accounting of land-based emissions and removals in corporate target-setting and disclosures. Agriculture, forestry and other land uses (AFOLU) are both a major driver of global greenhouse gas emissions and a major carbon sink. Agricultural or forestry products that can be bought and sold, referred to as commodities, represent the majority of land use. The majority of these emissions and removals are related to how land is managed (e.g., fertilizer use and tillage) and how land use changes (e.g. from a primary or secondary forest to a farm).

In order to align with the Paris Agreement, commodity management needs to change. Given the different aspects of commodity production (land management, yield etc.) there is a need to shed light on the expectations and opportunities for different commodities in terms of emission intensity (tonnes of carbon dioxide emitted per tonne of commodity, t CO2eq/t fresh weight of product) and carbon removal (tonnes of carbon dioxide removed per tonne of commodity, -t CO2eq/t fresh weight of product). Understanding these pathways can serve as a first step to help identify meaningful actions to reorient global commodity production to achieve climate targets.

Funded by the KR foundation, University of Aberdeen, PBL Netherlands Environmental Assessment Agency and Ecofys have developed a new methodology and tool based on the Sectoral Decarbonization Approach (SDA) (Krabbe et al., 2015) to set science based targets for nine key agricultural commodities (beef, chicken, dairy, pork, maize, palm oil, rice, soy, and wheat), and to qualitatively assess one forestry commodity (roundwood). These ten commodities cover over 50% of global GHG emissions from the AFOLU sector (Smith et al., 2016).

Based on updated Marginal Abatement Cost Curves and simulations in the Integrated Model to Assess the Global Environment (IMAGE 3.0) model of the so-called SSP2 scenario (van Vuuren et al., 2014, O'Neill et al., 2014), the PBL tool derived average emission intensity pathways from 2010 to 2050 per agricultural commodity across 26 regions. The average emission intensity is representative of cradle to farm gate emissions such as those associated with upstream production of fertilizers, on-field application of fertilizers, on-farm machinery use, manure management, and other relevant on-farm activities. For a full commodity-specific list of emissions included, please refer to the Smith et al., 2016, Section 3.3. These emissions are referred to as non-LUC emissions since they do not include land use change (LUC) related emissions. Similar to the SDA approach, the average emission intensity pathways of a commodity are translated to a company-specific emissions intensity target that can be calculated for any specific target year (until 2050). Removals and land use change emissions associated with the production of these commodities were not included in the intensity pathways in the original PBL tool.

Quantis and WWF partnered in this project to add into the PBL tool the high-level commodity pathways aligned with a 1.5 degree Celsius temperature rise above pre-industrial levels by 2100 from IMAGE 3.0. Specifically, this project achieved the following objectives:

1. Develop commodity-specific **land use change (LUC) mitigation pathways** for nine key agricultural commodities for the SBTi FLAG project: beef, chicken, dairy, pork, maize, palm oil, rice, soy, and wheat. Incorporate LUC values into existing PBL tool.

2. Introduce soil carbon sequestration as a **disaggregated removals pathway**. Incorporate removals into existing PBL tool.

3. Using newly available forest data, create a baseline for emissions and removals associated with timber and wood fiber. Incorporate **timber & wood fiber as a tenth commodity** into the existing PBL tool.

4. Finally, **deliver a user-ready tool** to be used by companies as part of new SBTi FLAG commodity pathways target setting process.

2. PBL TOOL & ASSOCIATED BACKGROUND DATA DESCRIPTION

2.1. Introduction

The foundation of this work is based on the existing data used for the SBTi FLAG project coming from the IMAGE 3.0 Integrated Assessment model (Stehfest et al. 2014), using the SSP2-2.6 scenario (Smith et al. 2016, van Vuuren et al. 2017), which was originally designed to align with global warming of 1.8°C, below the 2°C target. Following extensive expert consultation and model review, this pathway has also been qualified as 1.5°C compliant tool for FLAG target setting because for this agriculture, there the 1.8°C and 1.5°C mitigation outcomes in Integrated Assessment Models are aligned.[1]

The assessed commodities are the following:

- Beef
- Chicken
- Dairy
- Maize
- Palm oil

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[1] IPCC 2014 & Expert consultation with with IMAGE 3.0 modelers and authors, September 2021.

- Pork
- Rice
- Soya
- Wheat
- Timber & wood fiber (added in this release)

In the tool interface, the animal commodities (beef, chicken, and pork) are expressed in tonne of fresh weight as carcass[2], and dairy is expressed in tonne of fat and protein corrected milk (FPCM). The rest of the crop commodities are expressed in tonne of fresh weight as harvested, except for palm oil, which is expressed in tonne of crude oil (not fruit bunches) (Appendix *A1. Data setup for oil crops*). Timber and wood fiber (industrial roundwood, which excludes firewood) are expressed in cubic meters, solid under bark.

The IMAGE 3.0 model considers 26 regions globally, see Appendix *A2. IMAGE regions and correspondence* for additional detail.

LUC and non-LUC inputs made by users are checked as described in Appendix *A5. Data input validation and thresholds regarding data acceptability.*

2.2. Adaptations made to the tool

2.2.1. Oil crops data

The IMAGE data regarding oil crops (soybean and palm oil) was initially aggregated. The data has been disaggregated based on FAO data, and fresh palm fruit bunches have been converted to palm oil (Appendix *A1. Data setup for oil crops*).

2.2.2. Moisture content

For all commodities, IMAGE source data used in the tool are expressed in the metric of tonne of dry matter (DM); however, the end-use of the tool considers fresh matter. The conversion from DM to fresh matter has been implemented in the tool using the moisture content shown in Table 1.

Table 1: Moisture content used to convert dry matter to fresh matter of the commodities

Commodity	Moisture content	kg fresh/kg DM
Wheat	12%	1.14
Rice	13%	1.15
Maize	12%	1.14
Soya	8%	1.09

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[2] Carcass defined as “animal meat, fresh, chilled or frozen, with bone in”.

Palm oil	0.2%	1.002
Beef	50%	2.00
Dairy	87%	7.69
Pork	50%	2.00
Chicken	50%	2.00
Data used for the IMAGE 3.0 model, as mentioned by Smith et al (2016), page 21. For palm oil, the moisture content used here is for the oil itself, not the fruit bunches; 0.2% moisture content is the critical level to ensure oil conservation.		

2.2.3. Background data for timber and wood fiber

The background data for timber and wood fiber was not available in the IMAGE model and has been built as described in Section 5.

2.2.4. Non-LUC intensity cap

Another adaptation to the tool was to modify the formula of the pathway to ensure that there are no increases in emission intensity for non-LUC emissions. The original pathway calculation formula may, in some cases, allow an increase of the non-LUC emissions intensity pathway if the starting point for the user is low compared to the regional average. As allowing for an increase of the non-LUC emission intensity does not align with the purpose of the tool to guide emission reductions, the formula has been constrained to prevent it. Technically, this means that an annual value is capped at the level of the previous year and thus emission intensities in any given year cannot exceed those in previous years.

3. LAND USE CHANGE MITIGATION PATHWAYS

3.1. Methodology

3.1.1. Introduction

Land use change (LUC) refers to the change from one land use class to another. The LUC that is specifically targeted in this work is the **loss of primary and naturally regenerated forests** due to the expansion of agricultural production, also commonly referred to as deforestation.

