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CORSIA Methodology for Calculating Actual Life Cycle Emissions Values

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CORSIA

Carbon Offsetting and Reduction Scheme for International Aviation

This ICAO document is referenced in Annex 16 — *Environmental Protection*, Volume IV — *Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*. This ICAO document is material approved by the ICAO Council for publication by ICAO to support Annex 16, Volume IV and is essential for the implementation of the CORSIA. This ICAO document is available on the ICAO CORSIA website and may only be amended by the Council.

Table A shows the origin of amendments to this ICAO document over time, together with a list of the principal subjects involved and the dates on which the amendments were approved by the Council.

Table A. Amendments to the ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values"

Amendment	*Source(s)*	*Subject(s)*	*Approved*
1st Edition	Eleventh meeting of the Committee on Aviation Environmental Protection	First edition of the document.	25 Nov 2019
2nd Edition	2020 Steering Group meeting of the Committee on Aviation Environmental Protection	a) Addition of a sentence of clarification in Section 5, in order to consider possible direct land use change emissions associated with the conversion of high carbon dense ecosystems under the "unused land approach"; and b) Addition of clarifications to allow operators to claim the benefits of SAF feedstocks produced with "low LUC risk practices", without the need to wait for the inclusion of the feedstock in the ICAO document "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels".	12 March 2021
3rd Edition	Twelfth meeting of the Committee on Aviation Environmental Protection	a) Inclusion of methodologies to determine the emissions reductions from the use of CORSIA Lower carbon aviation fuels (LCAF) and eligibility against Sustainability Criterion 1.1 defined in the ICAO document "CORSIA Sustainability Criteria for CORSIA Eligible Fuels" b) Additional requirements for Landfill Emissions Credits (LEC) and Recycling Emission Credits (REC) c) Amendments to the low land use change (LUC) risk methodologies d) New methodology to obtain Direct Land Use Change (DLUC) emissions e) Inclusion of life cycle assessment methodologies for co-processed fuels f) Amendments to the positive list of wastes, residues, or by-products g) inclusion of a flowchart depicting the various methodologies available to calculate life cycle emission values of CORSIA eligible fuels.	3 June 2022

Amendment	*Source(s)*	*Subject(s)*	*Approved*
4th Edition	2023 Steering Group meeting of the Committee on Aviation Environmental Protection	a) inclusion of non-standard coconut, beef tallow, poultry fat, lard fat, and mixed animals fat in the positive list of wastes, residues and by-products b) explicit inclusion of transportation emissions downstream the fuel blender in the system boundary of core LCA values c) general restructuring of Section 2 of the document, and consequential amendments arising from the adoption of the second edition of Annex 16, Vol IV.	11 March 2024
5th Edition	2024 Steering Group meeting of the Committee on Aviation Environmental Protection	a) inclusion of wheat starch slurry and cobs as a processing residue in the positive list of wastes, residues and by-products	28 October 2024

CORSIA METHODOLOGY FOR CALCULATING ACTUAL LIFE CYCLE EMISSIONS VALUES

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1 ACRONYMS

API	American Petroleum Institute (API gravity)
bbl	Barrel
CCS	Carbon Capture and Sequestration
CEF	CORSIA eligible fuel. A CORSIA sustainable aviation fuel or a CORSIA lower carbon aviation fuel, which an operator may use to reduce their offsetting requirements
CH_4	Methane
CI	Carbon Intensity
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DLUC	Direct Land Use Change
DOC	Degradable organic carbon
DOC_F	Fraction of degradable organic carbon dissimilated
GHG	Greenhouse gas
GWP	Global warming potential
H_2	Hydrogen
ICAO-GREET	GREET model (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) for ICAO
ILUC	Induced land use change
ISO	International Organization for Standardization
LC	Baseline life cycle emissions values for aviation fuel, equal to 89 gCO_2e/MJ for Jet-A / Jet-A1 / Jet-B / TS-1 / No. 03 Jet Fuel and equal to 95 gCO_2e/MJ for AvGas.
LCA	Life cycle assessment
LCAF	Lower Carbon Aviation Fuel
LEC	Landfill emissions credit
LFG	Landfill gas
LFGCE	Landfill gas collection efficiency
LHV	Lower heating value
LMP	Land management practice

LUC	Land use change
L_{CEF}	Life cycle emissions value for a CORSIA eligible fuel in gCO_2e/MJ
MCF	Methane correction factor
MCON	Marketed Crude Oil Name
MIT	Massachusetts Institute of Technology
MSW	Municipal solid waste
N_2O	Nitrous oxide
OPGEE	Oil Production Greenhouse Gas Emissions Estimator
PRELIM	The Petroleum Refinery Life Cycle Inventory Model
REC	Recycling emissions credit
SAF	Sustainable aviation fuel
SCS	Sustainability certification scheme
SMR	Steam methane reforming
VFF	Venting, Flaring and Fugitives emissions

2 CORSIA METHODOLOGY FOR CALCULATING ACTUAL LIFE CYCLE EMISSIONS VALUES

2.1 General provisions

An aeroplane operator that intends to claim for emissions reductions from the use of CORSIA eligible fuels in a given year may use an Actual Life Cycle Emission Value or a Default Life Cycle emission value to compute these emission reductions (reference: Annex 16 Vol IV Part II Section 3.3.).

To use an Actual Life Cycle Emissions value, an Aeroplane Operator will have to provide documentation to their State showing compliance with the methodologies defined in this document. An Aeroplane Operator will need to work with a CEF supplier to obtain this information.

An Aeroplane Operator may use an actual life cycle value as part of an accepted fuel sustainability certification process if a fuel producer can demonstrate lower life cycle emissions compared to the default life cycle values provided in the ICAO document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels", or if a fuel producer has defined a new pathway that does not have a default life cycle value. If the Aeroplane Operator chooses to use an actual life cycle value, then the Aeroplane Operator will select an eligible Sustainability Certification Scheme from the ICAO document entitled "CORSIA Approved Sustainability Certification Schemes" to ensure the analysis is in accordance to the LCA methodology defined in this document. The SCS will ensure that the methodology is applied correctly and that relevant information on GHG emissions is transmitted through the chain of custody. The SCS will record detailed information about the calculation of actual values within their system and provide this information to ICAO on request.

The functional unit for final L_{CEF} results will be grams of CO_2e per megajoule of fuel produced and combusted in an aircraft engine, in terms of lower heating value (gCO_2e/MJ).

The Life Cycle Emissions value is calculated from the following equation:

$$L_{CEF} = \text{core LCA value} + \text{ILUC} - \text{emission credits; where:}$$

a) core LCA value is obtained from one of the following cases:

Case	Description	core LCA value
Case A	CEF is a CORSIA SAF based on primary or co-product feedstocks according to Section 4 of this document.	Calculated with the methodologies provided in Section 2.2
Case B	CEF is a co-processed CORSIA SAF	Calculated with the methodologies provided in Sections 2.2, 2.3 and 2.4
Case C	CEF is a CORSIA SAF based on Waste, residue, and by-product feedstocks according to Section 4 of this document.	Calculated with the methodologies provided in Sections 2.2 and 2.4
Case D	CEF is a CORSIA LCAF	Calculated with the methodologies described in Section 2.2 and Section 7 (there are no default values for CORSIA LCAF)
Case E	CEF is a CORSIA SAF that has a default core LCA value approved by ICAO	Default core LCA value*

b) ILUC is obtained from one of the following cases:

Case	Description	ILUC value
Case 1	CEF is a CORSIA SAF produced from a feedstock that is defined as a waste, residue, or by-product according to Section 4 of this document.	ILUC=0
Case 2	CEF is a CORSIA SAF produced from a feedstock obtained with the use of mitigation practices that avoid ILUC emissions according to Section 5 of this document	ILUC=0
Case 3	CEF is a CORSIA SAF that: • does not fall within Cases 1 or 2, and • whose feedstocks were sourced from land obtained through land use conversion **before** 1 January 2008; and • whose feedstock has a default ILUC value*	default ILUC value*
Case 4	CEF is a CORSIA SAF that: • does not fall within Cases 1 or 2, and • whose feedstocks were sourced from land obtained through land use conversion **after** 1 January 2008; and • whose feedstock has a default ILUC value*	direct land use change (DLUC) emissions will be calculated according to Section 8 of this document. if DLUC > default ILUC, then ILUC is replaced by DLUC. Otherwise ILUC = default ILUC*
Case 5	CEF is a CORSIA SAF that: • does not fall within Cases 1 or 2, and • whose feedstock does not have a default ILUC value*	default core LCA value and a default ILUC value will need to be added to the ICAO document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels" before the SAF feedstock can be included in CORSIA. *Note.— Information on how fuels can be added to the ICAO document entitled "CORSIA* Default *Life Cycle Emissions Values for CORSIA Eligible Fuels" can be found in Part I of the CORSIA Supporting Document "CORSIA Eligible Fuels* - *Life Cycle Assessment Methodology".*
Case 6	CEF is a CORSIA LCAF	ILUC=0
Case 7	CEF is a co-processed CORSIA SAF	Cases 1 to 5 apply equally to co-processed CORSIA SAF.

* default ILUC values and default core LCA values are provided in the ICAO document *"CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels"*.

c) emission credits are obtained with the methodologies listed in Section 6. The use of emission credits is optional.

2.2 Actual core LCA calculation – general provisions

The system boundary of the core LCA value calculation will include the full supply chain of CEF production and use. As such, the core LCA value will be obtained by summing up the emissions associated with the following life cycle stages of the CEF supply chain:

(1) production at source (e.g., feedstock cultivation);
(2) conditioning at source (e.g., feedstock harvesting, collection, and recovery);
(3) feedstock processing and extraction;
(4) feedstock transportation to processing and fuel production facilities;
(5) feedstock-to-fuel conversion processes;
(6) fuel transportation and distribution to the blend point;
(7) fuel transportation from the blending point to the aircraft uplift location; and
(8) fuel combustion in an aircraft engine.

