SCIENCE BASED TARGETS

DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

PARTNER ORGANIZATIONS

CDP DISCLOSURE INSIGHT ACTION

United Nations Global Compact

WORLD RESOURCES INSTITUTE

WWF

FOREST, LAND AND AGRICULTURE SCIENCE BASED TARGET-SETTTING METHODS ADDENDUM

September 2022

FLAG COMMODITY PATHWAYS

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).

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.

FLAG SECTOR PATHWAY

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) – 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

TABLE OF CONTENTS

1 INTRODUCTION

The SBTi Forest, Land and Agriculture (FLAG) Guidance allows companies to set mitigation targets specifically related to their land emissions. Agriculture, forestry and other land uses (AFOLU) are both a major driver of global greenhouse gas emissions and an important carbon sink. This Methods Addendum describes in detail the methods used to design and refine the 11 commodity pathways that are available for corporate use under FLAG.

Agricultural commodities represent a significant share of land use. Most of these emissions and removals are related to how land is managed (e.g., fertilizer use and tillage) and how land use is changed over time (e.g., from a primary or secondary forest to a farm).

PBL Netherlands Environmental Assessment Agency and Ecofys (Smith et al., 2016) developed a method 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 together cover over 50% of global GHG emissions from the AFOLU sector (Smith et al., 2016). This tool was built on pathways based on updated Marginal Abatement Cost Curves and simulations in the Integrated Model to Assess the Global Environment (IMAGE 3.0) of SSP2 scenario (van Vuuren et al., 2014; O'Neill et al., 2014).

The FLAG project updated the Smith et al. (2016) pathways to add needed emissions categories, mitigation categories, and commodity pathways. The methods associated with the below additions are the focus of this methods addendum:

1. Develop commodity-specific **land use change (LUC) mitigation pathways** for nine key agricultural commodities for the SBTi FLAG project: beef, chicken, dairy, maize, palm oil, pork, rice, soy, and wheat. Incorporate LUC values into existing commodity pathways (Section 3).

2. Include soil carbon sequestration as a **mitigation option across commodity pathways** (Section 4). Incorporate soil carbon sequestration mitigation in the commodity pathways.

3. Using newly available forest data, create a baseline for emissions and removals associated with timber & wood fiber. Incorporate **timber & wood fiber** alongside the other commodity pathways (Section 5).

4. Building on the beef commodity pathway, construct a new commodity pathway for **cattle hides (leather)** and incorporate it alongside the other commodity pathways (Section 6).

2 FLAG COMMODITY PATHWAY BACKGROUND

2.1. Introduction

The FLAG commodity pathways are based on an assessment of mitigation pathways for agricultural commodities (Smith et al., 2016). These pathways were built from the IMAGE 3.0 Integrated Assessment model (Stehfest et al., 2014), using the SSP2 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 a 1.5°C compliant tool for FLAG target setting because for agriculture, the 1.8°C and 1.5°C mitigation outcomes in Integrated Assessment Models are aligned.[1]

The assessed commodities included in the FLAG commodity pathways are the following:

- Beef
- Chicken
- Dairy
- Maize
- Palm oil
- Pork
- Rice
- Soya
- Wheat
- Cattle hide (added in this release)
- Timber & wood fiber (added in this release)

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

The IMAGE 3.0 model includes 26 regions of the world with specific mitigation pathways which are included for target setting in the FLAG commodity tool. See Appendix *A2. IMAGE regions and correspondence* for additional detail.

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

---

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

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

3 LAND USE CHANGE MITIGATION PATHWAYS

3.1. Methods

3.1.1. Introduction

Land use change (LUC) refers to a shift from one land use class to another. The LUC that is specifically targeted for addition to the FLAG commodity pathways 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 commodity in available data. Peat degradation, which may not always be categorized as a land use change in cases when continued management has been occurring on peatland, is also not considered in the current assessment.

LUC impacts and mitigation pathways were determined across 10 commodities and 27 geographies – including 26 regions and 1 global pathway. (LUC is considered separately for timber & wood fiber and is described in Section 5.) 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 20-year emissions allocation calculation is explained in Section 3.1.6.

3.1.2. Land use data

FAOSTAT land use data[3] were used for primary and naturally regenerated forests to assess forest loss between 1995 and 2015 using the data published in 2017. 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 livestock or 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.

3.1.3. Land use data for livestock and animal products

3.1.3.1. <u>Feed baskets</u>

The uncertainty in assessing LUC related to livestock feed baskets is high, with large variations even at the local level. Calculations for the FLAG commodity pathways are at a level

---

[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.

that captures the regional magnitude of LUC, focusing on key commodities and allowing 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 outlined in Table 1 and detailed in Appendix *A4. Ingredients used in feed baskets and LUC impacts associated with ingredients,* table A4-1. This simplification was needed to estimated land occupation. Future revisions could consider further refining land occupation associated with each of the GLEAM feed basket ingredients, although this refinement is unlikely to significantly change results.

The feed baskets associated with animal products, per region, are provided in the appendix tables A4-2 to A4-5.

Table 1: 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 with agricultural or food industry by-products (considered of low value, hence not driving the activity)
Maize	No notes
Soy	Includes soybean meal. In Europe contains 30% Brazilian soy.
Wheat	No notes
Cereal	Other cereals apart from those mentioned above
Oilseed meal	Allocation between oil and meal is based on economic value
Other	No impact associated (mostly non-agricultural products, e.g.: salt)

Animal feed baskets contain commodities that are also assessed in the tool independently. That is, 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 will be used 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 was 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. The conversion efficiencies provided by Doelman (2018) were used to calculate the DMI required per kg of animal product. These values were used together with the feed basket data to obtain the quantity of feed ingredient per kg of animal product.

The DMI required per kg of animal product, per region, is provided in the appendix tables A4-2 to A4-5.

With the quantity of feed ingredient as an input, 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), see following equations.

$$Land\ use_{feed\ ingredients} = \frac{1}{yield_{\ feed\ ingredient}}$$ Equation 1

$$Land\ use_{beef} = \sum \quad Land\ use_{feed\ ingredients\ including\ grass\ for\ pasture\ and\ hay}$$ Equation 2

$$Yield_{\ beef} = \frac{1}{Land\ use_{beef}}$$ Equation 3

Land use data associated with the feed basket and hence with 1 kg of animal product is needed to calculate LUC 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

LUC is calculated using the historical expansion method (method C as described by Smith et al. (2016)). This method considers statistical LUC for each crop or activity by attributing forest cover loss in the country proportionally to the area expansion rate of the crop or activity. This approach 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 the historical expansion approach serves as a good proxy for iLUC since it tends to capture the indirect effects of land demand. It is important to consider the market drivers of deforestation and avoid allocating an undue share of LUC impacts to smallholders who are expanding their land area into forest lands 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 per 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 LUC.

3.1.5. Deforestation impact calculation

Based on IPCC 2006 and 2019, deforestation impacts are calculated considering the following 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 based on FAO's Global Forest Resources Assessment 2015 (FAO, 2015).

After land use change, the same carbon pools have new values that are calculated based on the crop type and default land management parameters, and that are specific to each country, based Quantis International data as well as 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 undertaken for the weighted average of annual deforestation, which is already allocated to 1 ha of crop production for 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.

To estimate the regional deforestation-related emissions associated with livestock animal-based commodities (dairy, beef, pork, chicken), the feed basket composition and the related dry matter intake are multiplied by the deforestation impacts for animal feed ingredients provided in appendix table A4-6.

3.1.6. LUC reduction pathways

Deforestation causes GHG emissions (e.g., from soil) that can extend beyond the year when the forest's trees are cut down. There is a 20-year allocation rule deriving from IPCC practices and based on the GHG Protocol (WRI and WBCSD, 2014), which allocates deforestation and all LUC emissions over 20 years following a deforestation or LUC 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, so that emissions from deforestation are not carried past 2050; the data at which deforestation emissions end in alignment with Roe et al. (2019). The timing difference between deforestation and the related allocated emissions is illustrated in Figure 1.

Since there is not enough data resolution to calculate a reduction pathway for a specific crop-region combination that can be differentiated with sufficient certainty. The FLAG commodity pathways consider the same linear reduction rate for all commodities and for all regions, based on the emission pathway suggested by Roe et al. (2019).

The deforestation pathway is described below:

- Baseline = 2015 LUC value
- 25% reduction in 2020 (linear decrease)
- 100% reduction in 2030 (linear decrease)

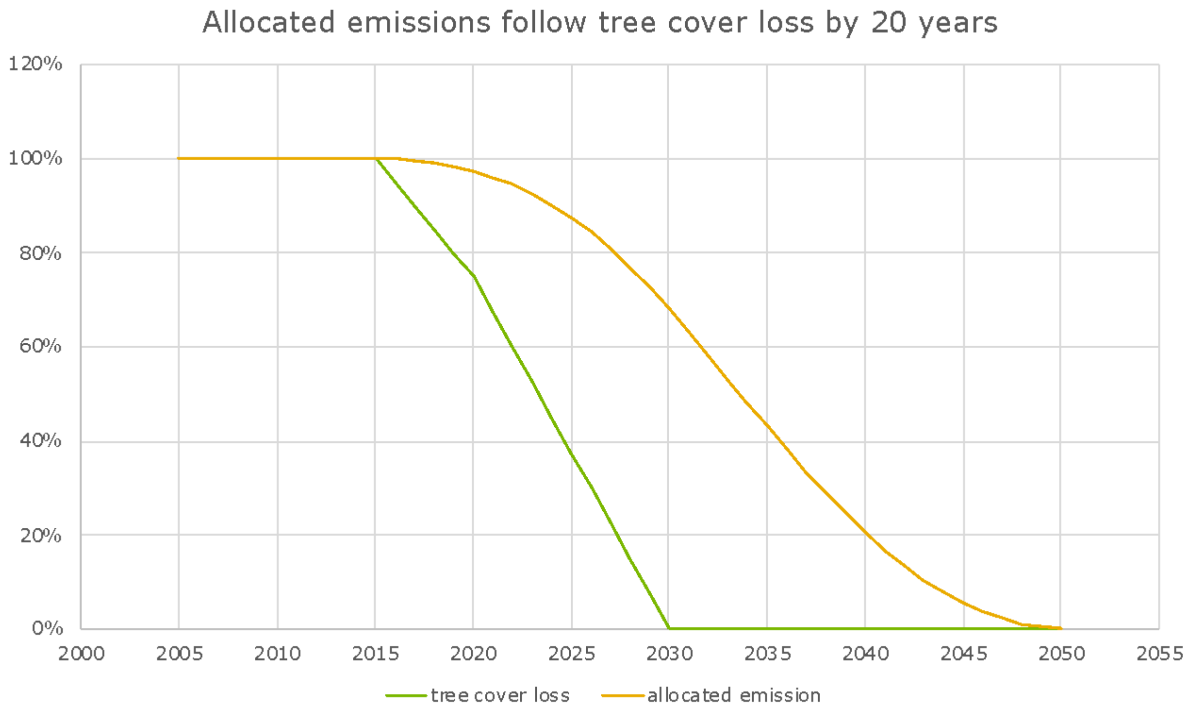

Figure 1: Deforestation and deforestation emission pathways

The deforestation emissions pathway is calculated from the deforestation pathway, using the 20-year allocation rule without discounting (hence equal allocation: 1/20th of the emissions related to deforestation event per year following the event).

In practice, the emissions reflect the sliding average of the tree cover loss over the 20 preceding years.

The reference deforestation emissions for a commodity i and a region r is calculated for 2015 and noted $DE_{ref, i, r}$

Mitigation factor for year y (assumed to be identical for all commodities and regions): MF_y

$$DE_{2022, i, r} = DE_{ref, i, r} * MF_{2022} \quad \text{Equation 4}$$

MF_y is the average of the tree cover loss intensity (green curve in figure above) of the 20 years before year y.

$$MF_y = \frac{\sum_{i=y-20}^{y-1} TC_i}{20} \quad \text{Equation 5}$$

See appendix A3 for values.

3.2. Limitations

Data variability

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 variable accuracy. Moreover, data definitions are occasionally subject to realignment, causing abrupt changes in data time series that are not actual changes in the field but can be interpreted as such when calculating LUC. Despite careful review of the results, LUC results will reflect the inconsistencies present in the FAO source data.