The reason for focusing on deforestation is because other land use changes across other land use classes (such as the conversion from annual crop to perennial crop, or grass land to planted forest) are not fully specified by the existing dataset. Moreover, peat degradation which may not always be categorized as a land use change in cases when continued management has been occurring on peatland, is not considered in the current assessment. Emissions and potential reductions associated with peatland degradation should be considered in future iterations of the tool.

LUC impacts and mitigation pathways were determined across 10 commodities and 27 geographies – including 26 regions and 1 global pathway. LUC values were first calculated for the reference year 2015 and then extrapolated through until 2030. The year 2030 is considered because deforestation impacts are allocated over 20 years, therefore impacts will continue to be distributed until 2050. This legacy calculation is explained in Section 3.1.6.

3.1.2. Land use data

FAOSTAT land use data[3] was used for primary and naturally regenerated forests to assess the forest loss between 1995 and 2015. The next release of FAO forest data (2020) was not available at the time of calculation.[4]

FAOSTAT crop data was used to assess the area expansion of the crop commodities between 1995 and 2015. While land use data is available for crops, it is not readily available for animal products. Therefore, regional level feed basket data is used to approximate land use associated with production of animal-based commodities.

Finally, FAOSTAT land use data was used to assess the area expansion of roundwood production. This is detailed further in Section 5.1.6.

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[3] http://www.fao.org/faostat/en/#data

[4] FAO forest data are published every five years. Coincidentally, Roe et al (2019) also use 2015 as a reference year.

3.1.3. Land use data for animal products

3.1.3.1. Feed baskets

The uncertainty on feed baskets is high, with large variations even at local level. The work realized here is at a level that captures the right level of magnitude of LUC, focusing on key commodities and allowing wide approximations for other potential LUC contributors.

Land use for animal products is almost entirely related to feed and pasture. Infrastructure area is therefore considered negligible and excluded in this work. Regionalized feed baskets are provided by GLEAM data (FAO 2018). GLEAM regions were matched to IMAGE regions as outlined in the table found in Appendix *A2. IMAGE regions and correspondence*.

Since the GLEAM feed baskets use more than 50 ingredients, they have been categorized into 9 feed ingredients as outline in Table 2, and outlined in detail in the table found in Appendix *A4. Ingredients used in feed baskets and corresponding GLEAM ingredients*. This simplification was implemented to expedite the estimated land occupation. Future revisions can consider tracking down land occupation associated with each of the GLEAM ingredients, although this refinement is unlikely to significantly change results.

Table 2: Simplified feed ingredients list used in the LULUC model

Model Feed ingredient	Note
Grass	Includes fresh grass (pasture), hay and grass silage
Fodder crop	Includes, depending on the region: green maize, pulses and cassava as proxies
By-product	No impact associated to agricultural or food industry by-products (considered of low value, hence not driving the activity)
Maize	---
Soy	Includes also soybean meal. In Europe: contains 30% Brazilian soy.
Wheat	---
Cereal	Other cereals than the ones mentioned above
Oilseed meal	Allocation between oil and meal is based on economic value
Other	No impact associated (mostly not agricultural product, e.g.: salt)

Animal feed baskets contain commodities that are also assessed in the tool, independently. It means that there is an overlap between these pathways. For instance, a portion of the maize pathway includes maize that will ultimately be consumed by cattle, and the beef pathway also includes that portion of maize as feed.

This overlap does not pose a double counting risk as these pathways should be considered independently.

3.1.3.2. Conversion efficiency and land used by the feed basket

After determining the feed basket, the land area associated with the feed basket needs to be estimated.

The amount of feed needed to produce a given animal product is known as the conversion efficiency. The conversion efficiency is the quantity of dry matter animal product output as a percentage of total dry matter intake (DMI) of feed (including pasture grass) by the animal during its lifetime. Th conversion efficiencies provided by Doelman (2018) were used to calculate the DMI required per kg of animal product. Combined with the feed basket, we therefore have the quantity of feed ingredient per kg of animal product.

Knowing the quantity of feed ingredient, the land area needed to produce feed crops and provide pasture can be determined based on FAOSTAT yield data complemented with World Food LCA Database (WFLDB) data for grass and pasture (Nemecek et al 2019).

Land use data associated with the feed basket and hence with 1 kg of animal product is needed for LUC calculation as described above and is a required input for the determination of the land area available for carbon removals, described in Section 4.

3.1.4. LUC calculation method

The LUC is calculated using the “historical expansion” method (method C) – as described by Smith et al. (2016). This method is chosen because it takes into account statistical LUC for each crop or activities, by attributing forest cover loss in the country proportionally to their area expansion rate. This is different from direct LUC (dLUC, where historical data from each field is used) and from indirect LUC (iLUC, where an economic model links the relation from cause to effect of land demand).

Statistical LUC as modelled using method C serves as a good proxy for iLUC since it tends to capture the indirect effects of land demand. It is crucial to consider the market drivers of deforestation and make sure to not allocate an unfair share of LUC impacts to small holders expanding their land area into the forest due to market forces from other actors’ large-scale land use pressures.

The reference LUC rate of each commodity in each country for 2015 (average yearly m^2 forest loss per ha cultivated in 2015) is expressed in $m^2\ ha^{-1}\ a^{-1}$. It is a weighted average of the yearly LUC of the 20 latest years (default time frame according to IPCC 2019), using a linear discounting allocation from 0.25% to 9.75% (Appendix *A3. LUC weighting factors*). Applying linear discounting places greater weight on recent years, this weighting can be considered to better capture the observed LUC trends than a non-weighted average.

The average carbon loss of primary and naturally regenerated forests is then used to calculate the impacts of this loss.

3.1.5. Deforestation impact calculation

Based on IPCC 2006 and 2019, the deforestation impacts are calculated considering the carbon pools: above ground vegetation, below ground vegetation, dead organic matter and soil organic carbon. These pools have an initial value for primary forest and naturally regenerated forest that are known based on FAO's Global Forest Resources Assessment 2015 (FAO 2015).

After land use change, the same pools have new values that are calculated based on the crop type and default land management parameters, specific to each country, based on Quantis internal database and WFLDB data (Nemecek et al. 2019).

The difference (loss) in the carbon pools is considered to be emitted into the atmosphere as CO_2. This calculation is made for the weighted average of the yearly deforestation, which is already allocated to 1 ha of crop production during one year, as described in the section above. Hence no additional allocation step is required; only the attribution of these emissions to 1 reference unit of the crop remains to be done, based on the average yield provided by FAO.

3.1.6. Reduction pathways

Deforestation causes GHG emissions (e.g. from soil) that can extend beyond the year when the forest's trees are cut down. Furthermore, there is a 20-year allocation rule commonly accepted based on the GHG Protocol (WRI and WBCSD 2014), which means deforestation emissions are allocated over 20 years following a deforestation event. Given these two different lines of logic (a. that deforestation emissions can continue after a deforestation event and b. the allocation of reported deforestation emissions continues after the event) deforestation must stop at the latest in 2030, in order to not carry emissions over the target date of 2050 where deforestation emissions must stop to align with the IMAGE SSP2-2.6 pathway and with Roe et al (2019). The timing difference between deforestation and the related allocated emissions is illustrated in Figure 1.