For life cycle stages 1-7, carbon dioxide equivalent (CO_2e) emissions of CH_4, N_2O and non-biogenic CO_2 from these activities will be calculated on the basis of a 100-year global warming potential (GWP). CO_2e values for CH_4 and N_2O will be based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (28 and 265, respectively).

For life cycle stage 7, the emissions associated to transportation downstream of the blender can be estimated by the economic operator (blender) according to the CORSIA Methodology for Calculating Actual Life Cycle Emissions Values, or be determined by the use of default values from the CORSIA Supporting Document "Life Cycle Assessment Methodology", both options being valid for the emissions accounting.

For life cycle stage 8 only non-biogenic CO_2 emissions from fuel combustion will be included in the calculation of CO_2e emissions.

The core LCA values will include upstream emissions associated with the material and utility inputs for operational activities, such as processing chemicals, electricity, and natural gas. Emissions generated during one-time construction or manufacturing activities (e.g., fuel production facility construction, equipment manufacturing) will not be included.

In many cases, the CEF supply chain of interest will result in the co-production of multiple commodities. Examples of co-products include non-CEF liquid fuels, chemicals, electricity, steam, hydrogen, and/or animal feed. Energy allocation will be used to assign emissions burdens to all co-products in proportion to their contribution to the total energy content (measured as lower heating value) of the products and co-products. CO_2e emissions will not be allocated to waste, residues and by-products that result from the CEF supply chain of interest.

2.3 Actual core LCA calculation – specific provisions for co-processed CORSIA SAF

For co-processing, a fuel producer will measure/estimate all inputs and outputs of the facility for scenarios both with and without co-processing operations. Refinery configuration changes will be limited to adding the co-processing facility to rule out other confounding factors in emission changes. The inputs include crude oil, bio-feed, energy input by type (e.g., natural gas and electricity), and any materials. The outputs include fuel products and refinery emissions. Crude oil inputs are normalized (see Figure 11 of the CORSIA Supporting document "LCA methodologies" for additional details on normalization). By subtracting the base (petroleum only) case from the co-processing case, the fuel producer calculates the changes in inputs and outputs. First, the changes in refinery emissions are allocated to the changes in fuel production (MJ). Since biogenic carbon emissions need to be carbon-neutral, carbon balance will be used to estimate biogenic carbon emissions from the refinery, which is then subtracted from the total refinery emissions. In order to calculate the upstream emissions associated with the changes in energy inputs, an LCA tool (e.g., GREET) needs to be used. The upstream emissions of the energy inputs are then allocated to the changes in fuel production (MJ). Based on the calculated bio-feedstock input allocated to MJ fuel production, emissions associated with bio-feedstock production and transportation can be calculated using the LCA tool. Similarly, downstream (fuel transportation/distribution and combustion) emissions can be calculated. Note that co-processed SAFs are considered to be biogenic, so CO_2 emissions from fuel combustion are not accounted for. Sustainability certification schemes (SCS) may prescribe measurements techniques (including but not limited to C14 testing and mass balance) and protocol (based on energy allocation as described in Section 2.2 to assign biogenic carbon content among the product and co-products, in proportion to their contribution to the total energy content), as a means to verify the modelled changes in inputs and outputs.

2.4 Actual core LCA calculation – specific provisions for CORSIA SAFs based on Waste, residue, and by-product feedstocks

Waste, residue, and by-product feedstocks as defined in Section 4 are assumed to incur zero emissions during the feedstock production, i.e., life cycle stage 1 described in Section 2.2. Emissions generated during the collection, recovery, extraction, and processing of these wastes, residues, and by-products, however, will be included (life cycle stages 2-8 described in Section 2.2).

3 TECHNICAL REPORT REQUIREMENTS

3.1 Reporting requirements

The SCS will require economic operators to document all relevant data appropriately in a Technical Report, which is verified by an accredited certification body. Upon request, the economic operator will submit the Technical Report to the SCS and on request, the SCS will submit the report to ICAO.

Relevant data include:

a) GHG emissions by life cycle step within the scope of certification, broken out by GHG emission species and aggregated in CO_2e (100 year GWP). The system boundary of the core LCA value calculation will include the full supply chain of CEF production and use. As such, emissions associated with the life cycle stages of the CEF supply chain listed in Section 2.2 will be accounted for.

b) The LCA inventory data by life cycle step within the scope of certification, including all energy and material inputs. For life cycle steps 1-4, the inventory data are to be provided per mass of feedstock, for the other steps per total fuel energy yield (MJ of fuel).

c) Emission factors used for calculating GHG emissions associated with energy and material inputs, including information about the source for the emission factors.

d) All relevant feedstock characteristics within the scope of certification, such as, for example, agricultural yield, lower heating value, moisture content, the content of sugar, starch, cellulose, hemicellulose, lignin, vegetable oil, or any other energy carrier (as applicable to feedstock of interest).

e) Quantities for all final and intermediate products, per total energy yield.

f) If Municipal Solid Waste is being used as a feedstock, then all relevant data required for the calculation of landfill emissions credits and recycling emissions credit will be disclosed to the SCS according to the MSW crediting methodology in Section 6 on “Emissions Credits”, on an annual basis.

g) In case a low LUC risk practice is being used, all relevant data required for the calculation and certification will be disclosed according to the Low LUC Risk Practices methodology.

The SCS will report evidence that the certification body has verified that the economic operator has accurately followed the methodology specified in this document to calculate its actual LCA value using the most recent and scientifically rigorous data available, and that the LCA value calculation is complete, accurate and transparent.

The SCS will report information on chain of custody system employed.

Data will be recorded and reported to ICAO upon request in a format conducive to re-calculation and verification, for example as a spreadsheet in .csv or .txt file format.

3.2 Flow of information along the supply chain for actual LCA values

Each economic operator along the supply chain will implement a robust and transparent system to track the flow of data outlined in Section 2.2, along the supply chain ("chain of custody system").

Tracking will occur each time the feedstock or fuel passes through an internal processing step or changes ownership along the supply chain.

The SCS will implement procedures that allow verification that the economic operator has used an appropriate chain of custody system.

4 FEEDSTOCK CATEGORIES

4.1 Definitions

Primary and co-products are the main products of a production process. These products have significant economic value and elastic supply, (i.e., there is evidence that there is a causal link between feedstock prices and the quantity of feedstock being produced).

By-products are secondary products with inelastic supply and economic value.

Wastes are materials with inelastic supply and no economic value. A waste is any substance or object which the holder discards or intends or is required to discard. Raw materials or substances that have been intentionally modified or contaminated to meet this definition are not covered by this definition.

Residues are secondary materials with inelastic supply and little economic value. Residues include:

a) Agricultural, aquaculture, fisheries and forestry residues: Residues directly deriving from or generated by agriculture, aquaculture, fisheries and forestry.

b) Processing residues: A substance that is not the end product that a production process directly seeks to produce; the production of the residue or substance is not the primary aim of the production process and the process has not been deliberately modified to produce it.

4.2 Positive list of materials classified as co-products, residues, wastes or by-products

The positive list provided in Table 1 includes feedstocks that have been classified as by-product, wastes and residues. It has been arrived at considering a broad range of publicly-available regulatory and voluntary approaches.

The positive list is non-exhaustive. It includes materials currently in use or in discussion to be used for sustainable aviation fuel.

The classification of specific feedstocks as by-products is subject to later revisions as part of the regular CORSIA review process in case there is strong scientific evidence showing that significant indirect effects could be associated to these feedstocks.

Table 1. Positive list of materials classified as co-products, residues, wastes or by-products

Residues	**Wastes**	**By-products**	**Co-products**
Agricultural residues:	Municipal solid waste (see details in Section 4.2.2)	Palm Fatty Acid Distillate	Molasses
Bagasse	Used cooking oil	Beef Tallow	
Cobs	Waste gases	Technical corn oil	
Stover		Non-standard coconuts (see details in Section 4.2.3)	
Husks		Poultry fat	
Manure		Lard fat	
Nut shells		Mixed Animals Fat	
Stalks			
Straw			
Forestry residues:			
Bark			
Branches			
Cutter shavings			
Leaves			
Needles			
Pre- commercial thinnings			
Slash			
Tree tops			
Processing residues:			
Crude glycerine			
Cobs			
Forestry processing residues			
Empty palm fruit bunches			
Palm oil mill effluent			
Sewage sludge			
Crude Tall Oil			
Tall oil pitch			
Wheat Starch Slurry (see details in Section 4.2.1)			

4.2.1 Specifications for wheat starch slurry

Wheat starch slurry is the leftover residue from wheat processing. The slurry is the residual product following several washing steps to separate the primary products – food grade wheat starch (A-type starch) and gluten. Processing steps include centrifuging to accurately separate A-type and B-type starches. The end result of processing is a slurry comprised of:

- B-type starch granules that measure up to 10 µm[1] in diameter, and have been subjected to centrifugal separation, such that any remaining food grade A-type starch cannot be practically recovered
- Some other residues from wheat processing such as pentosans, proteins and some remaining A-type starch granules
- Solid matter not exceeding 20%

4.2.2 Specifications for MSW

Note: as of the current version of this document, plastics are not included in the list of wastes, residues, or by-products approved by ICAO to produce SAF and claim emissions reductions under CORSIA. Under MSW, plastics will be considered as non-biogenic content.

4.2.3 Specifications for non-standard coconuts

"Non-standard coconuts" are inedible coconuts unintentionally obtained in coconut farms, collection centers or edible coconut oil industry, which meet any of the following criteria:

A) Too small; Too small coconuts are produced due to immaturity by nature. They cause inefficiencies for production processes in edible coconut product industries. Small size can be identified by weight or diameter of coconuts.