LUC reference year

Because the 2020 forestry data were not released at the time of realization of this method (FAO's Forest assessment data are released every 5 years) and Roe et al. (2019) use a 2015 reference year to define mitigation pathways, the LUC data in the FLAG commodity pathways use a 2015 reference year. This leads to two limitations: 1) the LUC data do not include the latest data available and 2) any year after 2015 is treated as the future in the tool, even if the suggested reduction pathway has not been implemented.

sLUC in countries where forestry plays an important role

The statistical LUC method that has been used attributes deforestation to all types of crops and plantations whose area is expanding. In some countries where natural forests are converted to planted forests or plantations in large scale (leading to a lower carbon stock and contributing to forest-related CO_2 emissions), these conversion impacts are also attributed to other crops (e.g., cereals), despite a weak causality link. This methodological issue is well-known and will be corrected in future release, by more clearly separating forestry-related LUC from other agricultural activities.

Oil crop production projection to 2050

Soy and palm oil production are combined in one 'oil crop' pathway in the tool because of limited data resolution availability in IMAGE. Greater resolution for both soy and palm oil pathways can be updated in future versions as more data become available.

At the regional level, the IMAGE data for soybeans and palm oil tend to diverge from FAO data, especially for palm oil in Indonesia and soybeans in Brazil, where FAO production data far exceed IMAGE's projection data already in 2018.

This data divergence is acknowledged, but IMAGE data were kept intact 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 FAO-adjusted data.

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. The FLAG commodity pathways consider each commodity individually and thus do not directly address burden shifting.

Feed baskets and conversion efficiency

There are two 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 nine 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.

4 CARBON REMOVALS FOR COMMODITY PATHWAYS

4.1. Methods

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 model review by Roe et al. (2019) forms the basis for the FLAG sector tool and is the most comprehensive source of data available at the time of tool development. The mitigation pathway set out by the authors includes, but is not limited to, the potential emissions and removals from afforestation, reforestation, sustainable forestry, agricultural emissions reductions, and agricultural soil carbon sequestration.

The carbon removals pathway implemented in the FLAG commodity tool focuses specifically on the potential of soil carbon sequestration and the use of biochar to globally remove 32 Gt of CO_2e from the atmosphere between 2020 and 2050 (see 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 separately in the timber & wood fiber pathway.

The procedure for translating a global carbon removal target into a commodity and region-specific removal intensity (i.e., considering removals that are relevant for the respective 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_2e (Figure 2). The tool divides this total over 30 years by using a linear annual rate of increase with a target of 1.3 Gt CO_2e/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 for the timber & wood fiber commodity is calculated separately and described in Section 5.1.7.

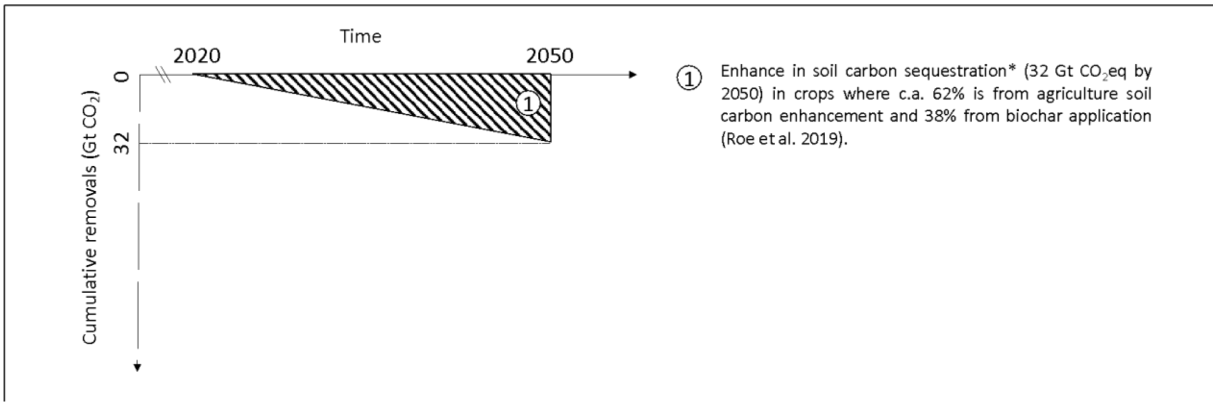

Figure 2: Cumulative removals in agriculture land from enhance in soil carbon sequestration from erosion control, use of larger root plants, reduced tillable, cover cropping, restoration of degraded soils and biochar amendments.*

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 was 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 (ton/hectare) for each commodity were multiplied by the total world production (in tons) 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 (Equation 6). This removals intensity is applied equally for all commodities in the FLAG commodity pathways (save timber & wood fiber) on a per hectare basis. As global removals increase linearly over time, the total removals per hectare also increase from 0.25 t CO_2e/ha in 2020 to 0.40 t CO_2e/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 (Equation 6). 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.

$$Removals\ intensity = \frac{((Global\ total\ (GtCO2e) * \frac{1000\ Mt}{1\ Gt})\ /\ Global\ total\ surface\ (Mha))}{Crop\ specific\ yield\ (t\ FW/\ ha)} \quad \text{Equation 6}$$

4.2. Limitations

Removals per hectare

As mentioned in Section 4.1.3, one limitation of 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 does not account for variability in potential removals between different geographies, climates, production systems and commodity types. Although there is a growing body of work on 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) considers 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 removals intensity based on the total amount of removals needed and 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 uncertainty related to how many hectares can be realistically used for carbon removals, and how much carbon removal can be realistically achieved per hectare.

Permanence

Last, this 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. Permanent storage is not guaranteed, and it is possible that carbon sequestered in the soil in one year may be emitted in the future. As the commodity pathways are to be used for target setting, users of the tool will need to comply with GHG Protocol guidance to ensure or otherwise account for permanence, leakage, and reversals associated with these removals.

---

[5] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch05_Cropland.pdf

5 TIMBER & WOOD FIBER COMMODITY PATHWAY

5.1. Methods

5.1.1. Introduction

The FLAG commodity pathways include a commodity pathway specific to timber & wood fiber, developed using newly available forest data to create an emissions baseline, both direct and LUC emissions, and to develop a mitigation pathway that also considers removals for timber & wood fiber. The development of a quantitative commodity pathway for timber & wood fiber builds on prior qualitative efforts presented in Smith et al., 2016, and further developments within the framework of Science Based Targets for Nature (see sections 5.1.3 and 5.1.4). A global pathway for the timber & wood fiber commodity has been integrated into the FLAG tool using the methods described below.

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

- Projections of industrial roundwood production from 2015 to 2050,
- Regionalized yields of industrial roundwood,
- Direct emissions from forestry operations from cradle-to-gate,
- Land-use change emissions allocated to timber & wood fiber, and
- A target value for carbon removal allocated to improved forest management.

5.1.2. Definitions

The timber & wood fiber commodity pathway draws on data on industrial roundwood (IRW), which 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 m^3 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 FLAG commodity pathway users may not be familiar with the term industrial roundwood, the pathway is referred to as "timber & wood fiber."

FAO (2020) includes under the definition of forest both “planted forests” and “plantation forests”, (Figure 2), the conversion of primary and secondary forests to planted forest is not considered land use change. However, for the purpose of implementing no-conversion supply chains & commitments (AFi, 2019), this type of conversion is accounted for as LUC and is addressed as such in the framework of the timber & wood fiber commodity pathway. Therefore, the “LUC emissions” calculated in the pathway are those resulting from the conversion of primary and secondary forests to planted forest (hereafter referred to as “conversion”).

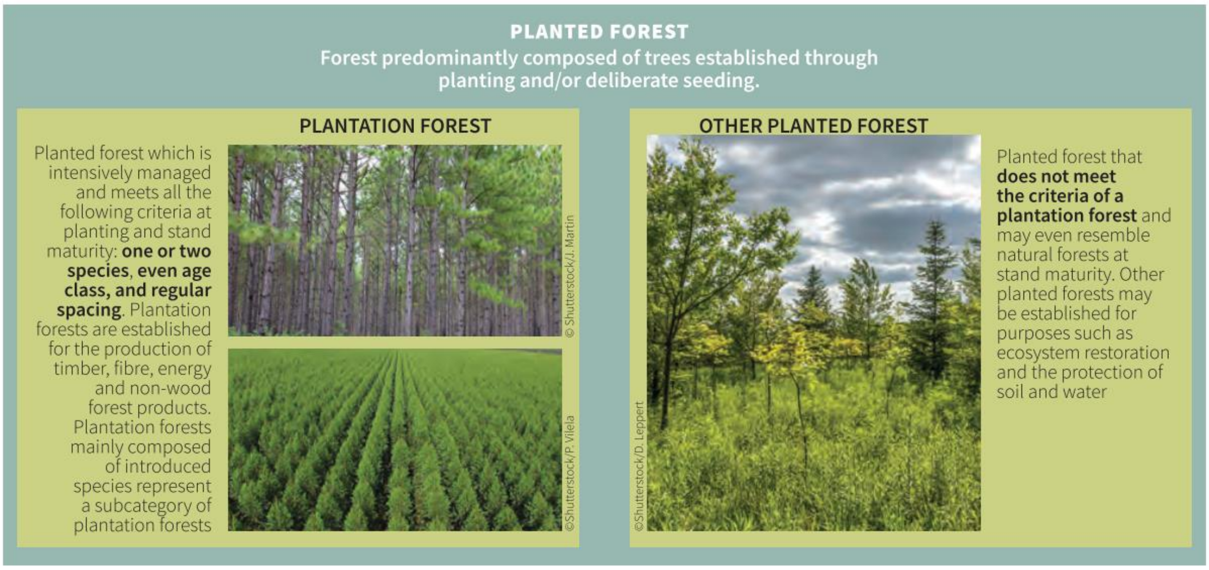

Figure 3: Definition of planted forest (FAO, 2020)

5.1.3. Modelling

Timber & wood fiber production volume was forecast using the economic equilibrium model, Global Forest Products Model (GFPM) (Johnston et al., 2019), and Shared Socioeconomic Pathway 2 (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 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 SSP2 (Jonhston et al., 2019).

In the timber & wood fiber commodity pathway, the production 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 & wood fiber yield is more complex than that of agricultural crops, primarily due to the large range of rotation lengths (i.e., time between two harvests), a high number of sourcing species, and higher variability among forestry management practices (e.g., between intense plantation vs naturally managed). Therefore, forest management systems, which include the type of harvest (e.g., clear cut or selective logging) and the type of regeneration (i.e. natural or planted), will yield different volumes of industrial roundwood per unit of area (Arets et al., 2011).

Forest plantations for 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 management, growing conditions, and tree species. For example, eucalyptus species can present yields ranging between 12-60 m^3/ha year (Brown, 2000; de Moraes Goncalves et al., 2013; Morales et al., 2015). Another important factor influencing yield is the rotation period, i.e., time between major harvests under clear-felling and replanting systems. Rotation length varies as a function of several factors including growth rates (which are determined by the site productivity, species, silviculture, the desired wood and fiber properties), site constraints, socioeconomic variables, and profitability (Brown, 2000). For example, teak rotation lengths vary from 40 to 90 years (Pandey et al., 2000). 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 conversion emissions allocated to m^3 of timber & wood fiber.

In the first version of the timber & wood fiber commodity pathway, the average yields in the timber & wood fiber commodity pathway were estimated based on literature review. In the second version, already updated, and within the framework of Science Based Targets for Nature, regionalized roundwood yields are estimated based on spatial data.

The spatial data used include:

- Aboveground live woody biomass density layer (Harris et al., 2021)
- Forest loss layer (terraPulse, 2021)
- Broadleaf cover layer (terraPulse, 2021)
- Needleleaf cover layer (terraPulse, 2021)
- Mixed cover layer (terraPulse, 2021)
- Forest management practices (Lesiv et al., 2021)
- Ecoregions layer (Olson et al., 2001)

Yields were estimated based on wood type, (i.e. hardwood and softwood, and management intensity). The forest managements considered are:

- **Naturally managed forests** under clear cut (temperate and boreal regions) or under selective logging (tropical regions);
- **Planted forests** that are managed and have rotation lengths beyond 30 years;
- **Short term plantations** intensively managed for timber and wood fiber with a rotation period of up to 30 years.