Since the remaining time frame between the year of this project is finalized (2021) and 2030 is narrow, there is not enough resolution to calculate a reduction pathway for a specific crop-region combination that can be differentiated with sufficient certainty.

Therefore, the choice has been made to consider the **same linear pathway for all commodities and for all regions**, building on the emission pathway suggested by Roe et al. (2019).

The deforestation pathway is described below:

- Baseline = 2015 LUC value
- 25% reduction in 2020
- 100% reduction in 2030

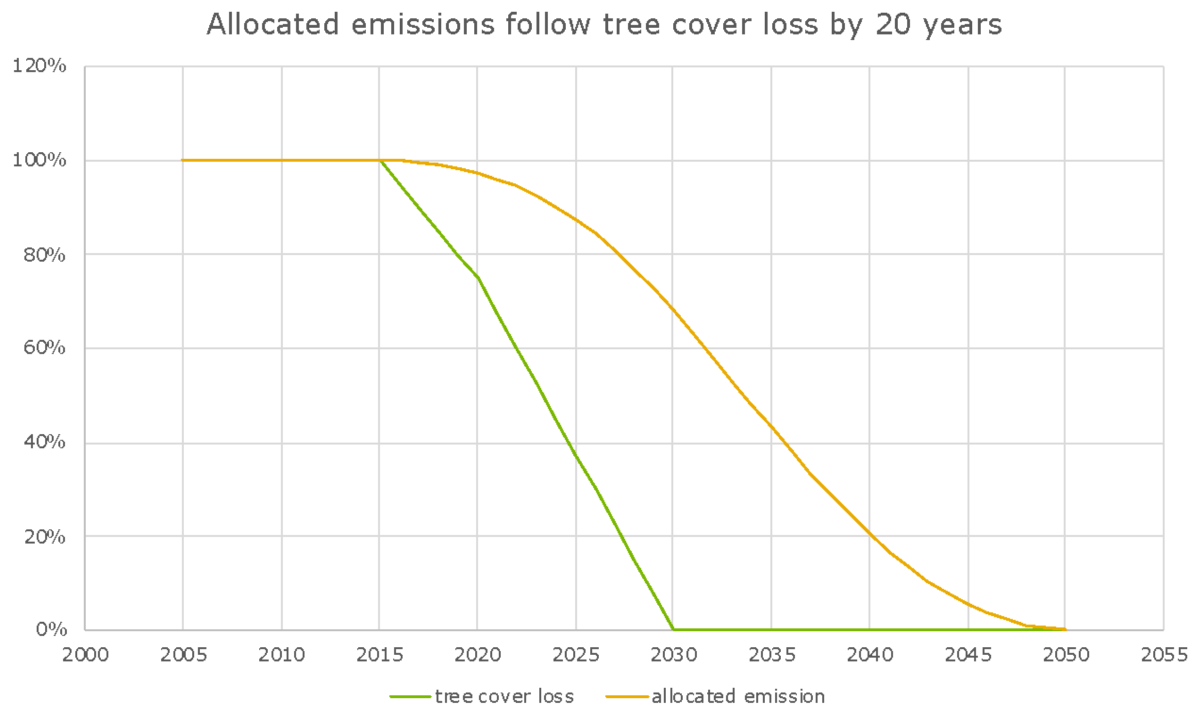

Figure 1: Deforestation and deforestation emission pathways

3.2. Limitations

3.2.1. <u>Data reliability</u>

The proposed methodological approach relies on FAO data. Although FAO data are carefully reviewed and are usually from official national statistics (FAO 2014), these data are reported by FAO member states with unequal accuracy. Moreover, data definitions are occasionally subject to realignment causing abrupt changes in data time series that are not actual changes on the field but can be interpreted as such when calculating LUC. Despite careful review of the results, LUC results will inevitably reflect the inconsistencies present in the source data.

3.2.2. <u>LUC reference year</u>

Because the 2020 forestry data were not released at the time of realization of this methodology (FAO's Forest assessment data are released every 5 years) and Roe et al (2019) uses a 2015 reference year to define mitigation pathways, the LUC data in the tool uses a 2015 reference year. This leads to two limitations: 1) the LUC data are not up to date with the latest data available and 2) this creates an effect that any year after 2015 is treated as the future in the tool, even when the suggested reduction pathway has not been taken in reality.

3.2.3. Oil crops production projection to 2050

Soybean and palm oil production have the same pathway in the tool given the data availability in IMAGE, while they may in reality diverge. This is an approximation that can be refined in future work.

At regional level, the IMAGE data for soybeans and palm oil tend to diverge from the FAO data, especially for palm oil in Indonesia and soybean in Brazil, where production far exceeds IMAGE's projection already in 2018 in both cases. This means that expert users of the tool will rapidly notice a discrepancy between regional production of the commodity as reported by the tool, and the actual value.

This data divergence is acknowledged, but IMAGE data was kept to maintain the consistency of the production data source in the tool. While the difference is visible for the total production, no effect on the pathways has been observed when comparing soy pathways calculated based on original data with soy pathways calculated with the new adjusted data.

3.2.4. Burden shifting

FAO data for land use are based on market-based values (for example, hectares cultivated for any given crop in a country). As a result, shifting from one crop to another to avoid LUC impacts will only shift the burden and not actually decrease the overall deforestation risk. This tool therefore does not address concerns of burden shifting.

3.2.5. Feed baskets and conversion efficiency

There are 2 major sources of uncertainty for animal products: 1) geographic breakdown of the feed baskets (the geographic regions for feed baskets are not identical to the IMAGE model) and 2) the aggregation of feed conversion efficiencies to 9 categories (there are above 50 in FAO GLEAM and potentially hundreds in reality). Likely these two sources of uncertainty do not significantly affect the results in terms of order of magnitude, directionality, and relative ranking of animal products, but this can certainly be refined in future versions.

4. CARBON REMOVALS PATHWAYS

4.1. Methodology

4.1.1. Introduction

Roe et al. 2019 defines the maximum land and agriculture sector emissions contribution to maintain planetary warming below 1.5°C higher than pre-industrial levels. The modeling performed by Roe et al. (2019) forms the basis for the FLAG sector tool and is the most comprehensive source of data available at this time. The mitigation pathway set out by Roe et al. (2019) includes but is not limited to the potential emissions and removals from afforestation, reforestation, sustainable forestry, bioenergy with carbon capture and storage (BECCS), agricultural emissions reductions, and agricultural soil carbon sequestration.

The carbon removals pathway implemented into the tool focuses specifically on the potential of soil carbon sequestration and the use of biochar to globally remove 32 Gt of CO_2-eq from the atmosphere between 2020 and 2050 (Figure 6 in Roe et al. 2019). As a result, carbon removals are only considered in response to land management changes. Forest carbon sequestration is covered in the timber & wood fiber pathway.

The procedure for translating a global carbon removals target into a commodity and region-specific removal intensity (i.e. considering removals that are relevant for the considered commodities) is outlined below.