B) Sprouted; Coconuts sprout due to precocious development, or to exposure to moisture after harvest. They do not have enough nutrients for human consumption. Sprouts can be detected visually.

C) Cracked; Coconuts are cracked when they are damaged during de-husking, delivery, or storing processes, or when they are discarded by edible coconut product industries. Cracked coconuts become rotten and unsuitable for human consumption. Cracks can be detected visually.

D) Rotten; Coconuts deteriorate and rot when they are unharvested, cracked, or precocious, or when they are discarded by edible coconut product industries. They contain harmful substances to human health. Rottenness can be identified visually by the outer shell color (turned in black) and/or the molds.

[1] See Peng et al, (1999), "Separation and Characterization of A- and B-Type Starch Granules in Wheat Endosperm", *Cereal Chemistry*. 76(3):375–379.

4.3 Inclusion of new materials in the positive list

The positive list is an open list. The ICAO Council can add materials to it, according to the definitions of feedstocks above and using the process shown in Figure 1 as a guide:

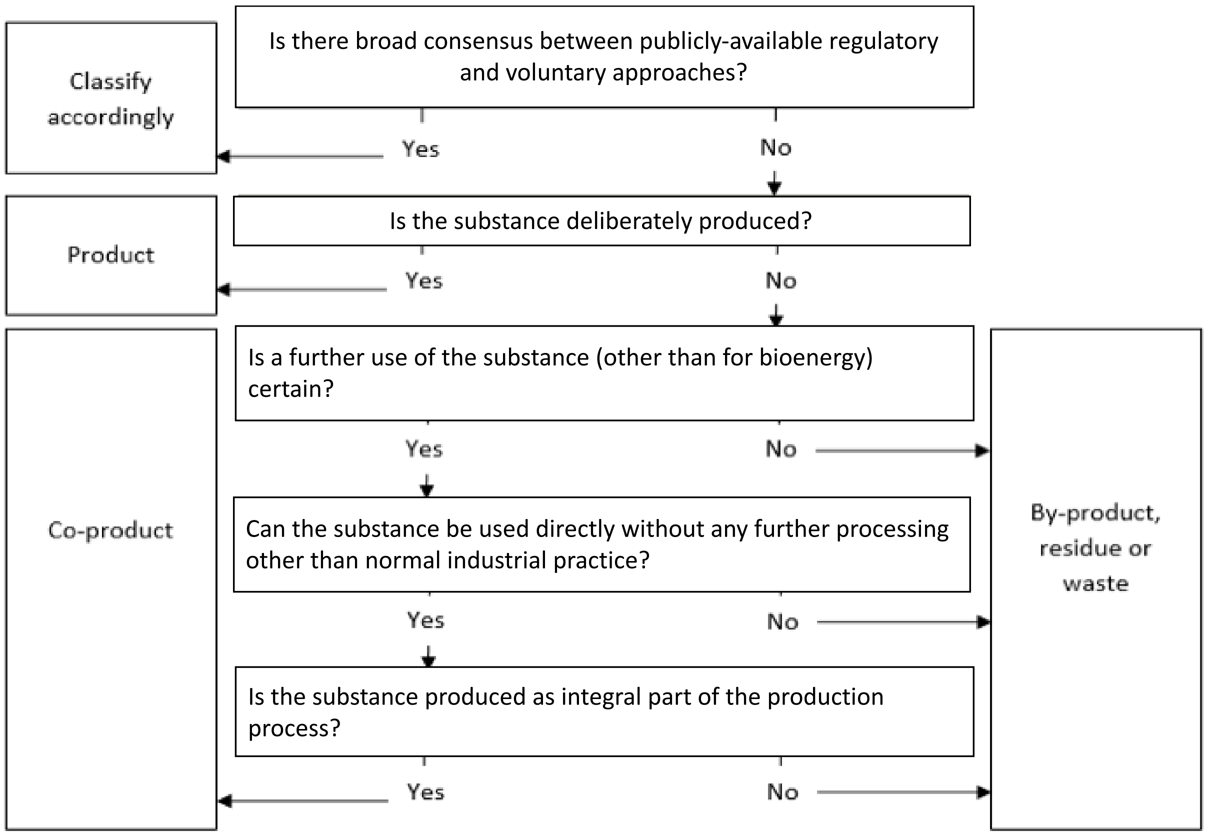


Figure 1. Guidance for inclusion of additional materials in positive list

Note: The CORSIA Supporting Document "CORSIA Eligible Fuels - Life Cycle Assessment Methodology" describes the process for requesting the inclusion of new materials in the positive list of materials classified as co-products, residues, wastes or by-products

5 LOW LAND USE CHANGE (LUC) RISK PRACTICES

Aeroplane Operators may choose to capture the benefits of utilizing land use change-risk mitigation practices, (e.g., land management practices) to avoid ILUC emissions as part of an accepted fuel sustainability certification process (see ICAO document "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes"). Mitigation practices that avoid ILUC emissions and the requirements that will be met to obtain these reductions can be found in this Section. The ILUC value of zero will be used in place of the default ILUC value to calculate total L_{CEF}. If the Aeroplane Operator chooses to claim emissions reductions from the implementation of land use change-risk mitigation practices, then the Aeroplane Operator will select an eligible Sustainability Certification Scheme from the ICAO document "CORSIA Approved Sustainability Certification Schemes" to provide documentation that the fuel was produced using land use change-risk mitigation practices according to this Section.

Feedstocks that are "low risk" for land use change have been identified and assigned as having zero emissions from land use change. The low land use change risk feedstock list includes: (1) feedstocks that do not result in expansion of global agricultural land use for their production; (2) wastes, residues, and by-products (see Section 4); and (3) feedstocks that have yields per surface unit significantly higher than terrestrial crops (~ one order of magnitude higher) such as some algal feedstocks. The feedstocks in these three categories will all receive an ILUC value of zero in the fourth column of the table in the ICAO document "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels".

For the purposes of CORSIA, using certain types of land, land management practices (LMP), and the incorporation of innovative agricultural practices could all be considered as contributing to low risk for land use change and therefore receive a value of zero for ILUC. The implementation of these low LUC risk practices for a project will avoid market mediated responses that lead to changes in land use, and lead to additional SAF feedstock available relative to a baseline, without increasing land requirements. It is assumed that under these practices increased emissions from direct LUC are negligible. If this is not the case, compliance with sustainability criterion 2.2 will be demonstrated.

SCS with a methodology consistent with the principles and criteria listed below could be authorized by the ICAO Council to assess the implementation of low LUC risk practices and certify their low LUC risk status on a case-by-case, project-specific basis. The methodology will be open, documented, and publicly communicated. SCS certification documentation must include a description of the low LUC risk method used and a description of the main features of the applied method.

Feedstocks designated under the Low LUC Risk Practices approach are designated as such until 2030, subject to periodic audits to ensure ongoing compliance with the original requirements when the feedstocks were certified by the SCS.

CORSIA approved SCSs will ensure that Low LUC claims are correctly tracked through the Chain of Custody and implement appropriate measures to ensure that no double-claiming of low LUC risk certified feedstocks and CEF occurs. This requires, among other measures, reviewing the CEF supply chain with the respective economic operators, including the mass balances and claims made not related to CORSIA.

The measures implemented will comply with the CORSIA sustainability criteria to account for, amongst other examples, situations where the low LUC risk practices may otherwise have a negative impact on environmental and social services of the land and resources used, or negatively affect the uses or productivity of resources in other places.

In all cases, this methodology considers that, for a specific project to be eligible for recognition as a low LUC risk practice, the practice will be verified as a net enhancement in SAF feedstock available per unit of land.

There are two approaches for low LUC risk SAF feedstock production:

a) Yield Increase Approach.

b) Unused Land Approach.

Low LUC risk practices implemented on or after 1 January 2016 could be eligible. The feedstock producer needs to provide credible and verifiable evidence of the nature of the new land management practice, timing of its implementation and level of additional feedstock production. Exceptionally, practices implemented between 1 January 2013 to 31 December 2015 may be accepted where it can be demonstrated that low LUC risk practices were implemented primarily as a result of demand for biofuels. This would have to be demonstrated on a project-specific basis.

5.1 Yield increase approach

Eligible land management practices for the yield increase approach could include, among others, sequential cropping where more than one crop is planted per year, cover crops, the use of fallow land in a prescribed crop rotation, significant post-harvest loss reduction, and significant project level productivity increases due to the introduction of good practices and technology.

The Yield Increase approach applies to any situation where feedstock producers are able to increase the amount of available feedstock out of a fixed area of land (i.e. without expanding the surface of the land). An increase in the harvested feedstock may be the result of:

a) an improvement in agricultural practices, (practices that increase yields through means such as increased organic matter content, reduced soil compaction/erosion, decreased pests, post-harvest loss reduction, etc.);

b) intercropping, (i.e. the combination of two or more crops that grow simultaneously, for example as hedges or through an agroforestry system);

c) sequential cropping, (i.e. the combination of two or more crops that grow at different periods of the year); and/or

d) improvements in post-harvest losses, (i.e. losses that occur at cultivation and transport up to but not including the first conversion unit in the supply chain).

If there is a decrease of the available feedstock for the food or feed market at the project level resulting from the LMP (e.g., reduced yield from the main crop) this will be accounted for in calculating the volume of low LUC risk SAF feedstock (i.e., the volume of low LUC risk SAF feedstock represents the net increase in feedstock after accounting for any reduction in production of the primary food/feed crop that had been grown historically). The calculation will be based on appropriate units of measurement (e.g. energetic value).