The detailed workflow used to estimate regionalized yields is included in Technical Documentation for the Commodity Assessment: Measuring Effects Land linked to the CAMEL Tool. The estimated yields were cross-checked with reference values retrieved from literature for the main species used for IRW (e.g., eucalyptus, pine species) and for the top producers (e.g., Canada, Brazil, USA and Russia). Values were in range and towards the lower end of the range from comparable data sources.

The yield estimations in the CAMEL Tool have a higher granularity than that required for the FLAG Tool, including higher granularity in terms of spatial resolution (10x10 km vs regional) and also in terms of management intensity and wood type (6 levels in CAMEL tool vs 1 level in Flag). To match the FLAG Tool format, yields were aggregated to obtain a final industrial roundwood yield for each IMAGE region (Figure 4). The roundwood yields were converted into industrial roundwood yields using the conversion factor 1.1 defined by the UK Forest Research

(2022).

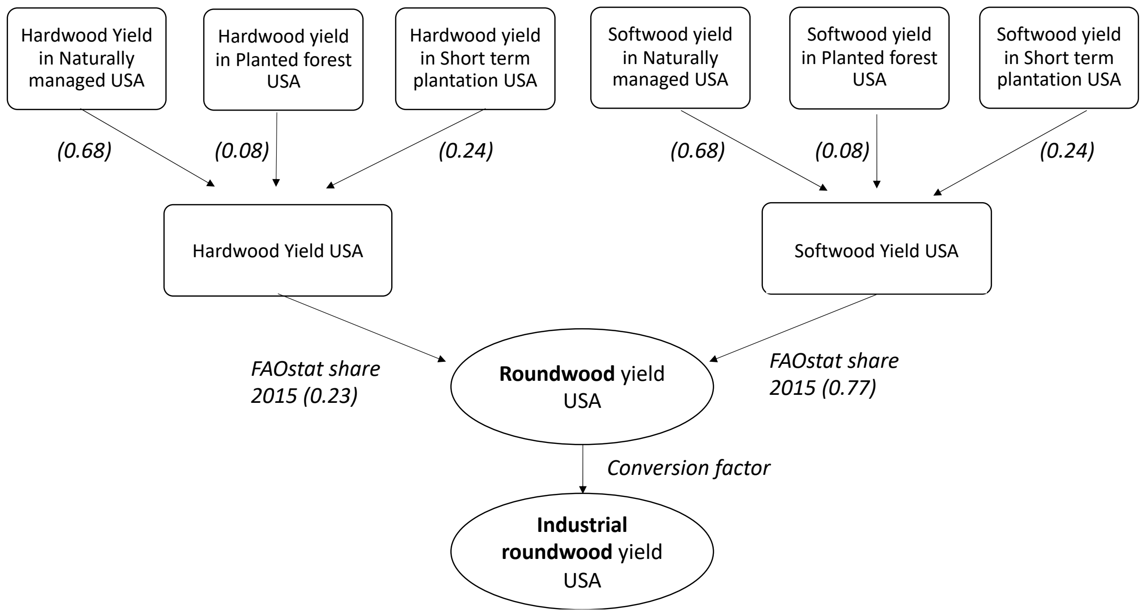

Figure 4: Example of the aggregation procedure of regionalized yields from CAMEL tool to FLAG Tool. The shares of managements are presented in the Technical Documentation of the CAMEL tool while the shares of hardwood and softwood were retrieved at national level from FAOstat (2015).

Two sets of yields were estimated for FLAG Tool. A yield considering all management practices used to estimate the land use for removals and another yield estimate based only on plantations used in LUC. The resulting conversion emissions and the estimated yields in planted forests are presented in Table 2.

5.1.5. Direct emissions from forestry operations

5.1.5.1. Context

Direct emissions associated with timber & wood fiber include all emissions related to forestry operations, site preparation and management, excluding LUC. Emission factors related to forestry activities vary largely depending on:

- Forest management: e.g., use of fertilizers in plantations and frequency of thinning, the amount of fuel used for machinery;
- 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;
- Tree species.

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., machinery and maintenance operations such as thinning). Any secondary transportation (hauling) to the mill was excluded as outside of the FLAG target boundary.

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 (see Annex A.9). The share of softwood and hardwood per country was retrieved from FAOSTAT (FAO, 2017). The weighted average emissions of different regions by type of wood were used to calculate regional and global averages. The final emissions intensity of the baseline year 2015 was calculated by dividing the emission factor (kg CO_2e/ fresh m^3) by the rotation length (years) obtained from literature review. To calculate the trend of emission factor intensity in the future, it was assumed that the intensity of timber & wood fiber commodity will evolve at a similar rate as the crop commodities, as calculated in the IMAGE model.

5.1.5.4. Emissions excluded

In this first version of the timber & wood fiber commodity pathway emissions from forest degradation are not included. For example, the degradation of wood residues left on the forest floor after harvest, from mortality and senescence. Emissions related to the damage of remaining trees during unsustainable practices are also excluded. Modelling these emissions could be considered in further work with additional data.

5.1.6. Emissions from conversion from primary or secondary forest to plantation

Conversion emissions are attributed to timber & wood fiber using the same approach as for LUC in the other commodity pathways (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 & 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. This is because establishing naturally or semi-naturally growing forests does not cause deforestation as defined in this project.

To allocate conversion emissions (CO_2 ha^{-1} yr^{1}) per m^3 industrial roundwood, the value is divided by country-specific yield (m^3ha^{-1} yr^{-1}). The difference between the LUC approach applied for the other commodities and that of timber & wood fiber lies in the yield estimation. (See Table 2.)

Table 2: Average emissions from the conversion of primary and secondary forests into planted forests related to timber & wood fiber commodity with reference year 2015

Image region	Conversion rate (1)	Conversion emissions per ha (1)	Yield (2)	Conversion emissions per m³	Production from planted forests (3)	Impact of conversion (4)
	m^2/ (ha.yr)	kg CO_2eq/ (ha.yr)	m^3/ (ha.yr)	kg CO_2eq/ (m^3)	1000 m^3 (2015)	t CO2eq/ha
Brazil	**105.0**	**2'470**	**5.7**	**437**	**136'177**	**235**
Canada	**85.3**	**541**	**6.0**	**91**	**59'292**	**63**
Central America	86.6	1'789	9.6	**187**	3'018	207
Central Asia	7.9	22	3.3	**7**	118	28
Central Europe	0.2	5	4.5	**1**	**83'977**	**202**
China region	**0.0**	**0**	**7.1**	**0**	**148'707**	**118**
Eastern Africa	31.9	279	10.0	**28**	7'787	87
India	0.0	0.00	9.7	**0**	49'517	0
Indonesia region	**62.8**	**1'679**	**12.9**	**130**	**48'577**	**267**
Japan	0.1	1.14	5.1	**0**	21'258	109
Korea region	13.0	213	3.6	**59**	4'540	165
Mexico	104.9	700	9.3	**75**	1'151	67
Middle East	0	0	4.5	**0**	600	0
Northern Africa	4.9	43	3.5	**12**	1'304	87
Oceania	8.8	117	6.3	**19**	57'216	133
Rest of South America	**30.4**	**663**	**6.0**	**111**	**73'424**	**218**
Rest of South Asia	11.7	236	4.3	**55**	3'429	202
Rest of Southern Africa	64.5	1'039	9.2	**113**	8'094	161
Russia region	**43.2**	**597**	**3.5**	**171**	**42'529**	**138**
South Africa	0.2	3.60	10.6	**0**	15'284	182
Southeastern Asia	40.7	599	10.8	**55**	46'752	147
Turkey	11.5	179	3.5	**52**	11'517	157
Ukraine region	0.1	0.9	3.6	**0**	13'502	178
USA	**8.7**	**119**	**7.6**	**16**	**216'405**	**137**
Western Africa	64.9	1'213	8.8	**138**	16'556	187
Western Europe	**63.4**	**645**	**4.0**	**160**	**219'063**	**102**

in **bold** top industrial roundwood producers in 2015 according to FAOSTAT

(1) Amount of primary/secondary forest lost per area of planted forest in 2015
(2) Yield from production plantations. For some temperate regions we used data on clear cut as data from plantations was not available in Arets et al., 2010.
(3) Regional production volumes of industrial round wood (year 2015), here referred to as timber & wood fiber, sourced from planted forests.
(4) Impact due to C biomass loss when primary and secondary forests are converted to planted forests, per ha converted. Degradation from primary to secondary forests is not accounted for due to lack of data.

In Table 2, “Conversion rate” represents the area of primary and secondary forests (m^2) converted to planted forest (ha of planted forest per year, 2015 in this assessment) for a given region. “Conversion emissions per ha” represents the yearly conversion emissions, expressed in kg CO_2eq per ha of planted forest and per year, while “conversion emissions per m3” allocates these emissions to each m3 of roundwood produced in 2015 from planted forests, via the regional yield.

The regionalized conversion rate can be high even where the total forest area (natural and planted forests) is stable or even increasing. Countries such as Sweden and Canada are examples of this process. In Western Europe the conversion rate appears high because there is a large area of secondary forest being converted to planted forest. (Forest expansion, which also is occurring in this region, is not included under forest conversion). In Western Africa, the conversion rate is similar to that in Western Europe but appears low compared to known regional forest loss because forest loss is primarily due to drivers other than forest plantations in Western Africa. In the US, there is an important fraction of planted forest that existed before the 1990s, and thus under the 20-year emission allocation framework no longer has conversion emissions allocated to it.

“Impact of conversion” represents the carbon stock (i.e., below and above ground biomass, dead wood and litter, and soil organic carbon) lost when primary or secondary forests are converted to a planted forest or a plantation for a given region. Loss of primary forest in tropical regions (e.g., Indonesia) has a higher impact in terms of carbon stock loss compared to temperate and boreal regions (e.g., Canada) due to the differences in carbon stock in these primary forests.

5.1.7. Carbon removals pathways for timber & wood fiber

The carbon removals pathway for timber & wood fiber is based on the approach described in Section 4. As with 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) (Figure 5). This includes removals resulting from optimizing rotation lengths and biomass stocks, reduced-impact logging, improved plantations and certification. Carbon removals from agroforestry were excluded as these are related to improvements in agriculture and grazing lands, and industrial roundwood sourced from agroforestry represents a very low contribution to the overall production. Evidence demonstrates that the concept of restoring forests (along with wetlands and peatlands etc.) has the potential to remove more CO_2 from that atmosphere than from forest management (see Figure 6 in Roe et al. 2019). However, removals from afforestation or reforestation are not included in the corporate timber and wood fiber pathway at this time.

The 30 $GtCO_2$ target by 2050 represents additional emission reductions and removals beyond current business as usual (BAU) or baseline levels. However, recognizing that timber & wood fiber companies and suppliers generally report on net emissions inclusive of both emissions and baseline removals, the tool was customized by 1) allowing users to enter baseline removals to generate a net emissions value; and by 2) adjusting the removals pathway to include baseline removals from managed forests (i.e., both plantations and natural and seminatural forests), based on the global average gross removals, 5.5 $GtCO_2$ yr^{-1}, from forest management and regeneration (Harris et al. 2021) (Figure 6).