4.1.2. Sequestration pathway

The total mitigation achieved in the roadmap established by Roe et al. is broken into eight priority portions, each with a mitigation potential that is derived from literature values found in Table 5 of the Roe et al. Supplementary Material documentation. The total removals from sequestration (soil and biochar) needed up until 2050 is 32 Gt CO_2eq. The tool divides this total over 30 years by using a linear annual rate of growth with a maximum target of 1.3 Gt CO_2eq/year in 2050. The yearly sequestration value represents the total carbon removal potential of global agricultural production, which is then subdivided to generate removals intensities based on commodity and region-specific choices. The estimated annual sequestration of timber and wood fiber commodity is calculated separately and described in Section 5.1.7.

4.1.3. Assigning sequestration to specific commodities

4.1.3.1. Land Use for Commodity Production

The land use area required for production of each commodity were determined using a combination of FAOSTAT data and animal feed basket modeling as outlined in Sections 3.1.2 and 3.1.3. These values vary based on regional differences in yield for crop commodities and feed baskets for animal-based commodities. All yield values are decreased by 1% to adjust for changes in yield that may occur due to the adoption of the new farming practices as suggested by the Project Drawdown Regenerative Annual Cropping Technical Summary (Project Drawdown 2021).

4.1.3.2. Determining an emissions intensity per commodity

Yields (tonne/hectare) for each commodity were multiplied by the total world production (in tonnes) for each commodity to generate a global land area (in hectares) of production. By dividing the yearly removals rate by the total land area, roughly 3.3 Gha, a per hectare removals intensity for each year from 2020 to 2050 was determined. This removals intensity is applied equally for all commodities in this version of the tool on a per hectare basis. As the global removals increase linearly over time, the total removals per hectare also increase from 0.25 t CO_2eq/ha in 2020 to 0.40 t CO_2eq/ha in 2050. This allows for gradual adoption of new agricultural practices that sequester carbon, which may require new knowledge or financial resources to implement.

Next, removals intensity on a per hectare basis was translated to a per kg of product basis using commodity and region-specific yield. The yearly removals target is graphed alongside the LUC and non-LUC emissions in the tool to provide a visual representation of the intended pathway for reduction.

4.2. Limitations

4.2.1. Removals per hectare

As mentioned in Section 4.1.3, one limitation to this calculation is the even distribution of removals across all agricultural hectares despite differences in geography and commodity type. This is a highly simplified assumption that ignores the variability in potential removals between different geographies, climates, production systems and commodity types. Although there is a growing body of work on the subject of agricultural soil carbon sequestration, there is still a large amount of uncertainty in the most widely used methods for determining changes in soil organic carbon.[5] Until further consensus and alignment is reached in the context of soil carbon sequestration, a consistent and simplified approach is considered in this assessment.

The total hectare value also represents a potential limitation to the tool, as it is dependent on a best-case scenario where every possible hectare in production is transformed using improved agricultural practices and the use of biochar to sequester carbon in soil. Roe et al. (2019) consider removals on 407 Mha of land by 2050 which represents a more ambitious per hectare removals target (see Roe et al.'s Table 5, Supplementary Material) than that which is considered here. The approach of considering a removals intensity based on the total amount of removals needed and

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[5] Potential source: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_05_Ch5_Cropland.pdf

the total amount of cultivated land, results in lower removals on a per hectare basis. In this way, the total mitigation is spread over more hectares, which may be more appropriate due to the variability of potential carbon sequestration in agricultural soils (Zomer et al. 2017), as well as considerations of permanent storage in the soil. The limitation in either approach is the uncertainty related to how many hectares can be realistically used for carbon removals, and how much carbon removal can be realistically achieved per hectare.

4.2.2. Permanence

Lastly, our approach assumes the sequestration that is achieved each year by soil and biochar is permanently removed from the atmosphere. Permanent removal is required to achieve the pathway. In reality, as there is no guarantee of permanent storage, it is possible that carbon sequestered in the soil in one year may be emitted in the future. However, as this tool is intended to be used for target setting, users of the tool will need to comply with GHG Protocol guidance to ensure or otherwise account for lack of permanence associated with these removals.

5. TIMBER AND WOOD FIBER COMMODITY PATHWAY

5.1. Methodology

5.1.1. Introduction

The goal of this work was to use newly available forest data to create an emissions baseline, both direct and LUC emissions, as well as develop a mitigation pathway that also considers removals for the timber and wood fiber commodity. The development of a quantitative commodity pathway for timber and wood fiber built on prior qualitative efforts present in the previous version of the PBL tool (Smith et al. 2016). A global pathway for timber and wood fiber commodity has been integrated into the latest version of the PBL tool using the methodology described below.

The integration of the timber and wood fiber commodity in the PBL tool is based on creation of five datasets:

- projections of industrial roundwood production until the year 2050,
- regionalized yields of industrial roundwood,
- direct emissions from forestry operations from cradle-to-gate,
- land-use change emissions allocated to this commodity, and
- a target value for carbon removal allocated to improved forest management.

5.1.2. Projections of industrial roundwood production

Industrial roundwood (IRW) includes all roundwood except wood fuel harvested and removed from forests and trees outside the forest (FAO 2021). Industrial roundwood (wood in the rough expressed in m³ of solid volume under bark) includes sawlogs, veneer logs, pulpwood and others (e.g. used for poles, piling, posts, fencing, wood wool, shingles and shakes, tanning, etc.). As the tool users may not be familiar with the term industrial roundwood, the tool refers to the commodity as "timber and wood fiber."

5.1.3. Modelling

The production volume forecast was estimated using the economic equilibrium model, Global Forest Products Model (GFPM) (Johnston et al. 2019), and the conservative shared socioeconomic pathway (SSP2). The GFPM simulates the evolution of the global forest sector by calculating successive yearly market equilibriums by maximizing a quasi-welfare function, as given by the sum of consumer and producer surpluses net of transaction costs. The model computes the market equilibrium, subject to a number of economic and biophysical constraints, including a market-clearing condition which states that the sum of imports, production, and manufactured supply of a given product in a given country must equal the sum of end-product consumption, exports, and demand for inputs in downstream manufacturing. The successive yearly equilibria of the GFPM were linked to reflect country-specific demographic and economic growth in accordance with the IPCC SSP2 (Jonhston et al. 2019).

In the PBL tool the forecast is based on the five-year interval results from the GFPM model scenario SSP2. The data were extrapolated using a linear regression to calculate the annual forecasts of 181 countries to estimate the global average volume production from 2020 to 2050.

5.1.4. Regionalized yields of industrial roundwood

The calculation of timber and wood fiber yield is more complex than that of agricultural crops. The main reason is the large range of rotation lengths (i.e., time between two harvests), a high number of sourcing species and a higher disparity among the forestry managements (e.g. between intense plantation vs naturally managed).

Forest plantations with industrial purposes are composed of fast-growing and high-yielding tree species (e.g. eucalyptus) and intensively managed plantations with slow-growing species and longer rotation cycles (e.g., teak) (Jürgensen et al. 2014). Forest plantation yields depend on the intensity and quality of the management, growing conditions, and tree species. For example, eucalyptus species can present yields ranging between 12-25 m^3/ha year in South America, South Africa and Australia (Brown 2000), and even higher yields can be observed in some African countries (Brown 2000). Another important factor influencing the yield is the rotation period, i.e. time between major harvests under clear-felling and replanting systems. Moreover, the rotation length varies in function of several factors such as growth rates which are determined by the site productivity, species, silviculture, the desired wood and fiber properties, site constraints, socioeconomic aspects and profitability (Brown 2000). For instance, teak rotation lengths vary from 40 to 90 years (Pandey et al. 2000). Therefore, due to the high variability in yields and rotation lengths, it is challenging to define an average yield at the global and regional scales. This source of uncertainty should be considered when using LUC emissions allocated to m^3 of timber and wood fiber.