For annual crops, measurements of yield increases and post-harvest loss reduction relative to a baseline are calculated based on historical practices using the annual yield per unit of land based on data from the preceding 5 years before the LMP measure takes effect from similar producers within the same region for the duration of the LMP measure. The low LUC risk feedstock thus represents additional feedstock obtained as a consequence of the improvement relative to the baseline.

For perennial crops, yield increase is calculated based on a standard growth curve of the same perennial crop from similar producers within the same region, as found in FAO and/or peer-reviewed data sources. Using a standard growth curve, the producer calculates its individual growth curve as a baseline and accounts for the additional yield achieved beyond this baseline after the implementation of the yield increase measure.

The amount of additional feedstock available and considered eligible for low LUC risk feedstock is calculated as follows:

1) For annual crops, the average amount of feedstock available historically, from the same or similar producers within the same region, is calculated based on actual net feedstock production (i.e., amount harvested less post- harvest losses) in the five years before the LMP measure takes effect. For perennial crops, the average amount of feedstock available historically is calculated based on a standard growth curve of the crop from the same or similar producers within the same region. Similar producers can be defined as producers growing the same (or equivalent) crops and using a similar management model (e.g., smallholder, small or large-scale plantation). For producers to be considered in the same region, the SCS must determine that the relevant location and site factors (e.g. soil, water and climate factors) are comparable and sufficiently representative.

2) The amount of feedstock available as a consequence of the LMP is calculated based on the current/new net feedstock production (amount harvested less post-harvest losses) that is attributable to the adoption of the new LMP measure.

3) The additional low LUC risk feedstock represents the difference between the values calculated via the two previous steps.

5.2 Unused land approach

Eligible lands for the unused land approach could include, among others, marginal lands, underused lands, unused lands, degraded pasture lands, and lands in need of remediation. Remote sensing data (when available) and other detective measures combined with auditing techniques such as interviews with local stakeholders may be needed to provide reliable results in the determination of land history and land status to verify “unused land” status.

For a land to be eligible for the unused land approach, it needs to meet one of the following criteria:

a) Land was not considered to be arable land or used for crop production during the five years preceding the reference date.

b) Land is identified as severely degraded land or undergoing a severe degradation process for at least three years, according to criteria proposed by a Sustainability Certification Scheme recognized under CORSIA, where the criteria are based on scientific literature.

For a land to be eligible for the unused land approach, it also needs to have little risk for displacement of provisioning services from that land onto different and equivalent amounts of land elsewhere. Provisioning services refer to products obtained from ecosystems such as food, animal feed, or bioenergy feedstocks. It can be assumed that the risk for displacement of provisioning services is little if the land was not used for provisioning of services in the three preceding years prior to the start of the LMP measure.

The amount of feedstock considered eligible for low LUC risk feedstock is equal to the amount of feedstock harvested for SAF production.

6 EMISSIONS CREDITS

The production of SAF from wastes and residues, as defined in Section 4 (Feedstock Categories), may generate emission credits that can be subtracted from the actual LCA values to calculate total L_{CEF}. If the Aeroplane Operator chooses to use a SAF that would generate such an emission credit, then the Aeroplane Operator will select an eligible Sustainability Certification Scheme from the CORSIA ICAO document "CORSIA Approved Sustainability Certification Schemes" to ensure the calculation of emission credits is in accordance with the specific methodologies defined in this document, as follows.

- Avoided Landfill Emissions Credit (LEC) for SAF derived from Municipal Solid Waste (MSW) – Section 6.1
- Recycling Emissions Credit (REC) for SAF derived from Municipal Solid Waste (MSW) – Section 6.2

The analysis to calculate these emission credits values will be documented in a technical report citing fully the data sources, such that the results are replicable and use the most recent data available. The technical report will also demonstrate that the emission credits claimed are permanent; directly attributable to the SAF production; exceed any emissions reductions required by law, regulation or legally binding mandate; exceed any GHG reductions or removals that would otherwise occur in a conservative, business-as-usual scenario that is assessed at a minimum every 7 years (including consideration of changing legal requirements, and key parameters); avoid double counting (including double issuance[2] or double claiming[3]) of such credits; and exceed emissions reductions that would otherwise occur in a business-as-usual scenario, including consideration of potential leakage.

Until additional requirements and guidance have been developed to resolve concerns regarding double counting for CEF, after the subtraction of credits, the total L_{CEF} value cannot be smaller than 0 gCO_{2e}/MJ.

Note: *the LEC and REC methodology (particularly LEC) currently are tailored to wastes that fall in the categories defined in the methodology, which are primarily materials that would come from household and municipal wastes, not construction/demolition wastes or industrial wastes.*

6.1 Methodology for calculation of landfill emissions credits

SAF produced from Municipal Solid Waste (MSW) feedstocks may generate an avoided Landfill Emissions Credit (LEC).

Economic operators will calculate credit volume as the portion in excess of what would be achieved if best management practices according to the regulations applicable to the landfill, particularly for management and collection of landfill gas, were implemented.

The economic operator will demonstrate that the economic activity does not lead to a reduction in recycling in the area of interest relative to that which would be recycled in the absence of the economic activity. Options for how this can be demonstrated include:

[2] In this instance, double issuance occurs when two or more credits or units are being issued for the same reduction.
[3] In this instance, double claiming occurs when the same unit was used by multiple entities.

a) Evidence that the materials recycled under the economic activity are recovered only from end-of-life-wastes and the economic operator is not claiming reductions from waste diverted through any existing recycling activity.

b) Directly measured final output of the recycling facility (e.g., weight of materials leaving the recycling facility (on a dry basis), segregated by type).

c) If the recycling facility is an existing activity, the average data on the amount of recycled materials from the previous three years of operation (a minimum of one-year data would be required if the facility is less than three years old) to be used for the estimation of the baseline recycling activity, with the activity of the economic operator consisting of the increase of the recycling capacity above this level.

The value of the LEC will be calculated as follows:

Step 1 – Estimate the proportional shares of each of the following four waste categories (*j*) that make up the MSW diverted from landfilling: paper/textiles; wood/straw; other (non-food) organic putrescible/garden and park waste; and food waste/sewage sludge. These shares should be expressed in terms of the dry mass of each waste category (*j*) per dry mass of MSW diverted from landfilling (before additional sorting and recycling, if applicable) (eg. $W_{paper/textiles}$ = 0.4 dry tonne per dry tonne of MSW).

Step 2 – Select the degradable organic carbon content (DOC) and the fraction of carbon dissimilated (DOC_F) values from Table 2 that best represent each waste category (*j*) in the MSW. Use weighted averages to generate DOC and DOC_F values that accurately represent each of the four waste categories of the MSW feedstock of interest.

Table 2. DOC and DOC_F

Material	DOC[4] (% of dry matter)	DOC_F (%)
Corrugated containers	47%	45%
Newspaper	49%	16%
Office paper	32%	88%
Coated paper	34%	26%
Food waste	50%	84%
Grass	45%	46%
Leaves	46%	15%
Branches	49%	23%
Gypsum board	5%	45%
Dimensional lumber	49%	12%
Medium-density fiberboard	44%	16%
Wood flooring	46%	5%

Step 3 – Select the methane correction factor (MCF) from Table 3 that most accurately represents the conditions of the landfill in question.

Table 3. Methane correction factor (MCF)[5]

Landfill conditions	MCF
Anaerobic managed solid waste disposal site	1.0
Unmanaged solid waste disposal site – deep	0.8
Semi-aerobic managed solid waste disposal site	0.5
Unmanaged solid waste disposal site - shallow	0.4

Step 4 – Use Equation 1 to calculate total CH_4 generation, *Q*, from each waste category, *j*, per dry tonne of diverted MSW.

Equation 1: Total CH_4 generation from waste category *j*, per dry tonne of diverted MSW [g CH_4 / t dry diverted MSW]

$$Q_j = W_j \times DOC_j \times DOC_{F\_j} \times F \times MCF \times (16/12) \times 10^6$$

where:

Q_j	= *total CH_4 generation over a 100-year period from waste category j*
W_j	= *dry mass of waste category j per dry mass of MSW diverted from landfilling [%]*
DOC	= *degradable organic carbon content from Table 4 [%]*
DOC_F	= *fraction of degradable organic carbon dissimilated from Table 2 [%]*
F	= *CH_4 concentration in LFG, 50%*
MCF	= *Methane correction factor from Table 3*
16/12	= *CH_4 to carbon ratio*
10^6	= *grams per tonne conversion [g / t]*

[4] EPA, "Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM). Management Practices Chapters." 2016. EPA Office of Resource Conservation and Recovery (ORCR). *https://www.epa.gov/warm/documentation-chapters-greenhouse-gas-emission-energy-and-economic-factors-used-waste*

[5] Intergovernmental Panel on Climate Change (IPCC). 2006 IPCC guidelines for national greenhouse gas inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html

Step 5 – Select the lifetime landfill gas collection efficiency (*LFGCE*) that most accurately represents the landfill-specific conditions in Table 4, for each waste category of the organic MSW diverted from the landfill. If the landfill in question is not managed, and landfill gas (LFG) is not collected, use a value of 0%. Note that in this case, it would be inappropriate to also select a MCF value of 1.0, which corresponds to an anaerobic managed solid waste disposal site.