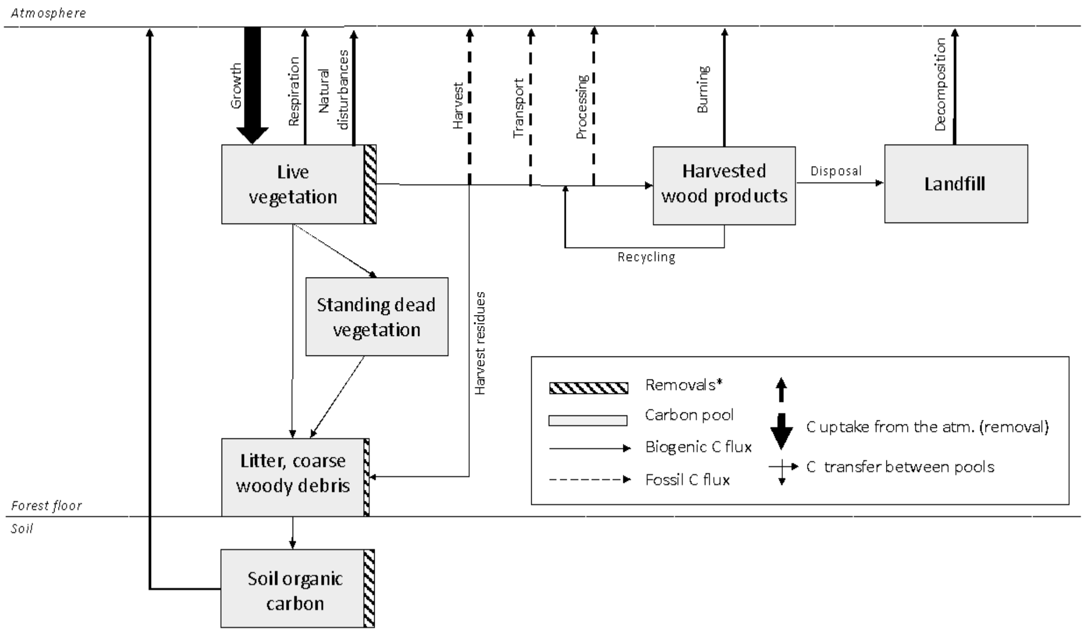

Figure 5: Carbon dynamics in a managed forest producing timber and wood fiber products. Arrows represent carbon fluxes and transfer between pools while boxes indicate carbon pools. The boxes with a lined pattern represent the additional removals from improved management, e.g. optimization rotation lengths and biomass stocks, reduced-impact logging, improved plantations, forest fire management and certification.*

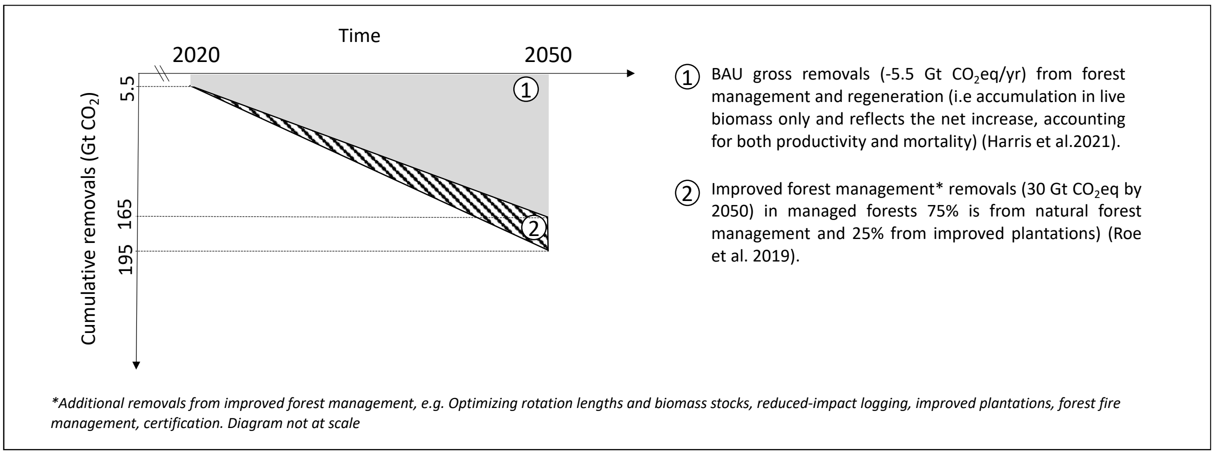

Figure 6: BAU gross removals (1) and additional removals from improved forest management(2), e.g. optimization rotation lengths and biomass stocks, reduced-impact logging, improved plantations, forest fire management and certification. Figure not at scale.*

With final target being defined by the most comprehensive data (i.e., BAU baseline plus additional removals beyond BAU), 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 for the global pathway. 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 2050 to estimate the available land area (i.e., 555 Mha). 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 m³ basis using region specific yields (Equation 7). The region-specific removals were aggregated to obtain the global value presented in the tool.

$$Removals\ intensity_{\ Timber\ \&\ wood\ fiber} = \frac{((Global\ total\ (GtCO2e) * \frac{1000\ Mt}{1\ Gt})\ /\ Global\ total\ ha\ (Mha))}{Industrial\ Roundwood\ yield\ (m^3\ u.b./\ ha)} \quad \text{Equation 7}$$

5.2. Limitations

Plantation conversion

The spatial data processing provides better estimate yields than those based on literature (Version 1.0). Nevertheless, averaging industrial roundwood yields at the regional scale, and generic for all management practices and species, remains a limitation in the conversion estimates as the in the previous version. Moreover, the combination of different spatial data from different sources underlines a combination of uncertainties related to each of those layers which is difficult to assess but should be acknowledged.

Forest loss data

Statistical tree cover loss data also has limitations; as satellite imagery becomes more readily available, it offers a promising alternative as it is more representative in capturing actual forest loss globally (i.e., where and how much forest has been lost).

Forest removals data

Finally, the estimate of 3.3 $GtCO_2\ yr^{-1}$ used as a baseline for BAU removals in managed forest is uncertain due to the embedded uncertainty of the removal factors used from the IPCC Guidelines (IPCC, 2019; Harris et al., 2021). This data can be updated as better data sources become available. Another limitation is related to the regional average yield values above-mentioned to estimate the land use for removals.

6 CATTLE HIDES (LEATHER)

6.1. Methods

6.1.1. Introduction

Cattle hides are co-products[6] of the meat and dairy industry, and given that FLAG commodity pathways are available for beef, the cattle hide commodity pathway was developed using that available data. The impacts associated with cattle hides in the tool are allocated as a share of the beef impacts. However, the impact and scope of cattle hide is much smaller than that of the other commodity pathways.

6.1.2. Definitions

The cattle hides included in the leather commodity pathway are accounted at the raw and unprocessed stage. The emissions from the tanning process needed to create leather are not included in the FLAG target boundary, nor are emissions associated with any other types of processing of hides.

The volume of cattle hides derived from the meat and dairy industry (**recovery rate**), as well as the share of the impacts allocated to hides (**allocation rate**), are the major parameters that influence the results and that were extrapolated to year 2050 according to different scenarios.

6.1.3. Cattle hides scenarios

The extrapolation of the recovery rate and allocation rate from 2020 to 2050 is based on interviews conducted in October and November 2021 with leather industry experts (see Appendix 9.6).

While the recovery rate can be calculated from world leather industry data and extrapolated based on hypotheses described in Appendix 9.7, the allocation rate is a choice reached by consensus of the interested parties in Europe. In the current PEFCR (De Rosa-Giglio et al.,2018, confirmed by Zampori & Pant , 2019), the choice is an allocation based on the economic value of the co-products. In other regions of the world, an estimate has been made with the help of experts for the year 2020. This value is expected to vary with time and can be reassessed in future pathway updates.

Three scenarios were elaborated to project future leather production: two extreme scenarios and a middle one (more details in Appendix 9.7):

[6] There is debate regarding this status, and the leather industry defends the position that leather should be considered as a by-product. This semantic distinction carries a heavy implication since a co-product receives a share of the environmental burden of the production process (by allocation), while a by-product is burden-free. This document does not take stance in this debate but refers to the current PEFCR (De Rosa-Giglio P. et al (2018), confirmed also by JRC (2019)) that allocates impacts to cattle hide, making it *de facto* a co-product of the meat and dairy industry.

- *Leather is rejected*: Leather is rejected as a material of choice with preference instead for vegan products; further, leather is not recognized or valorized as a material coming from recovered waste;
- *Leather comes back*: Leather production increases under the view of leather as a recovered material that is perceived positively;
- *Middle-ground scenario*: Average of the two previous scenarios.

The *leather comes back* scenario has been selected for the tool, to reflect a conservative (in terms of carried impacts) view that is also compatible with a future in which fossil products are progressively phased out and bio-based products and a circular economy are ascendant.

Maintaining a constant allocation rate through 2050 avoids inadvertently implying that climate impacts of leather can decrease without taking any action. This rate will be updated in future version of FLAG following updates in the PEFCR future review process.

Table 3: Hide allocation rate: share of the GHG emission impacts of beef attributed to the hide at slaughter (value retained for the duration of the scenario).

IMAGE regions	Regional hide allocation
World (as weighted in 2015)	1.61%
Canada	1.5%
USA	1.5%
Mexico	1.5%
Central America	1.0%
Brazil	1.0%
Rest of South America	1.0%
Western Europe	3.5%
Central Europe	3.5%
Ukraine region	2.5%
Turkey	2.5%
Northern Africa	1.5%
Western Africa	1.5%
Eastern Africa	1.5%
South Africa	1.5%
Rest of Southern Africa	1.5%
Russia region	2.5%
Central Asia	1.5%
Middle East	1.5%
Southeast Asia	1.5%
Indonesia region	1.5%
India	1.5%
Rest of South Asia	1.5%
China region	1.5%
Korea	1.5%
Japan	1.5%
Oceania	2.0%

6.2. Limitations

Allocation of cattle emissions to hides

While the allocation rate is based on a consensus for Europe, it is based on estimates for other regions. This is the key parameter that determines the impact of hides, and it will vary in the future based on economic changes and political agreements. A constant value is used to reflect impact changes that come from real mitigation efforts and not perceived improvements due to changes in allocation rate. However, any refinement or update in the allocation rate should be reflected in future versions of the tool.

Hide recovery rates

The recovery rate of hides on animal carcasses is an important parameter that reflects the demand for leather and that is coupled with the allocation rate. However, because of the choice of using the same allocation rate over time, it is not a key parameter in the scenario that is used in the tool.

Non-cattle hides

It has been chosen to use only the beef industry as a reference for hides, because of the simpler allocation between the coproducts; therefore, the hide impact is an allocated share of the existing beef impacts. Dairy impacts are not considered in the calculation.

7 SUMMARY OF KEY RECOMMENDATIONS

The following is a summary of key recommendations for **future improvements** that could be integrated into the FLAG commodity pathways as additional data become available to further refine the pathways:

1. LUC impacts from peat degradation were not explicitly included in the tool and could be added in future versions if data are available.

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 statistical LUC methods that have been used attributes deforestation to all types of crops and plantations whose area is expanding, even when natural forests are essentially converted to planted forests or plantations. Future releases will separate more clearly the forestry-related LUC from other agricultural activities.

5. 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.

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

7. 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 they become available.

8. 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.

9. Any refinement or update in the allocation rate of hides in the meat and dairy industry should be reflected in future versions of the tool.

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

Edited by: Christa Anderson (WWF), Tereza Bicalho (WWF)

8 REFERENCES

AFi (2019). Operational Guidance on Applying the Definitions Related to Deforestation, Conversion, and Protection of Ecosystems. Accountaiblity Framework initiative, June 2019. https://accountability-framework.org/wp-content/uploads/2019/05/Operational_Guidance_Applying_Definitions.pdf

Arets, E. J. M. M., van der Meer, P.J., Verwer, C.C., Nabuurs, G.-J., Hengeveld, G.M., Tolkamp, G.W., & van Oorschot, M. (2010). Global wood production: Assessment of industrial round wood supply from different management systems in different global regions. Wageningen, Alterra, Alterra-rapport 1808.