The average yields and rotation lengths in the tool were estimated based on literature review and forestry reports. When detailed information of the share of species used in plantations and non-plantations was available, the average rotation lengths were weighted in function of the share of species. Otherwise, general rotation lengths defined according to climate region (boreal, temperate, tropical) and wood type (hardwood, softwood) were used (Arets et al. 2010). Particular effort was given to define the rotation lengths and yields of the top producers of IRW (namely, Canada, Brazil, USA and Russia). The resulting LUC emissions and the chosen yields in tree plantations are presented in Table 3.

Table 3: LUC emissions and yields used for timber and wood fiber

Image region	**LUC emissions per ha**	**Yield**	**LUC emissions per m^3**		**Regional production 2015**
	kg CO_2eq/(ha.yr)	m^3/ha yr	kg CO_2eq/m^3	t CO_2eq/m^3	1000 m^3 IRW
Brazil	**2,470**	**18.2**	**136**	**0.136**	**136,177**
Canada	**543**	**3.80**	**143**	**0.143**	**151,358**
Central America	22,056	8.20	2690	2.690	4,472
Central Asia	382	2.33	164	0.164	118
Central Europe	**229**	**6.52**	**35.1**	**0.035**	**108,632**
China region	**1,999**	**4.65**	**430**	**0.430**	**148,864**
Eastern Africa	6,023	**10.4**	579	**0.579**	11,580
India	0.00	**5.35**	0.00	**0.000**	49,517
Indonesia region	**1,679**	**9.85**	**170**	**0.170**	**78,081**
Japan	1.27	2.80	0.45	0.000	21,258
Korea region	224	4.65	48	0.048	4,540
Mexico	764	13.7	56	0.056	5,353
Middle East	20.2	N/A	N/A	N/A	600
Northern Africa	171	15.6	11	0.011	1,304
Oceania	245	19.7	12	0.012	59,032
Rest of South America	**21,569**	**16.4**	**1316**	**1.316**	**81,030**
Rest of South Asia	739	6.00	123	0.123	7,062
Rest of Southern Africa	5'948	9.56	622	0.622	10,372
Russia region	**1,238**	**2.14**	**579**	**0.579**	**190,628**
South Africa	3.60	11.5	0	0.000	15,284
Southeastern Asia	3,262	6.0	544	0.544	49,888
Turkey	181	3.46	52	0.052	20,008
Ukraine region	33.5	2.80	12.0	0.012	19,539
USA	**121**	**8.23**	**15**	**0.015**	**354,678**
Western Africa	25,486	10.4	2451	2.451	35,293
Western Europe	**2,904**	**6.52**	**445**	**0.445**	**259,621**
in **bold** top IRW producers in 2015					

5.1.5. Non-LUC emissions (direct emissions from forestry operations)

5.1.5.1. Context

Non-LUC emissions associated with timber and wood fiber are all emissions related to forestry operations, site preparation and management. Emission factors related to forestry activities vary largely depending on:

- Forest management: e.g., use of fertilizers in plantations and frequency of thinning, thus amount of fuel used for machinery.
- Forestry operations also depend on topography and site conditions: e.g. different emissions depending on the share use between manual chainsaw and mechanization. Also, depending on the type of mechanization, skidder/forwarder, cable yarding or helicopter.
- Forest species that influence all the factors mentioned above as well as yield.

Defining a global or regional average non-LUC emission factor is challenging due to the lack of regionalized and species-specific emission factors for roundwood and inconsistencies among available emissions that have been reported.

5.1.5.2. Functional unit and system boundary

The functional unit considered is 1 m^3 of fresh roundwood under bark. The emission factor is allocated to the total rotation length. The system boundary considered is cradle-to-forest road, including soil preparation, seedling plantations (including nursery), forest management (e.g. fertilization) and forest operations (e.g. thinning). Any secondary transportation (hauling) to the mill was excluded as the distance can vary largely.

5.1.5.3. Data sources and processing

The emission intensities of 1 m^3 of timber production were calculated using default values from Ecoinvent datasets and species-specific values retrieved from literature. An exhaustive literature review was performed to search for species- and site-specific emissions factors that would also differentiate between intensive (plantations) and extensive (naturally managed) forest managements. The share of softwood and hardwood per country was retrieved from FAOSTAT (FAO 2017). The share in type of wood allowed the calculation of weighted average emissions of different regions that was used to obtain the global average. The final emission intensity of the baseline year 2015 was calculated by dividing the emission factor (kg CO_2 eq/ fresh m^3) by the rotation length (years) obtained from literature review. In order to calculate the trend of emission factor intensity in the future it was assumed that the intensity of timber and wood fiber commodity will evolve similarly to the crop commodities calculated in the IMAGE model.

5.1.6. LUC calculation method

LUC emissions associated with deforestation are attributed to timber and wood fiber using the same approach as for other commodities (Section 3). Tree cover loss at the country-level, based on statistical data from FAOSTAT, is aggregated at a global scale and attributed to the land use area expansion trends associated with timber and wood fiber. The expansion rate is calculated using planted forest area from FAOSTAT. This simplification ignores forestry production coming from naturally or semi-naturally growing forests, and hence does not fully cover the complexity of forestry systems.

In order to allocate LUC emissions (CO_2 ha^{-1} a^{-1}) per m^3 industrial roundwood, the value is divided by country-specific yield ($m^3 ha^{-1}$ a^{-1}). The difference between the LUC approach applied for the other commodities and that of timber and wood fiber lies in the yield estimation.

5.1.7. Carbon removals pathways for timber and wood fiber

The carbon removals pathway for timber and wood fiber was based on the approach explained in Section 4. Similarly to other commodities, a linear pathway was used based on the **target emissions removals of 30 $GtCO_2$** by 2050 from improved forestry management suggested by Roe et al. (2019). In other words, removals resulting from optimizing rotation lengths and biomass stocks, reduced-impact logging, improved plantations and certification. As done for the other emissions, removals were calculated at the country level using the land use estimates based on country-level production and yield data, and then aggregated at global scale as needed. The yield was calculated following the approach described in Section 5.1.4 with the difference that for removals we use the average yield of roundwood including all forest managements (i.e., plantations, clear-cut and selective logging). The global yield was then multiplied by the total world production of industrial roundwood in the year 2050 to estimate the available land area (i.e. 555 ha). The removals intensity per hectare for each year from 2020 to 2050 was calculated by dividing the total yearly removals by the total land area and then assigned on a per m^3 basis using region specific yields. The region-specific removals were aggregated to obtain the global value presented in the tool.