Table 4. Landfill gas collection efficiency (LFGCE)[6]

Climate zone		Boreal and temperate (MAT ≤ 20°C)						Tropical (MAT > 20°C)					
		Dry (MAP/PET < 1)			Wet (MAP/PET >1)			Dry (MAP < 1000 mm)			Moist and wet (MAP >1000 mm)		
Waste category, *j*	LFG collection	Active[a]	Moderate[b]	Minimal[c]	Active[a]	Moderate[b]	Minimal[c]	Active[a]	Moderate[b]	Minimal[c]	Active[a]	Moderate[b]	Minimal[c]
Slowly degrading waste	Paper/textiles waste	78%	70%	56%	82%	71%	56%	79%	70%	56%	83%	71%	56%
	Wood/straw waste	68%	63%	51%	74%	67%	54%	71%	65%	53%	76%	68%	55%
Moderately degrading waste	Other (non-food) organic putrescible/garden and park waste	80%	71%	56%	83%	69%	54%	83%	71%	56%	80%	61%	55%
Rapidly degrading waste	Food waste/Sewage sludge	82%	71%	56%	79%	59%	49%	84%	70%	55%	72%	46%	43%

MAT – Mean annual temperature; MAP – Mean annual precipitation; PET – Potential evapotranspiration.
[a] Active: Typically, the landfill operator is using horizontal LFG collectors from the early stage of cell development while still accepting MSW (less than a year after cells' first waste disposal), and vertical collectors once cells are capped.
[b] Moderate: Horizontal collectors are installed to capture LFG 1-3 years after cells' first waste disposal, and vertical collectors are used once cells are capped.
[c] Minimal: LFG is not collected during waste acceptance, but vertical collectors are used once cells are capped.

Step 6 – Select the oxidation rate that best represents the landfill conditions: 10% should be used for modern, sanitary, and well-managed landfills; 0% should be used in all other cases.[5]

Step 7 – Calculate non-captured CH_4 emissions, CH_4^n, per dry tonne of diverted MSW using Equation 2. Note that Q_j and $LFGCE_j$ are defined for each waste category, *j*.

Equation 2: Non-captured CH_4 emissions (CH_4^n) [g CH_4 / t dry MSW]

$$CH_4^n = \sum_j \left[Q_j \times \left(1 - LFGCE_j\right) \times (1 - \text{oxidation rate}) \right]$$

[6] Nine landfills were interviewed, and three landfills that represent active, moderate, and minimal LFG collection were selected and simulated based on the method provided in Lee et al. (2018) with phased collection efficiency specified in Barlaz et al. (2009).
Lee, U., Han, J. and Wang, M., 2017. Evaluation of landfill gas emissions from municipal solid waste landfills for the life-cycle analysis of waste-to-energy pathways. Journal of Cleaner Production, 166, pp.335-342.
Barlaz, M.A., Chanton, J.P., Green, R.B., 2009. Controls on landfill gas collection efficiency: instantaneous and lifetime performance. J. Air Waste Manag. Assoc. 59, 1399–1404.

Step 8 – Calculate biogenic CO_2 in non-captured CH_4 emissions, CO_2^n, and biogenic CO_2 that remains as carbon in the landfill, CO_2^s, using Equation 3.

Equation 3: CO_2^n and CO_2^s [g CO_2e / t dry MSW]

$$CO_2^n = CH_4^n \times 44/16$$

$$CO_2^s = \sum_j \left[W_j \times DOC \times (1 - DOC_F) \times (44/12) \times 10^6\right]$$

Step 9 – In the case that the project of interest diverts MSW from a landfill where collected CH_4 is used for electricity generation instead of flaring, calculate the avoided electricity credit using Equation 4.

Equation 4: Avoided electricity credit [g CO_2e / t dry MSW]

$$Avoided\ electricity\ credit\ = LHV_{CH4} \times \boldsymbol{\eta} \times CF \times [\Sigma_j (Q_j \times LFGCE_j)] \times CI_{elec} \times 10^{-3}$$

where:

LHV_{CH4}	= *lower heating value of CH_4, 0.0139 MWh / kg*
$\boldsymbol{\eta}$	= *net electricity generation efficiency (eg. 30%, dependent on landfill of interest)*
CF	= *capacity factor including downtime (eg. 85%, dependent on landfill of interest)*
Q_j	= *total CH_4 generation from waste category j from Equation 1[g CO_2e / t dry MSW]*
$LFGCE_n$	= *landfill gas collection efficiency selected from Table 3 [%]*
CI_{elec}	= *average carbon intensity of grid electricity in the region where the landfill generating electricity is located (use the highest spatial resolution regional-level CI published by a relevant national entity) [gCO_2e / MWh]*
10^{-3}	= *kilogram per gram conversion [kg / g]*

Step 10 – Calculate the final LEC of the SAF production process, as shown in Equation 5. This landfill- and waste-specific LEC value is to be subtracted from the core LCA value (g CO_2e/MJ) of MSW-derived SAF.

Equation 5: Final LEC calculation [g CO_2e/MJ]

$$LEC = \frac{CH_4^n \times (GWP_{CH4}) - CO_2^n - CO_2^s - [avoided\ electricity\ credit]}{Y}$$

where:

CH_4^n	= *non-captured CH_4 emission [g CH_4 / t dry MSW]*
GWP_{CH4}	= *100-year global warming potential of CH_4, 28 g CO_2e / g CH_4*
CO_2^n	= *Biogenic CO_2 in non-captured CH_4 emissions [g CO_2e / t dry MSW]*
CO_2^s	= *Biogenic CO_2 that remains as carbon in the landfill [g CO_2e / t dry MSW]*
[avoided electricity credit]	= *Emissions offset by replacing grid electricity with electricity from captured CH_4 [g CO_2e / t dry MSW]*
Y	= *Total energy yield (liquid fuels, other fuel and energy co-products and non-energy co-products) from MSW [MJ/ t dry MSW]. Note that this is calculated on the basis of MSW diverted from the landfill, before any additional sorting or recycling takes place.*

6.2 Methodology for calculation of recycling emissions credits

SAF produced from Municipal Solid Waste (MSW) feedstocks may generate a Recycling Emissions Credit (REC), due to additional recyclable material being recovered and sorted during feedstock preparation.

Economic operators will calculate credit volume as the portion in excess of what would be achieved if best management practices according to the regulations applicable to the landfill, particularly for management and collection of landfill gas, were implemented.

The economic operator will demonstrate that the economic activity does not lead to a reduction in recycling in the area of interest relative to that which would be recycled in the absence of the economic activity. Options for how this can be demonstrated include:

a) Evidence that the materials recycled under the economic activity are recovered only from end-of-life-wastes and the economic operator is not claiming reductions from waste diverted through any existing recycling activity.

b) Directly measured final output of the recycling facility (e.g., weight of materials leaving the recycling facility (on a dry basis), segregated by type).

c) If the recycling facility is an existing activity, the average data on the amount of recycled materials from the previous three years of operation (a minimum of one-year data would be required if the facility is less than three years old) to be used for the estimation of the baseline recycling activity, with the activity of the economic operator consisting of the increase of the recycling capacity above this level.

The emissions avoided for additional recycling of plastics and metals, calculated separately, are summed to generate a total REC value. REC will be calculated as follows:

1. Plastics

Step 1a. – Select the energy consumption factors for virgin plastic production and recycling from Table 5, for the plastic types recovered from the MSW feedstock in question.

Table 5: Energy factors for virgin plastic production and recycling[7]

Material	Specific electricity consumption for virgin plastic production (SEC_{bl})	Specific fossil fuel consumption for the production of virgin plastic (*SFC*)	Specific electricity consumption for plastic recycling (SEC_{rec})
	[MWh / t]	*[GJ / t]*	*[MWh / t]*
PET	1.11	15.0	0.83
HDPE	0.83	15.0	0.83
LDPE	1.67	15.0	0.83
PP	0.56	11.6	0.83

[7] United Nations Framework Convention on Climate Change (UNFCCC). 2018. *AMS-III.AJ.: Recovery and recycling of materials from solid wastes --- Version 7.0. Clean Development Mechanism.* Valid from August 2018.

Step 1b. – Select appropriate emission factors for electricity, and direct fossil fuels use, for virgin plastic production, that accurately represent the specific project in question.

CI_{elec}	*= average carbon intensity of grid electricity in the region where the virgin plastic production is being offset (use the highest spatial resolution regional-level CI published by a relevant national entity) [gCO_2e / MWh]*
CI_{ff}	*= carbon intensity of fossil fuel used in the virgin plastic production process [g CO_{2e} / GJ]. The life cycle CIs of coal, natural gas, fuel oil, and diesel, used as stationary fuels in US industrial processes, are 100.7, 69.4, 95.6, and 93.4 g CO_2e/MJ, respectively. Note that more regionally or context appropriate data should be substituted for the values given here, if available.*

Step 1c. – Estimate the emissions avoided by using recycled plastics to reduce virgin plastic production, per tonne of diverted MSW feedstock. This calculation should be carried out for each plastic type, and summed up, as shown in Equation 6.

Equation 6: REC associated with additional recycled plastic [g CO_2e / t dry MSW]

$$REC_{plastic} = \sum_i q_i \times \left[L_i \times \left(SEC_{bl,i} \times CI_{elec} + SFC_i \times CI_{ff}\right) - \left(SEC_{rec,i} \times CI_{elec}\right)\right]$$

where:

q_i	*= quantity of plastic i recycled [t / dry t MSW]. This is on the basis of per tonne of dry MSW diverted from the landfill, before additional recycling takes place.*
i	*= type of plastic recycled (eg. PET, HDPE, LDPE, or PP)*
L_i	*= adjustment factor for degradation in material quality and loss when using the recycled material, 0.75*
$SEC_{bl,i}$	*= specific electricity consumption for virgin material production for plastic i [MWh / t plastic]*
$SEC_{rec,i}$	*= specific electricity consumption for recycling of plastic i [MWh / t plastic]*
SFC_i	*= specific fossil fuel consumption for virgin material production of plastic i [GJ / t plastic]*

2. Metals

Step 2a. – Select the energy consumption factors for virgin metal production and recycling from Table 6, for the metal types recovered from the MSW feedstock in question.