Brown, C. (2000). The global outlook for future wood supply from forest plantations. Global Forest Products Outlook Study Working Paper Series, GFPOS/WP/03. Food and Agriculture Organization of the United Nations, Rome, Italy.

de Moraes Goncalves, J. L., Alvares, C. A., Higa, A. R., Silva, L. D., Alfenas, A. C., Stahl, J., et al. (2013). Integrating genetic and silvicultural strategies to minimize abiotic and biotic constraints in Brazilian eucalypt plantations. For Ecol Manag 301, 6-27. https://doi.org/10.1016/j.foreco.2012.12.030

De Rosa-Giglio, P., Fontanella, A., Gonzalez-Quijano, G., Ioannidis, I., Nucci, B., & Brugnoli, F. (2018). Leather product environmental footprint category rules (Leather PEFCR). Final version. https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_leather.pdf

Doelman, J. C., Stehfest, E., Tabeau, A., et al. (2018). Exploring SSP land-use dynamics using the IMAGE model: Regional and gridded scenarios of land-use change and land-based climate change mitigation. Glob Environ Chang 48,119–135. https://doi.org/10.1016/j.gloenvcha.2017.11.014

FAO (2014). The FAO Statistics Quality Assurance Framework. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/3/i3664e/i3664e.pdf

FAO (2015). Global Forest Resources Assessment 2015. Food and Agriculture Organization of the United Nations, Rome, Italy. Desk Ref. https://doi.org/10.1002/2014GB005021

FAO (2017). FAO Yearbook of Forest Products 2015. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/3/i7304m/i7304m.pdf

FAO (2018). Global Livestock Environmental Assessment Model (GLEAM), Model description Version 2.0, Revision 5. Food and Agriculture Organization of the United Nations, Rome, Italy. https://www.fao.org/gleam/resources/en/

FAO (2021). FAO Yearbook of Forest Products 2019. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/3/cb3795m/cb3795m.pdf

Forest Research (2022). Accessed the 28.07.2022. https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2018/sources/timber-2/conversion-factors/

Harris, N. L., Gibbs, D. A., Baccini, A., Birdsey, R. A., De Bruin, S., Farina, M., et al. (2021). Global maps of twenty-first century forest carbon fluxes. Nat Clim Change 11(3), 234-240. https://doi.org/10.1038/s41558-020-00976-6

IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K. (eds). Published: IGES, Japan. https://www.ipcc-nggip.iges.or.jp/support/Primer_2006GLs.pdf

IPCC (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P. & Federici, S. (eds). Published: IPCC, Switzerland. https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

Johnston, C. M., & Radeloff, V. C. (2019). Global mitigation potential of carbon stored in harvested wood products. Proc Natl Acad Sci 116(29), 14526-14531. https://doi.org/10.1073/pnas.1904231116

Jürgensen, C., Kollert, W., & Lebedys, A. (2014). Assessment of industrial roundwood production from planted forests. FAO Planted Forests and Trees Working Paper FP/48/E. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/forestry/plantedforests/67508@170537/en/

Krabbe, O., Linthorst, G., Blok, K., et al. (2015). Aligning corporate greenhouse-gas emissions targets with climate goals. Nat Clim Chang 5,1057–1060. https://doi.org/10.1038/nclimate2770

Lesiv, M., Schepaschenko, D., Buchhorn, M., See, L., Dürauer M., et al. (2021). Global forest management data at a 100m resolution for the year 2015 [Data set]. In Nature Scientific Data (Version 1). Zenodo. https://doi.org/10.5281/zenodo.4541513

Morales, M., Aroca, G., Rubilar, R., Acuna, E., Mola-Yudego, B., González-García, S. (2015). Cradle-to-gate life cycle assessment of Eucalyptus globulus short rotation plantations in Chile. J Clean Prod 99: 239-249.

Nemecek ,T., Bengoa, X., Rossi, V., et al. (2019) World Food LCA Database: Methodological guidelines for the life cycle inventory of agricultural products. Version 3.5. 88.

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., & Kassem, K. R. (2001). Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51(11), 933-938. http://dx.doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

Project Drawdown. Technical Summary Regenerative Annual Cropping. Accessed 2021. https://drawdown.org/solutions/regenerative-annual-cropping/technical-summary

Roe, S., Streck, C., Obersteiner, M., Frank, S., Griscom, B., Drouet, L., Fricko, O., Gusti, M., Harris, N., Hasegawa, T., Hausfather, Z., Havlík, P., House, J., Nabuurs, G., Popp, A., Sanz Sánchez, M., Sanderman, J., Smith, P., Stehfest, E., & Lawrence, D. (2019). 'Contribution of the land sector to a 1.5°C world'. Nat Clim Change (9), 817-828. https://doi.org/10.1038/s41558-019-0591-9

Smith, P., Nayak, D. R., Linthorst, G., Peters, D., Bucquet, C., Vuuren, D. P. V., Stehfest, E., Harmsen, M., & Brink, L. V. D. (2016). 'Science-Based GHG Emissions Targets for Agriculture and Forest Commodities.' University of Aberdeen, Ecofys, and PBL. https://www.pbl.nl/sites/default/files/downloads/pbl-2016-science-based-greenhouse-gas-emissions-targets-for-agriculture-and-forestry-commodities-2856.pdf

Stehfest, E., van Vuuren, D., Kram, et al. (2014). Integrated Assessment of Global Environmental Change with IMAGE 3.0. Model description and policy applications. PBL Netherlands Environmental Assessment Agency, The Hague, Netherlands.

terraPulse (2021). https://www.terrapulse.com/terraView/

van Vuuren, D. P., Stehfest, E., Gernaat, D. E. H. J., et al. (2017). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. Glob Environ Chang 42:237–250. https://doi.org/10.1016/j.gloenvcha.2016.05.008

WRI & WBCSD (2014). The Greenhouse Gas Protocol: Agricultural Guidance: Interpreting the Corporate Accounting and Reporting Standard for the agricultural sector. World Resources Institute & World Business Council for Sustainable Development. https://ghgprotocol.org/sites/default/files/standards/GHG%20Protocol%20Agricultural%20Guidance%20%28April%2026%29_0.pdf

Zampori, L & Pant, R. (2019). Suggestions for updating the Product Environmental Footprint (PEF) method, Joint Research Centre (JRC). https://eplca.jrc.ec.europa.eu/permalink/PEF_method.pdf

Zomer, R.J., Bossio, D.A., Sommer, R. et al. (2017). Global Sequestration Potential of Increased Organic Carbon in Cropland Soils. Sci Rep 7, 15554. https://doi.org/10.1038/s41598-017-15794-8

9 APPENDICES

1. A1. Data for oil crops

For FLAG commodity pathways for soybeans and palm oil, 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 accounted 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 Smith et al (2016), 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, due to high growth in production, which covers nearly 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 but 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 soybeans, unprocessed product data as provided by the IMAGE model, and split proportionally as described above, were used.
- For palm oil, like soybeans, unprocessed product data, split proportionally, were 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[7]) were used.

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

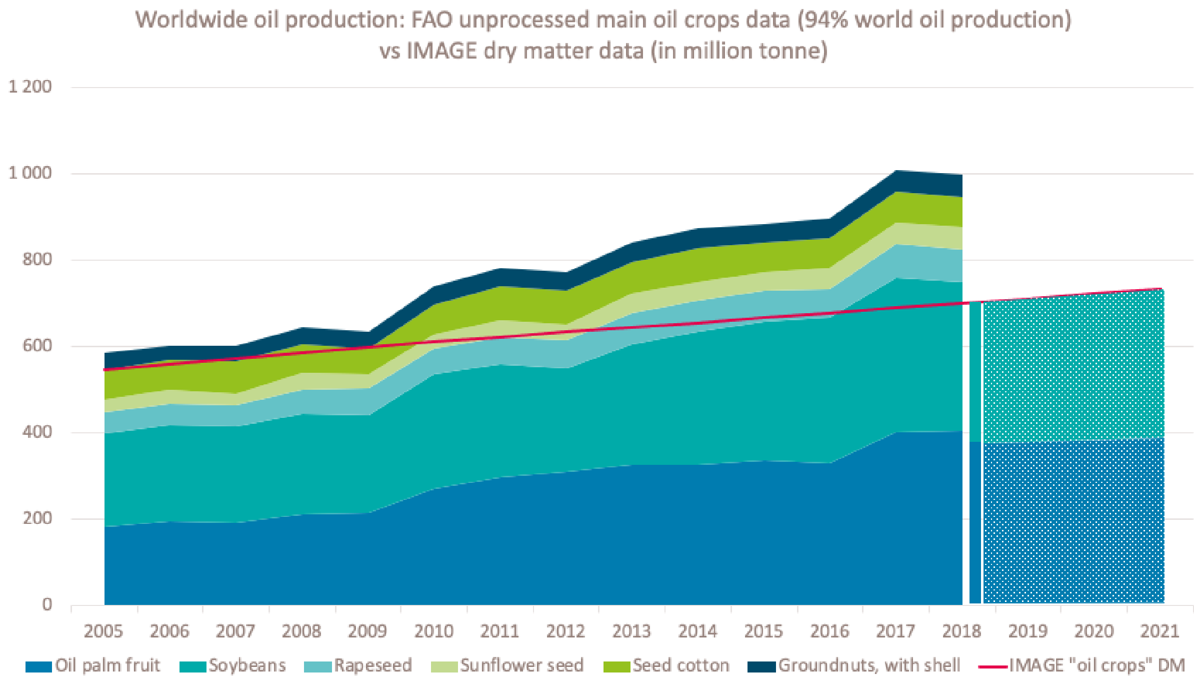

Figure A1-1: FAO data for unprocessed oil crops 2005 – 2018 and IMAGE data for oil crops 2005 – 2021. On the right of the chart, the proportions taken from FAO between soy and palm are conserved and are extrapolated according to IMAGE data (until 2050, not shown).

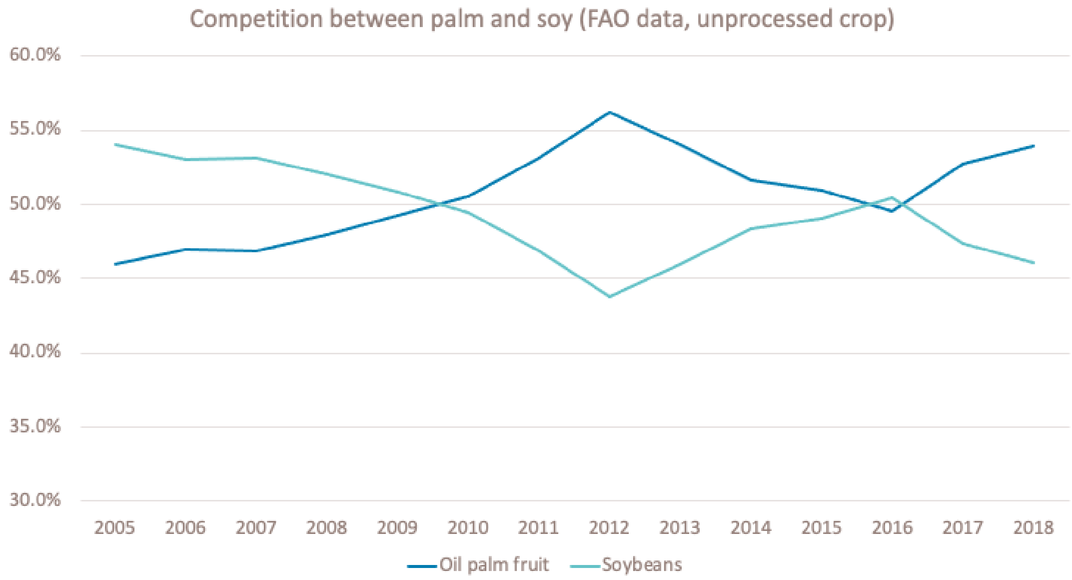

Figure A1-2: Trend of the worldwide production of soy and palm fruit (100% is the sum of the two)

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.

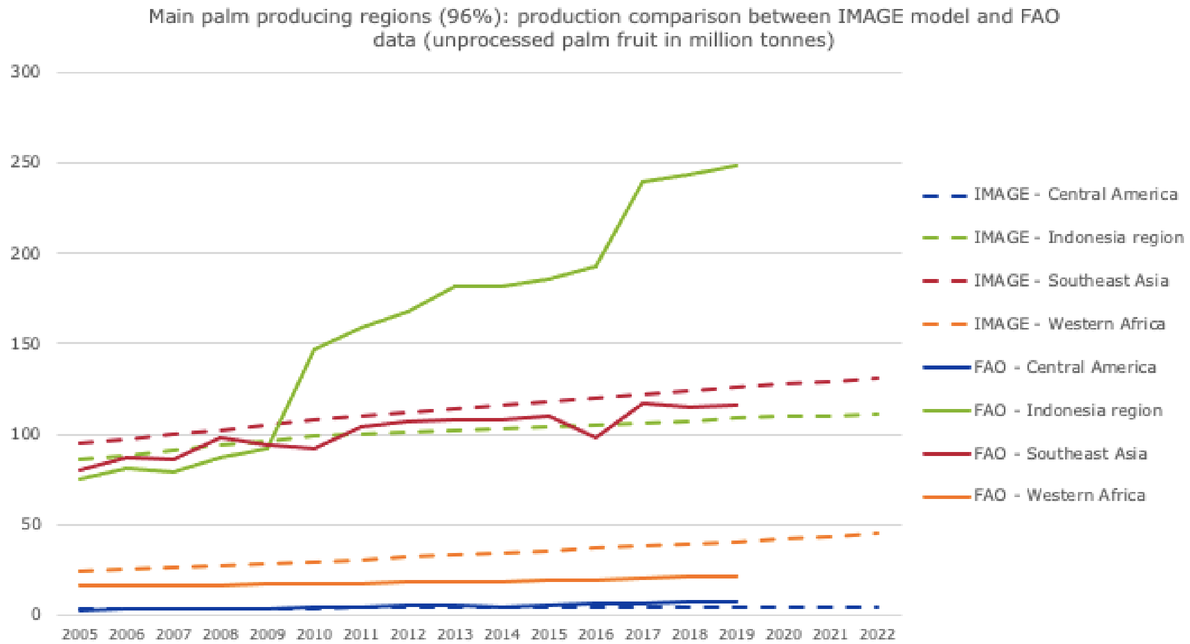

Figure A1-3: Comparison of IMAGE 3.0 data and FAO data for the major palm producing regions