5.2. Limitations

The limitation of the current version of the tool is the high uncertainty of the LUC estimates due to the use of average yields at a global scale which do not cover the complexity of forestry systems. Roundwood yields vary according to management intensity, growing conditions (e.g. climate and soil properties), tree species and rotation lengths; thus, defining an average yield is challenging. Statistical tree cover loss data also has limitations as satellite imagery becomes more readily available and is more representative in capturing actual forest loss globally (i.e. where and how much forest has been lost). Using spatial data at higher resolution of tree cover loss, tree cover change, forest stand age, and fraction between types of forests will better estimate yield and LUC in the future.

6. SUMMARY OF KEY RECOMMENDATIONS

The following is a summary of key recommendations for **future improvements** that could be integrated into the PBL tool to even better estimate FLAG commodity specific pathways:

1. LUC impacts from peat degradation were not explicitly included in the tool and can be added in future versions.

2. Soybean and palm oil production share the same pathway in the tool given the data disaggregation available in the IMAGE IAM. Disaggregation could be a part of future work.

3. The two major sources of uncertainty for animal products could be reduced by a) refining the geographic breakdown of the feed baskets using FAO GLEAM to expand regions beyond those found in the IMAGE model and b) implementing feed conversion efficiencies across 50 ingredient categories found in FAO GLEAM or another resource.

4. The current tool sets target carbon removals as constant across agricultural land on a per hectare basis regardless of commodity or region. Future refinements could introduce carbon removal diversity by using commodity, geography, or climate specific estimates.

5. High resolution spatial data of tree cover loss, aboveground biomass, and forest type breakdown to better estimate timber and wood fiber yield and LUC is underway and will be incorporated into a future tool.

6. Production data, including land use, was sourced from reliable sources such as FAO across all commodities for a given period to both establish a baseline and extrapolate trends into future years. Regular updates of these data are warranted as the they become available.

7. The carbon removals pathway focuses on soil carbon sequestration due to land management changes, operating under the assumption that carbon stocks from vegetation remain relatively similar. This approach could be further refined by introducing vegetation carbon stock variation in response to land use management practices; as well as potentially introducing other types of land use change into the assessment – such as the shift from annual to perennial cropping systems – that could potentially increase carbon stocks in vegetation and therefore offer another carbon removals option.

Prepared by: Vincent Rossi (Quantis) • Paula Sanginés de Cárcer (Quantis) • Chris Casolaro (Quantis) • Alexi Ernstoff (Quantis) • Tetyana Pecherska (Quantis)

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8. APPENDICES

8.1. A1. Data setup for oil crops

For the purpose of this project, IMAGE-compatible pathways for the production of soybeans and palm oil are required. Because soybeans are often traded as beans and not as oil, soy was left as a harvested product, whereas palm which is typically traded as oil was converted from harvested palm bunches to oil.

The available data for oil crops from the IMAGE model, as present in the initial version of the PBL tool, are assumed to represent unprocessed, harvested product. This assumption was tested by comparing IMAGE with FAO data: Figure A1-1 shows that the IMAGE total matches well the FAO data for the total unprocessed oil crops in 2005. However, it largely underestimates the total in 2018 which barely covers the total of soybeans and oil palm fruits.

Given the discrepancies between IMAGE and FAO data, for consistency with the tool, this project uses the IMAGE data for 2019 as the total for soybeans and palm oil fruit yet splits this value between the two crops according to the FAO regional proportions in 2019 (proportionally split at world level 45% for soybeans and 55% for oil palm fruit). It is assumed both crops follow the same production pathway as projected by IMAGE for oil crops in general. This assumption was tested by comparing the relative worldwide market competition (Figure A1-2), which shows no clear pattern or trend of market competition between these two crops.

- For soybean, unprocessed product data as provided by the IMAGE model, and split proportionally as described above, were used.
- For palm oil, like soybean, unprocessed product data, split proportionally, are used. Additionally, the regionalized oil extraction rate, calculated using the palm oil plus the palm kernel oil production, and palm fruit production in each IMAGE region (2018 FAO data[6]) is used.

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[6] Crude kernel palm oil data were not available for 2019, hence extraction rates have been calculated with 2018 data.

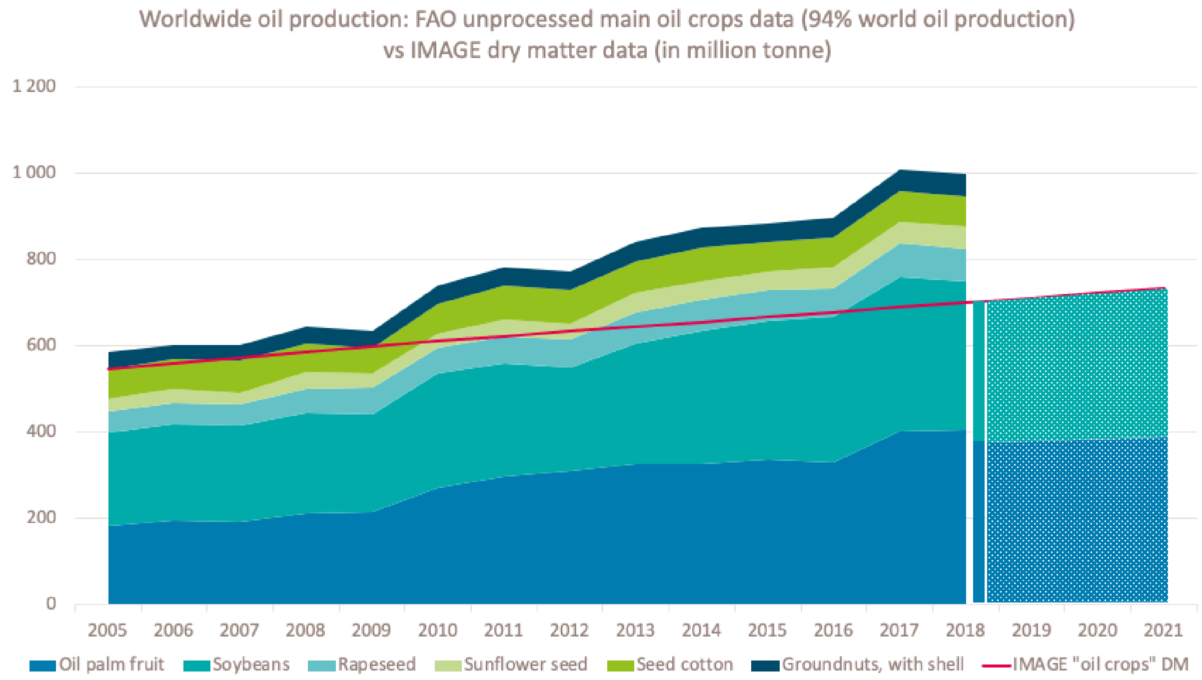

Figure A1-1: FAO data for unprocessed oil crops 2005 – 2018 and IMAGE data for oil crops 2005 – 2021. On the right of the chart, the proportions taken from FAO between soy and palm are conserved and are extrapolated according to IMAGE data (until 2050, not shown).