Table 6: Emissions and energy factors for virgin metal production recycling[8]

Material	Emission factor for virgin metal production (*CI*)	Specific electricity consumption for metal recycling (SEC_{rec})
	[g CO_{2e}e / t]	*[MWh / t]*
Aluminium	8.40 x 10^6	0.66
Steel	1.27 x 10^6	0.9

Step 2b. – Select an appropriate emission factor for electricity use in virgin metal production that accurately represents the specific project in question.

CI_{elec}	*= average carbon intensity of grid electricity in the region where virgin metal production is being offset (use the highest spatial resolution regional-level CI published by a relevant national entity) [gCO_2e / MWh]*

Step 2c. – Estimate the emissions avoided by using recycled metals to reduce virgin metal production, per tonne of diverted MSW feedstock. This calculation should be carried out for each metal type, and summed up, as shown in Equation 7.

[8] United Nations Framework Convention on Climate Change (UNFCCC). 2018. *AMS-III.AJ.: Recovery and recycling of materials from solid wastes --- Version 7.0. Clean Development Mechanism.* Valid from August 2018.

Equation 7: REC associated with additional recycled metal [g CO_2e / t dry MSW]

$$REC_{metal} = \sum_{i} q_i \times \left[L_i \times (CI_i) - \left(SEC_{rec,i} \times CI_{elec}\right)\right]$$

where:

q_i	*= quantity of metal i recycled [t / dry t MSW]. This is on the basis of per tonne of dry MSW diverted from the landfill, before additional recycling takes place.*
i	*= type of metal recycled (eg. steel, or aluminum)*
CI_i	*= emission factor for virgin production of metal i [g CO_2e / t metal]*
L_i	*= adjustment factor for degradation in material quality and loss when using the recycled material, 0.75*
$SEC_{rec,i}$	*= specific electricity consumption for recycling of metal i [MWh / t plastic]*

Step 3 – Sum up emissions credits from plastics and metals, and convert to a basis of per MJ of fuel, as shown in Equation 8.

Equation 8: Final REC calculation [gCO_2e/MJ]

$$REC = \frac{REC_{plastic} + REC_{metal}}{Y}$$

where:

Y	*= Total energy yield (liquid fuels, other fuel and energy co-products and non-energy co-products) from MSW [MJ/ t dry MSW]. Note that this is calculated on the basis of MSW diverted from the landfill, before any additional sorting or recycling takes place.*

7 LOWER CARBON AVIATION FUELS

LCAF producers can reduce GHG emissions from conventional petroleum fuel production and use supply chain to make their fuel eligible as a CEF. GHG emissions reductions could be achieved through measures such as carbon capture and sequestration (CCS), renewable and low carbon intensity hydrogen, and renewable and low carbon intensity electricity. Further, LCAF producers and their crude suppliers can use additional mitigation measures, such as methane emission management (venting, flaring and fugitives - VFF) and use of newly developed crudes.

In addition to the requirements for documentation in Section 3, LCAF producers will need to demonstrate in the Technical Report that the emission reductions claimed avoid double counting.

7.1 Eligibility under sustainability criterion 1.1 and accounting for emissions reductions

The formula for calculating the life cycle emissions value for purpose of eligibility[9] of an LCAF under sustainability criterion 1.1 is provided in Equation 1.

Equation 1: Life cycle emissions for LCAF eligibility

$$L_{LCAF} = CP + MP$$

where:

L_{LCAF}	*= life cycle emissions value for LCAF (in gCO_2e/MJ), for purpose of assessing eligibility under sustainability criterion 1.1*
CP	*= life cycle greenhouse gas emissions, not accounted for under MP, after LCAF measures are introduced, as certified by an SCS after measures are incorporated (in gCO_2e/MJ)*
MP	*= methane emissions from venting, and fugitive leakage (converted to CO_2e emissions) and carbon dioxide emissions of methane flaring after methane management practices and LCAF measures are introduced, as certified by an SCS after the measures and practices are incorporated (in gCO_2e/MJ)*

The formula for calculating the life cycle emissions value for the purpose of determining emissions reductions from the use of LCAF, as defined in Annex 16 Vol IV, Part II, Section 3.3.1, is provided in Equation 2.[10]

Equation 2: Life cycle emissions reductions value from the use of LCAF

$$L_{CEF} = LC - (CO - CP) - (MA - MP), \text{ where } CO \leq 84.1 \ gCO_2e/MJ$$

where:

L_{CEF}	*= life cycle emissions value for a LCAF for use in Annex 16 Vol. IV. Part II. Section 3.3.1 (in gCO_2e/MJ)*
LC	*= baseline life cycle emissions for jet fuel, 89 gCO_2e/MJ*

[9] For eligibility under sustainability criterion 1.1, LCAF is treated the same as SAF in terms of the life cycle accounting method. In both cases, the life cycle emissions need to be certified by an SCS after technologies and measures are in place to produce the LCAF or SAF.

[10] The LCA methodology for accounting the emissions reductions from the use of LCAF within CORSIA differs from that of SAF and from that used to calculate eligibility in Equation 1. Emissions reductions from the use of LCAF are captured on a project-specific level by comparing the life cycle emissions before and after implementation of LCAF mitigation measures. As the emissions before the introduction of LCAF mitigation measures could differ from the baseline value, LC, a project-specific approach is used for LCAF that considers the life cycle emissions both before and after LCAF mitigation measures were implemented. This approach separates Venting, Flaring and Fugitives (VFF) emissions from crude oil recovery and processing from GHG emissions.

CO	*= life cycle greenhouse gas emissions, not accounted for under MP, before LCAF measures are introduced,*[11] *as certified by an SCS for ongoing operations at some future date (in gCO_2e/MJ), where CO≤ 84,1 gCO2e /MJ*
CP	*= life cycle greenhouse gas emissions, not accounted for under MP, after LCAF measures are introduced, as certified by an SCS after the measures are incorporated (in gCO_2e/MJ)*
MA	*= industry average emissions of methane venting, flaring, and fugitive emissions; which include methane emissions of venting and fugitive leakages (converted to CO_2e) and carbon dioxide emissions of methane flaring*
MP	*= methane emissions from venting, and fugitive leakages (converted to CO_2e emissions) and carbon dioxide emissions of methane flaring from crude oil recovery and processing after methane management practices and LCAF measures are introduced, as certified by an SCS after the measures and practices are incorporated (in gCO_2e/MJ)*

Both CO and CP include combustion emissions of 74 gCO_2e/MJ for jet fuel.

To maintain consistency with SAF crediting and provide a safeguard against over-crediting due to high life cycle emissions before implementation of LCAF mitigation measures and methane emission management, $CO + MA \leq LC$.[12] Since MA is the industry average of 4.9 gCO_2e/MJ, *CO* is not allowed to exceed 89 – 4.9 = 84.1 gCO_2e/MJ for the calculation of LCAF crediting.

Sections 7.2 through 7.5 describe the steps and methods for calculating CO, CP, MA, and MP, respectively.

7.2 Facility baseline CI values before deploying mitigation measures: CO

The *CO* term includes emissions from the GHG emission species mentioned in Section 2.2 along the supply chain of CEF production and use (life cycle stages 2-8 described in Section 2.2 excluding VFF emissions as shown in Equation 3. All of the terms in Equation 3 need to include upstream emissions (e.g., if electricity is used, emissions for electricity production should be accounted for in each stage), according to Section 2.2.

Equation 3: Facility baseline CI values before deploying mitigation measures

$$CO = CI_{crude\ oil} + CI_{crude\ trans} + CI_{refinery} + CI_{jet\ trans} + CI_{combustion}$$

where:

$CI_{crude\ oil}$	*= emissions (carbon intensity, CI) associated with the recovery and processing of the crude mix used by an LCAF producer (gCO_2e/MJ crude), life cycle stages 2-3*
$CI_{crude\ trans}$	*= emissions from crude oil transportation (gCO_2e/MJ crude), life cycle stage 4*
$CI_{refinery}$	*= refinery emissions allocated to jet fuels (gCO_2e/MJ jet), life cycle stage 5*
$CI_{jet\ trans}$	*= emissions from jet fuel transportation (gCO_2e/MJ jet), life cycle stage 6*
$CI_{combustion}$	*= jet fuel combustion emissions (74 gCO_2e/MJ jet), life cycle stage 7*

Determination of crude oil mix for existing crudes

At the year when an LCAF producer begins to produce LCAF (defined here as "Year 1" of LCAF production), its crude oil mix based on the average over the 3 years prior to Year 1 will be used for determining CO. The crude oil mix will be fixed at Year 1 when the LCAF producer commences LCAF production.

Determination of crude oil mix for newly developed crudes

[11] See subsection Section 7.2 on determination of crude oil mix

[12] The baseline was calculated considering both upstream and downstream emissions, therefore *MA* is part of the baseline.

For newly developed crudes, the LCAF producer needs to provide evidence that these new crude volumes were not traded before Year 1. In this case, this crude type or a proportion of the crude volume can be claimed as a newly developed crude for calculating L_{CEF} for the period starting in Year 1 with a periodic re-evaluation.

While GHG emissions of crude oil production (recovery and processing) and transportation are presented in terms of MJ crude, GHG emission of crude refining are in terms of MJ of jet. A MJ of the energy content in jet fuel is from a MJ of the energy content in crude. Thus, the CI values of crude and jet can be added together in Equation 3.

Determination of $CI_{crude\ oil}$

Equation 4 provides the $CI_{crude\ oil}$ of an individual LCAF producer, which is the energy-weighted CIs of all crude types used by the producer.