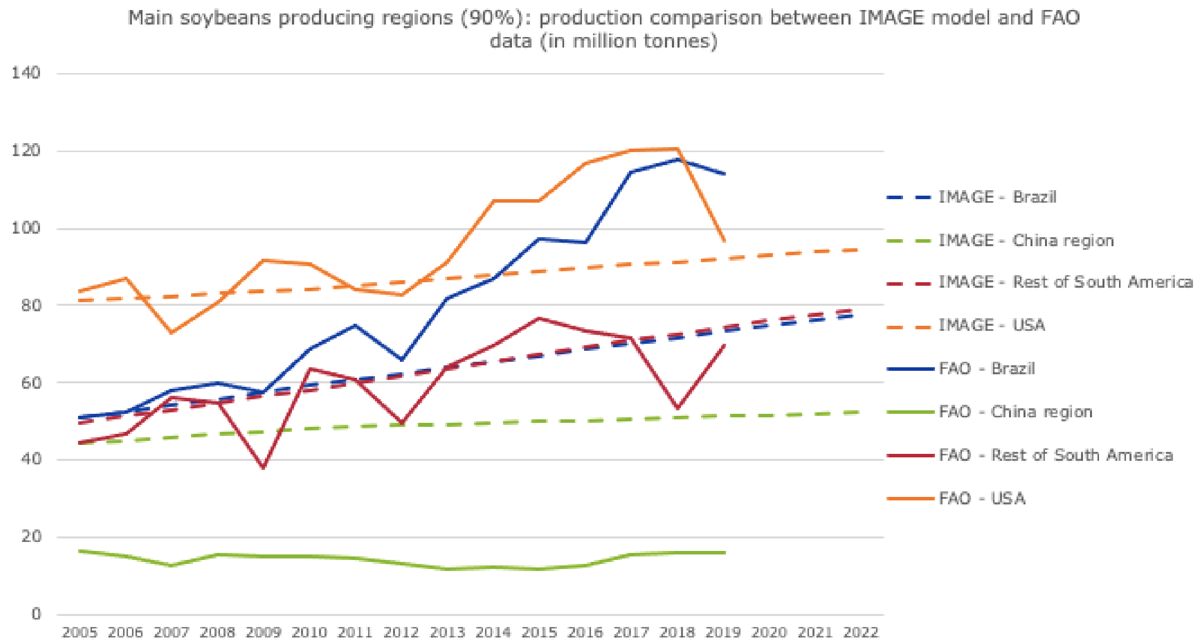

Figure A1-4: Comparison of IMAGE 3.0 data and FAO data for the major soybeans producing regions

2. A2. IMAGE regions and correspondence

Table A2-1: Regional 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

3. A3. LUC weighting factors and pathways

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.	

Tree cover loss' pathway linearly reaches zero in 2030, in two linear segments: 25% decrease between the reference level of 2015 and the intermediate step of 2020, and the rest between 2020 and 2030.

The allocated emissions follow the trend but slowly: they represent the sliding average of the tree cover loss over 20 years.

Table A3-2: Deforestation and deforestation emission pathways

Year	Tree cover loss	Tree cover loss reduction	Allocated emission	Allocated emission reduction
2010	100%	0%	100%	0%
2011	100%	0%	100%	0%
2012	100%	0%	100%	0%
2013	100%	0%	100%	0%
2014	100%	0%	100%	0%
2015	100%	0%	100%	0%
2016	95%	5%	100%	0%
2017	90%	10%	100%	0%
2018	85%	15%	99%	1%
2019	80%	20%	99%	2%
2020	75%	25%	98%	3%
2021	68%	33%	96%	4%
2022	60%	40%	95%	5%
2023	53%	48%	93%	7%
2024	45%	55%	90%	10%
2025	38%	63%	88%	13%
2026	30%	70%	84%	16%
2027	23%	78%	81%	19%
2028	15%	85%	77%	23%
2029	8%	93%	73%	27%
2030	0%	100%	68%	32%
2031	0%	100%	63%	37%
2032	0%	100%	58%	42%
2033	0%	100%	53%	47%
2034	0%	100%	48%	52%

2035	0%	100%	43%	57%
2036	0%	100%	38%	62%
2037	0%	100%	33%	67%
2038	0%	100%	29%	71%
2039	0%	100%	25%	75%
2040	0%	100%	21%	79%
2041	0%	100%	17%	83%
2042	0%	100%	14%	87%
2043	0%	100%	11%	90%
2044	0%	100%	8%	92%
2045	0%	100%	6%	94%
2046	0%	100%	4%	96%
2047	0%	100%	2%	98%
2048	0%	100%	1%	99%
2049	0%	100%	0%	100%
2050	0%	100%	0%	100%

4. A4. Ingredients used in feed baskets and LUC impacts associated with ingredients

1. 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

2. Feed baskets associated with animal production

Table A4-2: Dairy cattle feed basket (DMI is expressed per kg of milk dry matter)

IMAGE Country or region	kg DMI/kg product	Feed basket in %						
		By-product	Cereal	Fodder crop	Grass	Pasture	Maize	Oilseed meal
Canada	8.53	8.4	23.2	32.7	15.5	13.3	0	5.9
USA	8.53	8.4	23.2	32.7	15.5	13.3	0	5.9
Mexico	16.65	8.4	23.2	32.7	15.5	13.3	0	5.9
Central America	16.65	17	3.9	7.7	30.3	39.1	0	2
Brazil	16.65	17	3.9	7.7	30.3	39.1	0	2
Rest of South America	16.65	17	3.9	7.7	30.3	39.1	0	2
Western Europe	8.53	7.9	12.4	26.2	20.1	25.9	0	7.5
Central Europe	8.53	8.5	9.8	32.7	22.6	22.4	0	4
Ukraine region	10.93	8.5	9.8	32.7	22.6	22.4	0	4
Turkey	10.93	23.1	0.9	8.1	43	23.9	0	1
Northern Africa	10.93	23.1	0.9	8.1	43	23.9	0	1
Western Africa	44.05	10.9	1.5	6.3	45.1	35.7	0	0.5
Eastern Africa	44.05	10.9	1.5	6.3	45.1	35.7	0	0.5
South Africa	44.05	10.9	1.5	6.3	45.1	35.7	0	0.5
Rest of Southern Africa	44.05	10.9	1.5	6.3	45.1	35.7	0	0.5
Russia region	10.93	8.3	10.4	32.8	22.3	22.3	0	3.9
Central Asia	10.93	23.1	0.9	8.1	43	23.9	0	1
Middle East	10.93	23.1	0.9	8.1	43	23.9	0	1
Southeast Asia	13.90	34	5	16	21.1	21.1	0	2.8
Indonesia region	13.90	34	5	16	21.1	21.1	0	2.8
India	13.90	49.8	2.5	4.9	23.4	17.4	0	2
Rest of South Asia	13.90	49.8	2.5	4.9	23.4	17.4	0	2
China region	12.01	34	5	16	21.1	21.1	0	2.8
Korea	8.53	34	5	16	21.1	21.1	0	2.8
Japan	8.53	34	5	16	21.1	21.1	0	2.8
Oceania	8.53	2.5	15.5	11	5.1	60.9	0	5

Table A4-3: Beef cattle feed basket: weighted average of 2 systems: feedlot and non-feedlot systems (DMI is expressed per kg of meat dry matter)

IMAGE Country or region	kg DMI/kg product	Feed basket in %						
		By-product	Cereal	Fodder crop	Grass	Pasture	Maize	Oilseed meal
Canada	52.0	0.5	32.2	13.3	26.2	26.0	0.0	1.0
USA	52.0	0.1	61.3	21.3	8.2	7.5	0.0	1.4
Mexico	113.0	0.4	37.3	14.7	23.1	22.8	0.0	1.1
Central America	113.0	14.0	9.8	10.0	11.4	52.7	0.0	2.1
Brazil	113.0	14.0	9.8	10.0	11.4	52.7	0.0	2.1
Rest of South America	113.0	14.0	9.8	10.0	11.4	52.7	0.0	2.1
Western Europe	52.0	6.0	27.3	19.6	10.2	29.5	0.0	7.4
Central Europe	52.0	8.8	6.9	31.8	21.6	28.2	0.0	2.7
Ukraine region	41.9	8.8	6.9	31.8	21.6	28.2	0.0	2.7
Turkey	41.9	27.8	0.7	16.5	30.4	24.1	0.0	0.5
Northern Africa	41.9	27.8	0.7	16.5	30.4	24.1	0.0	0.5
Western Africa	139.4	6.8	1.8	5.6	45.0	40.8	0.0	0.0
Eastern Africa	139.4	6.8	1.8	5.6	45.0	40.8	0.0	0.0
South Africa	139.4	9.8	11.6	4.5	38.4	32.6	0.0	3.0
Rest of Southern Africa	139.4	6.8	1.8	5.6	45.0	40.8	0.0	0.0
Russia region	41.9	8.3	10.4	32.8	22.3	22.3	0.0	3.9
Central Asia	41.9	27.8	0.7	16.5	30.4	24.1	0.0	0.5
Middle East	41.9	27.8	0.7	16.5	30.4	24.1	0.0	0.5
Southeast Asia	192.7	34.7	2.9	16.6	24.0	20.3	0.0	1.5
Indonesia region	192.7	34.7	2.9	16.6	24.0	20.3	0.0	1.5
India	192.7	50.6	0.0	5.0	26.1	17.3	0.0	1.0
Rest of South Asia	192.7	50.6	0.0	5.0	26.1	17.3	0.0	1.0
China region	70.5	36.0	7.9	18.4	19.2	16.3	0.0	2.1
Korea	52.0	36.7	10.4	19.3	16.8	14.4	0.0	2.4
Japan	52.0	36.7	10.4	19.3	16.8	14.4	0.0	2.4
Oceania	52.0	3.9	16.0	11.5	6.1	62.1	0.0	0.4

Table A4-4: Pork feed basket: weighted average of 3 systems: backyard, intermediate and industrial systems (DMI is expressed per kg of meat dry matter)

IMAGE Country or region	kg DMI/kg product	Feed basket in %							
		By-product	Cereal	Fodder crop	Maize	Oilseed meal	Other	Soy	Wheat
Canada	8.9	4.1	15.4	0.0	55.6	0.9	3.2	10.8	10.0
USA	8.9	4.1	15.4	0.0	55.6	0.9	3.2	10.8	10.0
Mexico	9.1	4.1	15.4	0.0	55.6	0.9	3.2	10.8	10.0
Central America	9.1	15.7	7.0	3.2	33.7	0.2	2.5	27.1	10.8
Brazil	9.1	15.7	7.0	3.2	33.7	0.2	2.5	27.1	10.8
Rest of South America	9.1	15.7	7.0	3.2	33.7	0.2	2.5	27.1	10.8
Western Europe	8.9	6.8	22.0	2.4	11.9	11.0	2.7	15.8	27.4
Central Europe	8.9	7.2	9.3	0.3	25.1	9.9	4.9	14.4	29.0
Ukraine region	8.8	12.8	10.1	1.5	19.8	11.3	3.8	12.3	28.6
Turkey	8.8	21.8	13.1	9.4	12.5	7.1	2.8	13.5	20.0
Northern Africa	8.8	39.9	6.5	5.7	5.0	12.4	0.0	2.7	28.0
Western Africa	8.5	31.9	10.0	41.0	8.6	2.7	0.0	5.8	0.0
Eastern Africa	8.5	31.9	10.0	41.0	8.6	2.7	0.0	5.8	0.0
South Africa	8.5	16.9	24.2	29.4	17.5	2.3	3.0	5.8	0.0
Rest of Southern Africa	8.5	17.8	22.2	31.5	16.8	2.4	2.4	5.8	0.0
Russia region	8.8	13.5	9.0	2.3	13.7	14.2	3.7	13.3	30.2
Central Asia	8.8	20.4	13.3	9.4	12.5	7.0	2.8	13.7	21.1
Middle East	8.8	39.9	6.5	5.7	5.0	12.4	0.0	2.7	28.0
Southeast Asia	9.6	24.0	14.3	1.7	32.9	2.0	1.9	18.3	4.9
Indonesia region	9.6	24.0	14.3	1.7	32.9	2.0	1.9	18.3	4.9
India	9.6	25.7	28.1	11.4	6.8	5.8	2.5	16.0	3.4
Rest of South Asia	9.6	45.4	13.4	14.7	1.9	5.3	0.0	13.6	5.7
China region	10.5	19.0	13.3	1.9	38.1	1.9	2.5	19.0	4.4
Korea	8.9	11.7	12.0	1.6	46.0	1.2	3.2	20.6	3.9
Japan	8.9	11.7	12.0	1.6	46.0	1.2	3.2	20.6	3.9
Oceania	8.9	19.0	41.6	3.7	2.8	0.2	1.4	14.2	15.4