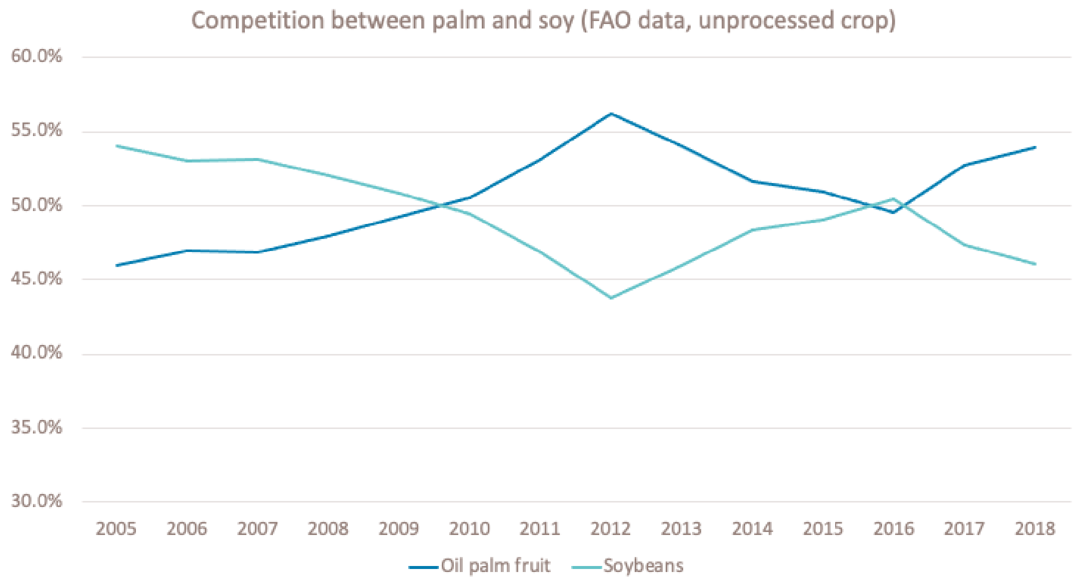

Figure A1-2: Trend of the worldwide production of soy and palm fruit (100% is the sum of the two)

Table A1-1: Regional split

IMAGE region	Oil palm fruit production 2019 (t)	Soybeans production 2019 (t)	Total for both crops (t)	% palm	% soy	OER 2018
Brazil	2 583 293	114 269 392	116 852 685	2.21%	97.79%	18.8%
Canada		6 045 100	6 045 100	0.0%	100.0%	0.0%
Central America	7 090 959	64 193	7 155 152	99.1%	0.9%	29.4%
Central Asia		295 905	295 905	0.0%	100.0%	0.0%
Central Europe		1 756 239	1 756 239	0.0%	100.0%	0.0%
China region	665 925	15 728 776	16 394 701	4.1%	95.9%	32.4%
Eastern Africa	109 675	183 179	292 854	37.5%	62.5%	22.2%
India		13 267 520	13 267 520	0.0%	100.0%	0.0%
Indonesia region	248 314 965	940 000	249 254 965	99.6%	0.4%	18.7%
Japan		217 800	217 800	0.0%	100.0%	0.0%
Korea		369 260	369 260	0.0%	100.0%	0.0%
Mexico	1 194 210	232 680	1 426 890	83.7%	16.3%	13.3%
Middle East		162 130	162 130	0.0%	100.0%	0.0%
Northern Africa		44 696	44 696	0.0%	100.0%	0.0%
Oceania	308 949	15 136	324 085	95.3%	4.7%	11.7%
Rest of South America	12 173 629	69 762 759	81 936 388	14.9%	85.1%	21.1%
Rest of South Asia		144 735	144 735	0.0%	100.0%	0.0%
Rest of Southern Africa	356 391	551 692	908 083	39.2%	60.8%	21.4%
Russia region		4 361 984	4 361 984	0.0%	100.0%	0.0%
South Africa		1 170 345	1 170 345	0.0%	100.0%	0.0%
Southeast Asia	116 497 101	447 156	116 944 257	99.6%	0.4%	21.8%
Turkey		150 000	150 000	0.0%	100.0%	0.0%
Ukraine region		3 762 949	3 762 949	0.0%	100.0%	0.0%
USA		96 793 180	96 793 180	0.0%	100.0%	0.0%
Western Africa	21 401 595	1 147 406	22 549 001	94.9%	5.1%	14.0%
Western Europe		1 787 480	1 787 480	0.0%	100.0%	0.0%
World total	410 696 692	333 671 692	744 368 384	55%	45%	19.7%

The following charts illustrate how IMAGE data and FAO data may diverge in certain cases. To maintain consistency with data used to model production of all other agricultural commodities in the tool, the IMAGE data was prioritized despite some observed inconsistencies with FAO data.

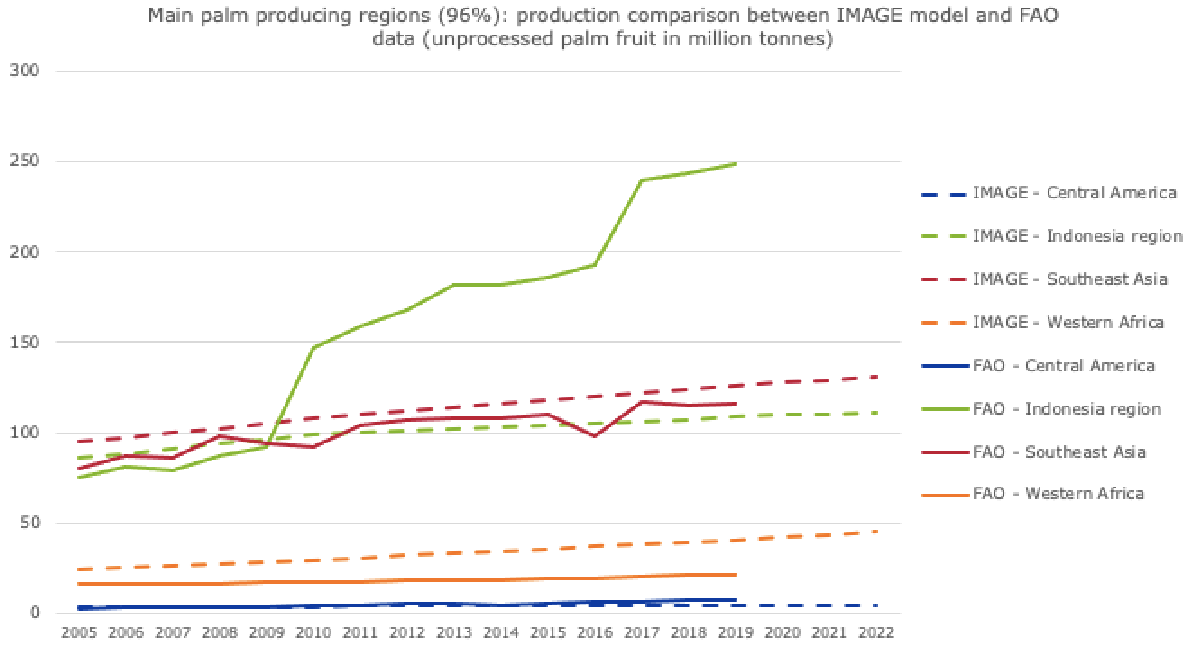

Figure A1-3: Comparison of IMAGE 3.0 data and FAO data for the major palm producing regions