Equation 4: Crude oil recovery CI value

$$CI_{crude\ oil} = \sum_i [CI_i \times E_i]$$

where:

CI_i = emissions of crude type i (gCO_2e/MJ crude), excluding VFF emissions from crude oil recovery and processing

E_i = energy share (%) of crude type i used by an LCAF producer (average crude mix of the 3 years prior to Year 1)

One of the two methods can be used to determine $CI_{crude\ oil}$ of a given crude type: a) reporting-value method or b) estimation method. Both methods follow the process-level energy allocation approach required according to Section 2.2.

a) Reporting-value method: Determined using key energy input and emission values for crude recovery that are entered into an LCA tool such as ICAO-GREET to calculate crude recovery GHG emissions. This method is similar to developing actual life cycle emissions values for CORSIA SAFs.

b) Estimation method: Determined using the data in Table 1,[13] which was developed from the OPGEE[14] (Oil Production Greenhouse Gas Emissions Estimator) model for estimating GHG emissions of recovering specific crude.

To determine the $CI_{crude\ oil}$, the fuel producer will need the CI value of each of its input crude oil types with the average of the crude mix for the 3 years prior to Year 1 when LCAF begins to be produced. These may be obtained from Table 1, which provides a lookup table of the CI values of individual crude types available globally. LCAF producers can also use actual CIs of their crudes, which is to be used with the reporting-value method. If a specific crude type is not listed in the lookup table, crude properties such as the API and sulfur content together with geology similarity and geographic proximity may be used to select a similar crude type from the lookup table. Note that the CI values in Table 1 represent crude oil production excluding VFF emissions.

[13] The details of developing crude oil CI values are reported in Table 1, see footnotes of Table 1.

[14] OPGEE: Oil Production Greenhouse Gas Emissions Estimator, Stanford University: https://eao.stanford.edu/opgee-oil-production-greenhouse-gas-emissions-estimator

Table 1 - CI Look-up Table for Crude Production of Individual Marketed Crude Oil Name (MCON), MCONs are sorted by refined volume in 2019[15]

Crude Stream[16]	Source Country	Country ISO Code	API	Sulphur (wt%)	Crude Quality[17]	Estimated LHV (MJ/bbl)	Country avg. Upstream CI (w/o VFF) (gCO_2e/MJ)	Crude Upstream CI (w/o VFF) (gCO_2e/MJ)[18]
Girassol	Angola	AGO	29.7	0.42	Medium Sweet	5,834	1.49	1.31
Dalia Blend	Angola	AGO	23.1	0.51	Heavy Sour	6,013		1.18
Cabinda Blend	Angola	AGO	32.2	0.15	Medium Sweet	5,766		1.56
Nemba Blend	Angola	AGO	37	0.28	Medium Sweet	5,635		1.59
Kissanje Blend	Angola	AGO	30.7	0.36	Medium Sweet	5,807		1.69
Pazflor	Angola	AGO	25.6	0.43	Heavy Sweet	5,946		1.72
Greater Plutonio	Angola	AGO	33.2	0.37	Medium Sweet	5,739		1.72
Murban	United Arab Emirates	ARE	40.5	0.74	Light Sour	5,539	3.32	1.96
Upper Zakum	United Arab Emirates	ARE	33.9	1.84	Medium Sour	5,720		2.18
Das	United Arab Emirates	ARE	39.7	1.1	Light Sour	5,561		7.75
Domestic Oil Other Argentina	Argentina	ARG	33	0.5	Medium Sweet	5,744	3.73	3.50
Escalante	Argentina	ARG	23.2	0.16	Heavy Sweet	6,011		5.45
Pyrenees	Australia	AUS	19	0.1	Heavy Sweet	6,126	1.92	0.89
Cooper Basin	Australia	AUS	44.6	0.02	Light Sweet	5,427		1.59
Montara Area	Australia	AUS	37	0.1	Medium Sweet	5,635		1.32
Azeri BTC	Azerbaijan	AZE	37.6	0.17	Medium Sweet	5,618	2.84	2.11
Lula	Brazil	BRA	29.3	0.36	Medium Sweet	5,845	6.31	3.21
Domestic Oil Onshore Brazil	Brazil	BRA	36	0.25	Medium Sweet	5,662		5.49
Sapinhoa	Brazil	BRA	29.8	0.38	Medium Sweet	5,831		3.08
Roncador Heavy	Brazil	BRA	18	0.6	Heavy Sour	6,154		12.43
Seria Light	Brunei Darussalam	BRN	39	0.07	Light Sweet	5,580	1.41	0.79
Cold Lake	Canada	CAN	21.2	3.69	Heavy Sour	6,066	12.88	10.98
Oil Sands Synthetic	Canada	CAN	33	0.3	Medium Sweet	5,744		25.36
Western Canadian Select	Canada	CAN	20.9	3.36	Heavy Sour	6,075		17.83
Wabasca	Canada	CAN	23	0.5	Heavy Sweet	6,017		2.13
Midale	Canada	CAN	29.7	2.3	Medium Sour	5,834		3.07

[15] The CI lookup table for crude oil production excludes crude oil transportation and VFF emissions. The CI values are based on the original study authored by Masnadi et al. (2018) published in Science. The study was based on the analysis of ~9000 oilfields worldwide and used OPGEE to estimate the CI values for each of the oil fields crude oil production. The values in the table have been augmented by a follow-on study, led by MIT Laboratory for Aviation and the Environment (MIT-LAE), that expands the initial work by developing an optimizer to determine each oil fields assigned to an MCON based on infrastructure constraints (i.e., pipelines), crude quality matching crude assays specifications, and refinery reported crude intake. The table reports the CI values for the most relevant MCONs; based on 2019 volume refinery crude intake.

[16] Crude Stream is represented by crude name, API, and sulphur content, which are subject to change.

[17] Crude quality categorization is informative and can change depending on the API and sulphur ranges.

[18] To determine the CI at the refinery gate of crude inputs, a fuel producer will add the VFF CI value and crude transportation CI to corresponding CI values for each crude as reported in this table.

Crude Stream[16]	Source Country	Country ISO Code	API	Sulphur (wt%)	Crude Quality[17]	Estimated LHV (MJ/bbl)	Country avg. Upstream CI (w/o VFF) (gCO_2e/MJ)	Crude Upstream CI (w/o VFF) (gCO_2e/MJ)[18]
Suncor Synthetic H	Canada	CAN	19.3	3.11	Heavy Sour	6,118		7.82
Hibernia	Canada	CAN	35	0.45	Medium Sweet	5,689		0.95
Mixed Sweet Blend	Canada	CAN	38.8	0.47	Light Sweet	5,586		10.05
W. Canada Conventional Light Sweet (Alberta)	Canada	CAN	35.1	0.4	Medium Sweet	5,687		12.33
Light Sour Blend	Canada	CAN	39.5	0.77	Light Sour	5,567		22.22
Bow River	Canada	CAN	25.3	2.4	Heavy Sour	5,954		6.05
Domestic Oil Other China	China	CHN	36	0.3	Medium Sweet	5,662	2.67	5.30
Daqing	China	CHN	32.2	0.11	Medium Sweet	5,766		2.73
Shengli	China	CHN	24.2	0.84	Heavy Sour	5,984		1.06
Liaohe	China	CHN	33.5	0.17	Medium Sweet	5,730		0.94
Jilin	China	CHN	35.7	0.5	Medium Sweet	5,670		1.42
Lokele	Cameroon	CMR	20.2	0.45	Heavy Sweet	6,094	1.37	1.40
Djeno	Congo	COG	27.3	0.42	Heavy Sweet	5,901	2.02	2.04
Castilla	Colombia	COL	18.8	1.97	Heavy Sour	6,132	3.45	2.99
Vasconia	Colombia	COL	26.4	0.75	Heavy Sour	5,924		4.22
South Blend	Colombia	COL	27	0.75	Heavy Sour	5,908		2.32
Oriente	Ecuador	ECU	24	1.2	Heavy Sour	5,990	2.51	2.71
Western Desert Blend	Egypt	EGY	41	0.34	Light Sweet	5,526	2.12	2.44
Suez Blend	Egypt	EGY	31.3	1.41	Medium Sour	5,791		2.00
Qarun	Egypt	EGY	34.4	0.29	Medium Sweet	5,706		2.18
Belayim Blend	Egypt	EGY	23.5	2.76	Heavy Sour	6,003		2.24
Mandji	Gabon	GAB	30	1	Medium Sour	5,826	1.97	2.48
Rabi Export Blend	Gabon	GAB	35.1	0.12	Medium Sweet	5,687		2.08
Oguendjo	Gabon	GAB	32.4	0.91	Medium Sour	5,761		1.68
Forties Blend	United Kingdom	GBR	38.7	0.79	Light Sour	5,588	1.3	2.21
Brent Blend	United Kingdom	GBR	37.5	0.4	Medium Sweet	5,621		1.13
Foinaven	United Kingdom	GBR	26.8	0.37	Heavy Sweet	5,913		0.88
Flotta Blend	United Kingdom	GBR	36.2	0.98	Medium Sour	5,657		1.29
Clair	United Kingdom	GBR	23.7	0.44	Heavy Sweet	5,998		1.14
Captain	United Kingdom	GBR	19.2	0.7	Heavy Sour	6,121		1.20
Jubilee	Ghana	GHA	36.8	0.29	Medium Sweet	5,642	1.07	1.07
New Zafiro Blend	Equatorial Guinea	GNQ	30.6	0.27	Medium Sweet	5,810	1.18	1.25
Ceiba	Equatorial Guinea	GNQ	30.7	0.46	Medium Sweet	5,807		1.03
Banyu Urip	Indonesia	IDN	32	0.3	Medium Sweet	5,771	7.68	2.57
Minas	Indonesia	IDN	33.9	0.09	Medium Sweet	5,718		22.40
Duri	Indonesia	IDN	20.3	0.21	Heavy Sweet	6,091		18.57
Geragai	Indonesia	IDN	46.4	0.03	Light Sweet	5,378		0.76