Table A4-5: Chicken feed basket: weighted average of 2 systems: backyard and broiler systems (DMI is expressed per kg of meat dry matter)

IMAGE Country or region	kg DMI/kg product	Feed basket in %							
		By-product	Cereal	Fodder crop	Maize	Oilseed meal	Other	Soy	Wheat
Canada	8.9	0.0	0.0	0.0	63.0	5.0	7.0	25.0	0.0
USA	8.9	0.0	0.0	0.0	63.0	5.0	7.0	25.0	0.0
Mexico	9.1	0.0	0.0	0.0	63.0	5.0	7.0	25.0	0.0
Central America	9.1	19.8	4.0	1.5	47.0	0.7	1.2	25.2	0.5
Brazil	9.1	19.8	4.0	1.5	47.0	0.7	1.2	25.2	0.5
Rest of South America	9.1	19.8	4.0	1.5	47.0	0.7	1.2	25.2	0.5
Western Europe	8.9	8.1	5.0	1.1	24.9	3.8	2.0	21.5	33.6
Central Europe	8.9	6.8	1.2	0.0	24.3	9.8	1.6	22.7	33.7
Ukraine region	8.8	17.0	2.9	0.0	18.7	15.5	1.0	19.3	25.8
Turkey	8.8	29.0	10.7	0.8	25.0	3.3	1.7	12.0	17.7
Northern Africa	8.8	46.3	11.3	1.2	12.1	4.4	0.7	4.8	19.2
Western Africa	8.5	41.8	10.1	11.1	21.6	3.1	0.4	9.9	1.9
Eastern Africa	8.5	41.8	10.1	11.1	21.6	3.1	0.4	9.9	1.9
South Africa	8.5	36.6	8.8	9.7	27.1	2.7	0.6	12.0	2.4
Rest of Southern Africa	8.5	41.8	10.1	11.1	21.6	3.1	0.4	9.9	1.9
Russia region	8.8	18.1	3.4	0.4	16.1	12.2	1.0	18.3	30.7
Central Asia	8.8	52.1	11.5	1.4	7.9	4.7	0.3	2.4	19.7
Middle East	8.8	46.3	11.3	1.2	12.1	4.4	0.7	4.8	19.2
Southeast Asia	9.6	22.3	14.0	0.8	33.1	1.7	2.0	18.0	8.1
Indonesia region	9.6	22.3	14.0	0.8	33.1	1.7	2.0	18.0	8.1
India	9.6	44.0	17.2	0.8	9.3	4.8	0.8	12.4	10.6
Rest of South Asia	9.6	44.0	17.2	0.8	9.3	4.8	0.8	12.4	10.6
China region	10.5	27.9	15.3	1.1	28.8	1.8	1.7	16.4	7.3
Korea	8.9	0.0	9.0	0.0	50.3	1.3	3.3	24.4	11.7
Japan	8.9	0.0	9.0	0.0	50.3	1.3	3.3	24.4	11.7
Oceania	8.9	9.4	22.5	10.8	6.8	1.6	6.4	15.1	25.6

3. Deforestation impacts associated with ingredients

Table A4-6: Deforestation impacts related to animal feed

IMAGE Country or region	Deforestation kg CO_2eq/kg ingredient dry matter							
	Cereal	Fodder crop	Grass	Pasture	Maize	Oilseed meal	Soya	Wheat
Canada	0.13	0.07	0.002	0.00	0.04	0.09	0.93	0.11
USA	0.48	0.00	0.031	0.03	0.05	0.71	0.12	0.27
Mexico	2.55	0.21	0.006	0.01	0.72	3.17	3.00	0.46
Central America	2.54	0.23	0.098	0.10	2.99	0.83	1.66	6.34
Brazil	7.25	9.14	0.014	0.01	1.55	8.08	3.54	8.39
Rest of South America	2.36	0.70	0.144	0.14	1.05	1.78	0.96	3.28
Western Europe	0.31	0.56	0.012	0.01	0.08	2.59	1.83	0.08
Central Europe	0.41	0.73	0.038	0.04	0.19	0.23	0.66	0.20
Ukraine region	0.10	0.19	0.002	0.00	0.05	0.08	0.13	0.08
Turkey	0.31	0.91	0.008	0.01	0.06	0.16	0.71	0.14
Northern Africa	0.61	0.84	0.002	0.00	0.01	0.87	0.00	0.68
Western Africa	3.95	5.89	0.008	0.01	3.82	4.54	9.07	10.57
Eastern Africa	1.80	0.91	0.010	0.01	0.67	2.19	1.59	0.43
South Africa	0.59	0.03	0.000	0.00	0.16	0.77	0.61	0.12
Rest of Southern Africa	4.10	1.00	0.007	0.01	9.92	4.80	10.07	6.93
Russia region	2.17	2.67	0.032	0.03	1.20	1.95	2.83	1.50
Central Asia	0.39	11.40	0.003	0.00	0.14	0.46	0.29	0.28
Middle East	0.49	1.11	0.026	0.03	0.16	0.67	0.32	0.22
Southeast Asia	6.52	0.97	0.022	0.02	1.02	7.58	6.70	3.84
Indonesia region	7.88	1.91	0.027	0.03	1.74	5.69	11.37	0.00
India	0.14	0.12	0.000	0.00	0.05	0.15	0.23	0.03
Rest of South Asia	1.34	3.32	0.000	0.00	0.47	1.41	2.05	0.35
China region	0.06	0.08	0.000	0.00	0.04	0.07	0.08	0.01
Korea	3.70	2.42	0.040	0.04	0.90	4.36	0.84	5.19
Japan	1.42	0.02	0.000	0.00	0.70	1.95	1.43	0.30
Oceania	1.68	0.84	0.005	0.01	0.48	0.93	3.51	0.69

Note: no LUC is associated with by-products or residues of the food industry

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%				

6. A6. Experts consulted to build leather scenarios

- Federico Brugnoli, Chief Executive Officer, Spin360. Interviewed on 15th Oct 2021
- Gustavo Gonzale-Quijano, Secretary at COTANCE. Email exchanges 4 Oct - 13 Oct 2021
- Dr Kerry Senior, Secretary of the ICT and Director of Leather UK. Email exchanges 11 Oct - 12 Oct 2021
- Fernando Bellese, Chief Sustainability Officer at PrimeAsia Leather Company. Email exchanges between 13 Oct and 17 Nov, call on 19 Nov.
- Mauricio Bauer, Senior Director, Beef & Leather Supply Chains Markets at World Wildlife Fund.

7. A7. Leather demand scenarios built by Quantis

1. <u>Leather is rejected</u>

Leather is attacked by NGOs, vegan trend is strong, leather is not recognized or valorized as a material coming from recovered waste. Competition with other materials is hard. Leather demand does not follow the increase of beef consumption and recovery rate starts falling in 2027, creating a gap between beef production and hides recovery. From 90% until 2026, the world average recovery rate reaches 68% in 2050.

Prices drop by 2030 and might even become negative, as in many places, wasted hides treatment is not free and landfill can even be forbidden.

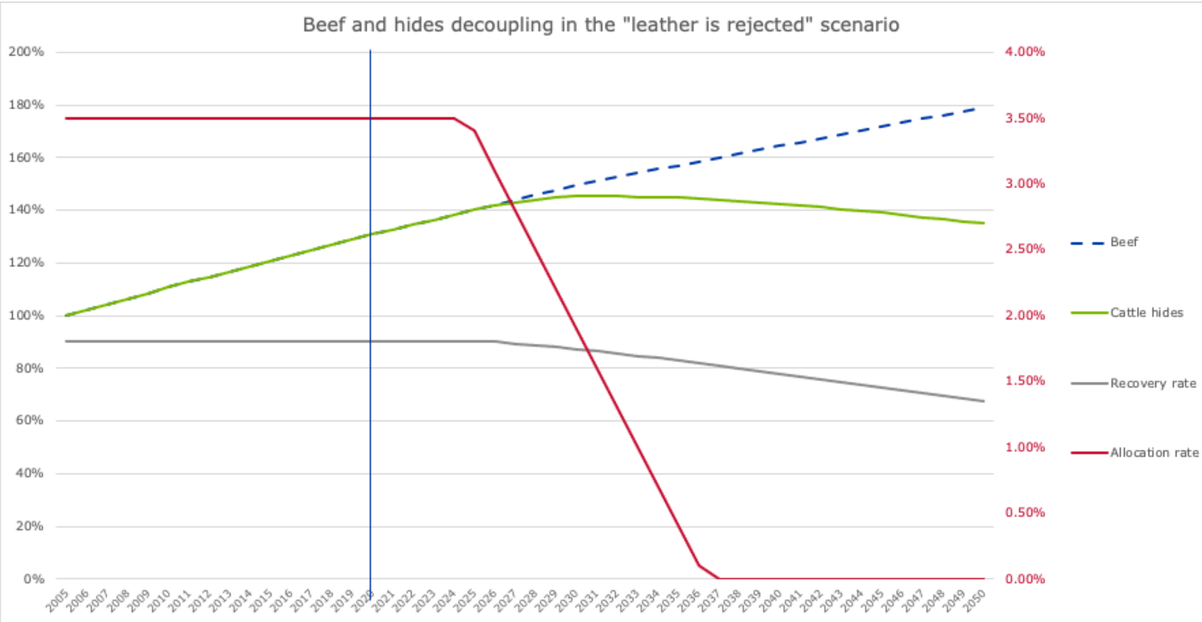

Figure 6: Recovery and allocation rates in the scenario where leather is rejected by consumers.

As a consequence, the allocation rate drops to zero by the same time (from the PEFRC rate of 3.5% until 2024, to zero in 2037), and leather production peaks in 2029 only to reach 2022 production level in 2050.

2. Leather comes back

Leather becomes less attacked by NGOs, the perception of using recovered material gains momentum and gives a positive image to leather. Competition with other materials is hard, but leather plays in the sustainable, bio-based materials field. Leather demand follows the increase of beef consumption, recovery rate remains at 90% (default cap).

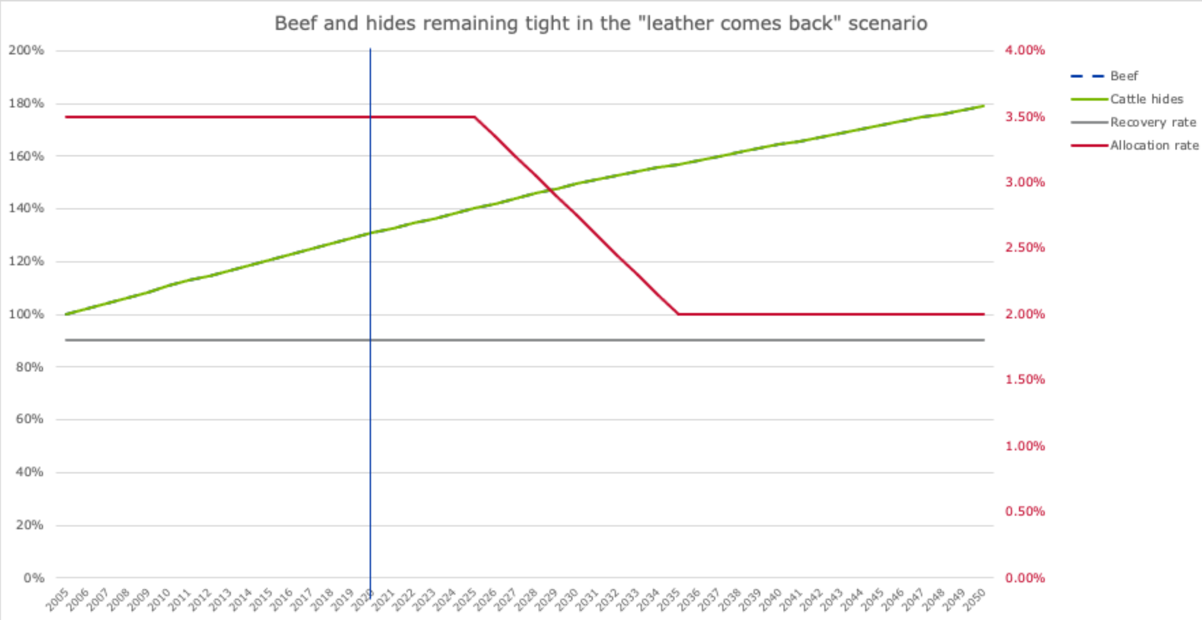

Figure 7: Recovery and allocation rates in the scenario where leather comes back into positive perception by consumers.