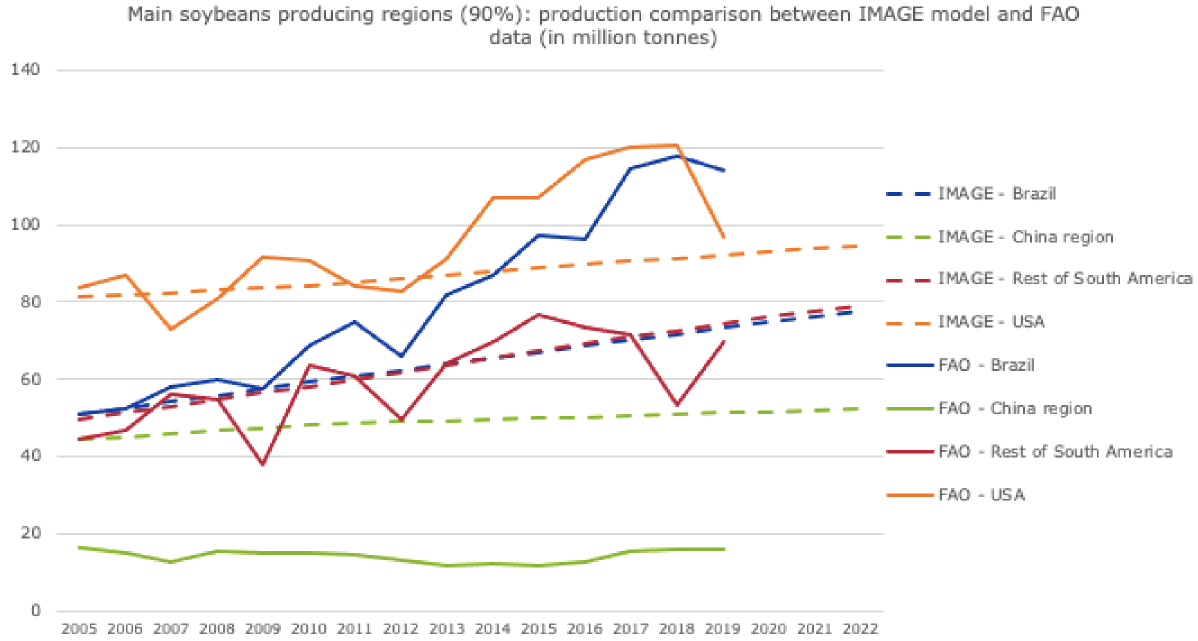

Figure A1-4: Comparison of IMAGE 3.0 data and FAO data for the major soybeans producing regions

8.2. A2. IMAGE regions and correspondence

Table A2-1: Regions correspondence between IMAGE, Doelman and GLEAM

IMAGE region	Doelman region	GLEAM region
Canada	OECD	NA
USA	OECD	NA
Mexico	Latin America	NA
Central America	Latin America	LAC
Brazil	Latin America	LAC
Rest of South America	Latin America	LAC
Western Europe	OECD	WE
Central Europe	OECD	EE
Ukraine region	Russia/Middle East	EE
Turkey	Russia/Middle East	NENA
Northern Africa	Russia/Middle East	NENA
Western Africa	Sub-Saharan Africa	SSA
Eastern Africa	Sub-Saharan Africa	SSA
South Africa	Sub-Saharan Africa	SSA
Rest of Southern Africa	Sub-Saharan Africa	SSA
Russia region	Russia/Middle East	RUS
Central Asia	Russia/Middle East	NENA
Middle East	Russia/Middle East	NENA
Southeast Asia	South/SouthEast Asia	ESEA
Indonesia region	South/SouthEast Asia	ESEA
India	South/SouthEast Asia	SA
Rest of South Asia	South/SouthEast Asia	SA
China region	China	ESEA
Korea	OECD	ESEA
Japan	OECD	ESEA
Oceania	OECD	OCE

8.3. A3. LUC weighting factors

Table A3-1: linear weighting factors

Years before assessment	Weight
21 or more	0.00%
20	0.25%
19	0.75%
18	1.25%
17	1.75%
16	2.25%
15	2.75%
14	3.25%
13	3.75%
12	4.25%
11	4.75%
10	5.25%
9	5.75%
8	6.25%
7	6.75%
6	7.25%
5	7.75%
4	8.25%
3	8.75%
2	9.25%
1	9.75%
0	0.00%
No LUC is considered for the assessment year, since no legacy is known yet for what is considered the present.	

8.4. A4. Ingredients used in feed baskets and corresponding GLEAM ingredients

Table A4-1: GLEAM ingredients that are included in the simplified feed categories

Simplified feed basket ingredient	GLEAM ingredient
Grass	Hay
	Fresh grass (pasture)
	Grass and leaves (local)
	Leaves
Fodder crop	Cassava (local)
	Cassava (non-local)
	Fodder beet
	Legumes and silage
	Pulses (local)
	Pulses (non-local)
	Pulses straw
	Pulses straw (local)
	Rapeseed (non-local)
	Rapeseed meal (non-local)
By-product	Banana residues
	Bran
	Crop residues
	Dry by-product grain industries (local)
	Dry by-product grain industries (non-local)
	Molasses
	Molasses (non-local)
	Pulp
	Sugarcane tops
	Sugarcane tops (local)
	Swill
	Wet distilleries grain
Maize	Maize (local)

	Maize (non-local)
Soy	Soybean (local)
	Soybean (non-local)
	Soybean meal (local)
	Soybean meal (non-local)
Wheat	Wheat (local)
	Wheat (non-local)
Cereal	Barley (local)
	Barley (non-local)
	Grains
	Millet (local)
	Millet (non-local)
	Rice (local)
	Rice (non-local)
	Sorghum (local)
	Sorghum (non-local)
Oilseed meal	Cottonseed meal (local)
	Cottonseed meal (non-local)
	Oilseed meal (local)
	Oilseed meal (non-local)
	Oilseed meals
	Palm kernel cake (non-local)
Other	Complements (amino acids, minerals) (non-local)
	Fishmeal (non-local)
	Limestone

8.5. A5. Data input validation and thresholds regarding data acceptability

The quality of users' data inputs is key to obtaining valid results from the tool. Regarding LUC and non-LUC emissions inputs, eight cases where validation and thresholds are relevant are reported and outlined in the table below.

Table A5-1: Data input validation and thresholds regarding data acceptability

#	Total Emissions known?	Non-LUC emissions known?	LUC emissions known?	Decision
1	N	N	N	Default non-LUC and LUC
2	Y	N	N	Total is split into non-LUC and LUC according to proportions of default non-LUC and LUC values. **Threshold warning message** If non-LUC < 0.5 default non-LUC If LUC < 0.5 default LUC
3	N	Y	N	Default LUC relative to non-LUC added and incorporated into total.
4	N	N	Y	Default non-LUC relative to LUC added and incorporated into total.
5	Y	Y	(Y)	**Threshold warning message** If LUC < 0.5 default LUC
6	Y	(Y)	Y	**Threshold warning message** If non-LUC < 0.5 default non-LUC
7	(Y)	Y	Y	N/A
8	Y	Y	Y	**Error** message if total is not equal to sum of non-LUC and LUC entered.
In all cases, check values. For non-LUC, if input value is not within the range 33% - 150% of the default, **threshold warning message** will arise. For LUC, range is 20% - 200%				