Despite the positive image, leather prices are maintained at the relatively low levels of 2021, and never get back to high levels that justified the 3.5% allocation of the PEFCR.

Hence, by decision of the interested parties, the allocation rate is progressively corrected over a decade, from 3.5% in 2025 to 2% in 2035.

3. Middle-ground scenario

This scenario is built as the average of the two previous scenarios.

A decoupling of the leather demand and the beef industry becomes clear in the 2030's, where prices drop significantly. The hide recovery rate is reduced to 79% in 2050.

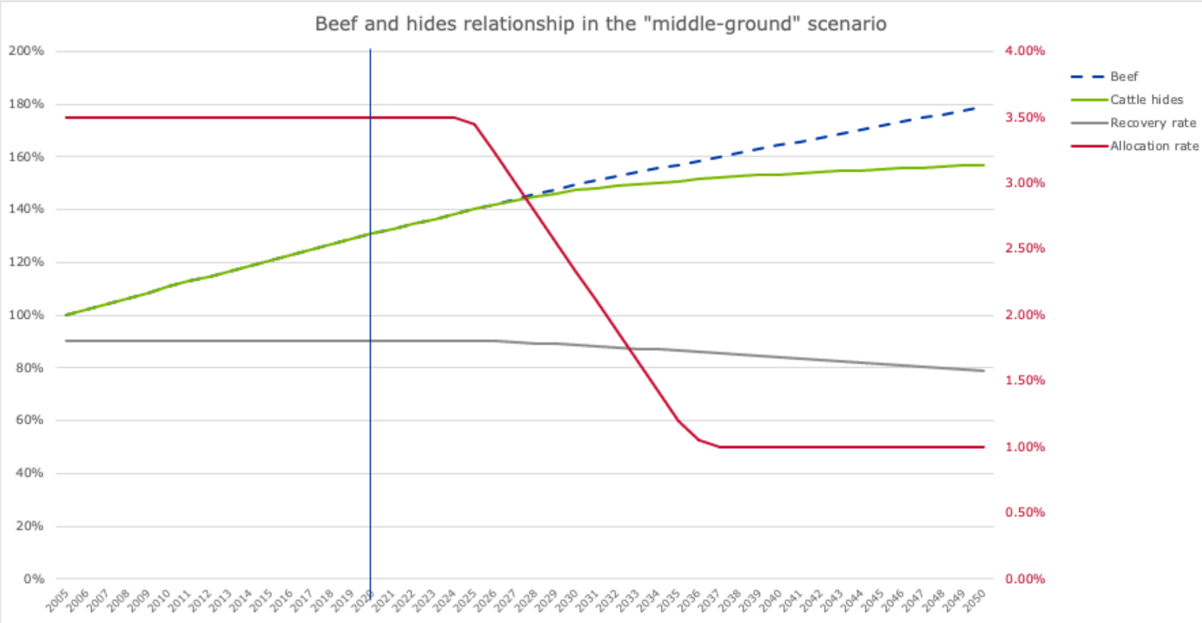

Figure 8: Recovery and allocation rates in the middle-ground scenario.

Calculation is made for the world average. Regions follow the world curve in a parallel way. We have no indication, at this stage, allowing to determine if a region would follow another trend, or would follow a similar trend with a time shift.

8. A8. Additional commodity pathway modifications

Moisture content

For all commodities, IMAGE source data used in the tool are expressed in the metric of tons of dry matter (DM); however, the end-use of the tool inputs fresh matter as the common unit of measurement for companies. The conversion from dry matter to fresh matter has been implemented in the tool using the moisture content shown in Table A8-1.

Table A8-1: Moisture content used to convert dry matter to fresh matter of the commodities

Commodity	Moisture content	kg fresh/kg DM
Beef	50%	2.00
Chicken	50%	2.00
Dairy	87%	7.69
Maize	12%	1.14
Palm oil	0.2%	1.002
Pork	50%	2.00
Rice	13%	1.15

Soya	8%	1.09
Wheat	12%	1.14
Leather	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.		

Intensity cap

The commodity pathways were updated so that no increases in emission intensity are permitted. The original pathway calculation formula would, in some cases, allow an increase of the emissions intensity pathway if the starting point for the user is low compared to the regional average. 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.

9. A9. Calculations of regional non-LUC emission intensity for roundwood

	Hardwood Species															Softwood species										Emission intensity	
Image_Region	Species 1	Proxy	kg CO2 eq /m3	Avg. Rotation	Share*	Species 2	Proxy	kg CO2 eq /m3	Avg. Rotation	Share*	Species 3	Proxy	kg CO2 eq /m3	Avg. Rotation	Share*	Species 1	Proxy	kg CO2 eq /m3	Avg. Rotation	Share	Species 2	Proxy	kg CO2 eq /m3	Avg. Rotation	Share	kg CO2 eq /m3 year**	References
Brazil	*Eucalyptus sp.*	Ecoinvent Eucalyptus TH	19.10	12	0.71											*Pinus sp.*	Pine plantation Salles Ferro et al 2018	8.54	12.00	0.29						1.34	1,2,7
Canada																*Picea sp.*	Mix softwood ecoinvent boreal	24.70	100.00	1.00						0.25	1 , 7
Central America	*Mix softwoods*	Birch RoW	9.85	40	0.83											*Pinus*	Pinus RoW	11.80	40.00	0.17						0.25	1, 7
Central Asia																	China emission factor as proxy									0.60	
Central Europe	*Salix sp.*	Average of Sweden intensive and extensive	11.20	11	0.09	Birch	Ecoinvent Birch Ro2	9.85	40	0.09	Populus	Italy populus average of intensive and extensive	10.25	10	0.09	*Pinus sp.*	Average of pines in Europe and	11.77	80.00	0.37	*Picea*	Average of of Spruce	10.36	80	0.37	0.31	1, 3,4, 5, 7
China region	*Cunninghamia lanceolata*	Ecoinvent pine parana	28.00	30	0.40	Populus sp.	Poplar Italy extensive Gonzalez-Garcia et al	11.00	30	0.40						*Pinus sp.*	Ecoinvent pinus extensive (RoW)	11.80	30.00	0.20						0.60	1, 5, 7
Eastern Africa																	Using Western Africa emission factor as									0.28	
India	*Eucalyptus, Acacia*	Ecoinvent Eucalyptus TH	19.10	18	0.88											*Pinus sp.*	Ecoinvent pinus extensive (RoW)	11.80	25.00	0.12						0.99	1,7
Indonesia region	*Eucalyptus, Acacia*	Ecoinvent Eucalyptus TH	19.10	25	1.00												as HW includes short term rotations species									0.76	1
Korea region																	Same emission as China as proxy									0.60	
Mexico	*Mix softwoods*	Birch RoW	9.85	40	0.13											*Pinus*	Pinus RoW	11.80	40.00	0.87						0.29	
Middle East																											
Northern Africa	*Acacia sp.*	Eucalyptus extensive	8.30	28	0.35											*Pinus sp.*	Rest of the world	11.80	60.00	0.65						0.23	3, 8
Oceania	*Eucalyptus sp.*	Eucalyptus Portugal intensive	16.90	12	0.36											*Pinus sp.*	Pinus Portugal plantation intensive	11.20	30.00	0.64						0.75	1, 3, 6, 7
Rest of South America	*Eucalyptus sp.*	Eucalyptus Portugal intensive	16.90	12	0.66											*Pinus sp.*	Ecoinvent pinus extensive (RoW)	11.80	30.00	0.34						1.06	1
Rest of South Asia	*Mix HW*	Eucalyptus Portugal intensive	16.90	25	1.00																					0.68	1, 7
Rest of Southern Africa	*Eucalyptus sp.*	Eucalyptus Portugal extensive	8.30	20	0.64											*Pinus sp.*	Pinus Portugal plantation extensive	4.80	30.00	0.36						0.32	3
Russia region																*Mix softw*	Mix softwoods ecoinvent boreal	24.70	100.00	1.00						0.25	7
South Africa	*Eucalyptus*	Eucalyptus Portugal intensive	16.90	12	0.56											*Pinus sp.*	Pinus Portugal plantation intensive	11.20	30.00	0.44						0.95	1, 3, 7
Southeastern Asia																	Same emission factors as South East Asia									0.68	
Turkey	*Oak*	Birch RoW	9.85	40	0.31											*Pinus*	Pinus RoW	11.80	80.00	0.69						0.18	1, 7
Ukraine region																	Same emission factors as Central Europe									0.31	
USA	*Mix HW*	Birch RoW	9.85	40	0.26											*Pinus sp.*	Pinus taeda SE intensive	35.25	25.00	0.37	*Other pines*	Extensive pine ecoinvent	11.80	80	0.37	0.64	
Western Africa	*Acacia sp.*	Eucalyptus Portugal extensive	8.30	30	1.00																					0.28	
Western Europe	*Salix sp.*	Average of Sweden intensive and extensive	11.20	11	0.10	Birch	Ecoinvent Birch Ro2	9.85	40	0.10	Populus	Italy populus average of intensive and extensive	10.25	10	0.10	*Pinus sp.*	Average of pines in Europe and	11.77	80.00	0.36	*Picea*	Average of of Spruce	10.36	80	0.36	0.32	1, 3,4,5, 7
WORLD																										0.57***	

*The share between hardwood and softwood was calculated based on national production volume from FAO (year 2015) and aggregated into IMAGE regions. ** The emission intensity of each wood type and region is the average of the intensity emission of main species. The rotation lengths were u calculated as the weighted average of emissions factors of SW and HW based on the share of SW and HW.*** Weighted average of emission intensity based on production volumes.

1 Arets, E. J. M. M., Van der Meer, P. J., Verwer, C. C., Hengeveld, G. M., Tolkamp, G. W., Nabuurs, G. J., & Van Oorschot, M. (2011). Global wood production: assessment of industrial round wood supply from forest management systems in different global regions (No. 1808)

2 Ferro, Fabiane Salles, et al. "Environmental Life Cycle Assessment of industrial pine roundwood production in Brazilian forests." Science of The Total Environment 640 (2018): 599-608.

3 Dias, A. C., & Arroja, L. (2012). Environmental impacts of eucalypt and maritime pine wood production in Portugal. Journal of Cleaner Production, 37, 368-376.

4 González-García, S., Moreira, M. T., Dias, A. C., & Mola-Yudego, B. (2014). Cradle-to-gate Life Cycle Assessment of forest operations in Europe: environmental and energy profiles. Journal of cleaner production, 66, 188-198.

5 González-García, S., et al. "Comparing environmental impacts of different forest management scenarios for maritime pine biomass production in France." Journal of cleaner production 64 (2014): 356-367

6 May, B., et al. "Review of fertiliser use in Australian forestry." Forest and wood products Australia limited project number: RC072–0708. Victoria, Australia (2009).

7 Ecoinvent Database. Available at: https://ecoinvent.org/the-ecoinvent-database/ (Accessed July 2022)

8 Global planted forests thematic study: results and analysis, by Del Lungo, A., Ball, J. and Carle J. Planted Forests and Trees, Working Paper 38. Food and Agriculture Organization of the United Nations, Rome, Italy.