Crude Stream[16]	**Source Country**	**Country ISO Code**	**API**	**Sulphur (wt%)**	**Crude Quality[17]**	**Estimated LHV (MJ/bbl)**	**Country avg. Upstream CI (w/o VFF) (gCO_2e/MJ)**	**Crude Upstream CI (w/o VFF) (gCO_2e/MJ)[18]**
Domestic Oil Mumbai India	India	IND	38	0.2	Medium Sweet	5,608	2.09	1.73
Domestic Oil Barmer-Sanchor Graben India	India	IND	26	0.34	Heavy Sweet	5,935		1.94
Domestic Oil Cambay India	India	IND	36	0.3	Medium Sweet	5,662		1.99
Domestic Oil Assam-Arakan India	India	IND	32	0.3	Medium Sweet	5,935		2.03
Iran Heavy	Iran	IRN	29.5	1.99	Medium Sour	5,840	7.17	10.43
Ahwaz-Asamri	Iran	IRN	32.5	1.46	Medium Sour	5,758		3.63
Marun	Iran	IRN	33.9	1.3	Medium Sour	5,720		11.23
Iran Light	Iran	IRN	33.4	1.36	Medium Sour	5,733		8.01
Foroozan	Iran	IRN	29.7	2.34	Medium Sour	5,833		2.12
Nowruz/Soroush	Iran	IRN	18.9	3.44	Heavy Sour	6,129		1.72
Basrah Light	Iraq	IRQ	28.9	3.19	Medium Sour	5,856	3.64	3.65
Basrah Heavy	Iraq	IRQ	23.7	4.12	Heavy Sour	5,998		2.31
CPC (Kazakhstan)	Kazakhstan	KAZ	45.3	0.56	Light Sour	5,408	3.49	3.86
Azeri Light (Kazakhstan)	Kazakhstan	KAZ	34.8	0.15	Medium Sweet	5,695		3.28
Domestic Oil South Turgai Kazakhstan	Kazakhstan	KAZ	39.9	0.2	Light Sweet	5,556		3.29
Tengiz	Kazakhstan	KAZ	47.2	0.55	Light Sour	5,356		2.87
El Sharara	Libya	LBY	43.1	0.07	Light Sweet	5,468	2.95	3.29
Es Sider	Libya	LBY	36.7	0.37	Medium Sweet	5,643		3.67
Amna	Libya	LBY	37.1	0.17	Medium Sweet	5,632		3.49
Sarir	Libya	LBY	37.5	0.17	Medium Sweet	5,621		3.29
Bouri	Libya	LBY	26	1.82	Heavy Sour	5,935		1.08
Maya	Mexico	MEX	21.8	3.33	Heavy Sour	6,050	3.53	2.44
Isthmus	Mexico	MEX	32.5	1.5	Medium Sour	5,758		2.48
Kikeh	Malaysia	MYS	34.9	0.11	Medium Sweet	5,692	2.79	3.97
Tapis	Malaysia	MYS	44.6	0.03	Light Sweet	5,427		1.30
Labuan	Malaysia	MYS	32	0.09	Medium Sweet	5,771		4.29
Bintulu	Malaysia	MYS	37.7	0.05	Medium Sweet	5,617		2.88
Kimanis	Malaysia	MYS	38.6	0.06	Light Sweet	5,591		1.38
Angsi	Malaysia	MYS	40.2	0.03	Light Sweet	5,548		1.80
Dulang	Malaysia	MYS	37.2	0.05	Medium Sweet	5,629		1.62
Miri	Malaysia	MYS	30.8	0.14	Medium Sweet	5,804		2.22
Qua Iboe	Nigeria	NGA	36	0.13	Medium Sweet	5,662	3.01	3.55
Forcados	Nigeria	NGA	31.5	0.22	Medium Sweet	5,785		3.14
Escravos	Nigeria	NGA	33.5	0.17	Medium Sweet	5,730		4.82
Bonny Light	Nigeria	NGA	35.1	0.15	Medium Sweet	5,687		2.24
Agbami-Ekoli	Nigeria	NGA	47.2	0.04	Light Sweet	5,356		3.44
Brass River	Nigeria	NGA	40.1	0.18	Light Sweet	5,550		2.99

Crude Stream[16]	Source Country	Country ISO Code	API	Sulphur (wt%)	Crude Quality[17]	Estimated LHV (MJ/bbl)	Country avg. Upstream CI (w/o VFF) (gCO_2e/MJ)	Crude Upstream CI (w/o VFF) (gCO_2e/MJ)[18]
Erha	Nigeria	NGA	34.2	0.18	Medium Sweet	5,711		3.08
Bonga	Nigeria	NGA	30.2	0.25	Medium Sweet	5,821		2.64
Amenam Blend	Nigeria	NGA	39	0.09	Light Sweet	5,581		4.21
Antan Blend	Nigeria	NGA	29.2	0.3	Medium Sweet	5,848		2.26
Ekofisk Blend	Norway	NOR	40.1	0.17	Light Sweet	5,550	2.26	0.84
Gullfaks Blend	Norway	NOR	39.1	0.22	Light Sweet	5,578		1.27
Troll Blend	Norway	NOR	35.9	0.15	Medium Sweet	5,666		0.70
Grane	Norway	NOR	18.7	0.83	Heavy Sour	6,135		6.65
Oseberg Blend	Norway	NOR	38.5	0.24	Light Sweet	5,594		2.40
Statfjord Blend	Norway	NOR	39.5	0.22	Light Sweet	5,567		5.20
Alvheim Blend	Norway	NOR	38.4	0.11	Light Sweet	5,596		1.17
Åsgard Blend	Norway	NOR	50.2	0.13	Light Sweet	5,274		0.77
Heidrun	Norway	NOR	25	0.52	Heavy Sour	5,963		1.01
Tui	New Zealand	NZL	42	0.04	Light Sweet	5,498	1.59	1.30
Domestic Oil Peru	Peru	PER	35	0.5	Medium Sweet	5,689	4.51	28.75
Al-Shaheen	Qatar	QAT	28	2.37	Medium Sour	5,881	1.95	1.55
Qatar Marine	Qatar	QAT	32.7	1.85	Medium Sour	5,754		2.22
Domestic Oil West Siberia Russia	Russian Federation	RUS	36	0.4	Medium Sweet	5,662	3.21	3.16
Urals NWE	Russian Federation	RUS	30.8	1.48	Medium Sour	5,805		3.08
ESPO	Russian Federation	RUS	34.7	0.53	Medium Sour	5,698		3.16
Domestic Oil Volga-Urals Russia	Russian Federation	RUS	32	0.4	Medium Sweet	5,771		3.39
Urals Med	Russian Federation	RUS	30.2	1.41	Medium Sour	5,821		3.16
Sokol	Russian Federation	RUS	36.7	0.25	Medium Sweet	5,643		3.35
Siberian Light	Russian Federation	RUS	35.1	0.57	Medium Sour	5,687		3.75
Arab Light	Saudi Arabia	SAU	33	1.83	Medium Sour	5,744	1.07	1.04
Arab Heavy	Saudi Arabia	SAU	27.6	2.94	Heavy Sour	5,892		0.65
Arab Medium	Saudi Arabia	SAU	31	2.42	Medium Sour	5,799		1.15
Nile Blend	Sudan	SDN	32.8	0.04	Medium Sweet	5,751	3.63	2.46
Domestic Oil Thailand	Thailand	THA	36	0.1	Medium Sweet	5,662	1.22	0.88
Benchamas	Thailand	THA	43	0.04	Light Sweet	5,471		2.45
Calypso	Trinidad and Tobago	TTO	30.8	0.59	Medium Sour	5,803	7.61	3.89
West Texas Intermediate	United States	USA	38.7	0.5	Light Sweet	5,588	4.58	4.53
Eagle Ford Crude	United States	USA	44.4	0.13	Light Sweet	5,433		2.95
Bakken	United States	USA	39	0.2	Light Sweet	5,580		2.41
Light Louisiana Sweet	United States	USA	36.4	0.1	Medium Sweet	5,651		3.26
Mars Blend Deepwater	United States	USA	28.9	2.05	Medium Sour	5,856		2.16
Alaska North Slope	United States	USA	31.6	0.9	Medium Sour	5,783		3.82

Crude Stream[16]	Source Country	Country ISO Code	API	Sulphur (wt%)	Crude Quality[17]	Estimated LHV (MJ/bbl)	Country avg. Upstream CI (w/o VFF) (gCO_2e/MJ)	Crude Upstream CI (w/o VFF) (gCO_2e/MJ)[18]
SGC Blend	United States	USA	29.4	2.25	Medium Sour	5,842		1.75
Heavy Louisiana Sweet	United States	USA	32.6	0.4	Medium Sweet	5,755		4.43
Niobrara	United States	USA	40	0.08	Light Sweet	5,553		2.18
San Joaquin Valley Hvy	United States	USA	14.6	1.06	Heavy Sour	6,247		30.67
West Texas Sour	United States	USA	31.7	1.6	Medium Sour	5,780		2.36
Lloyd Blend	United States	USA	21.9	2.92	Heavy Sour	6,047		11.80
Thunder Horse	United States	USA	32.7	0.62	Medium Sour	5,752		2.80
Hoops Blend	United States	USA	31.6	1.15	Medium Sour	5,782		6.14
South Texas	United States	USA	50.6	0.04	Light Sweet	5,264		3.09
Utica Light	United States	USA	41	0.1	Light Sweet	5,526		2.09
Kansas Sweet	United States	USA	38.4	0.48	Light Sweet	5,597		2.17
Merey	Venezuela	VEN	16	2.45	Heavy Sour	6,208	12.65	12.32
DCO	Venezuela	VEN	17	3	Heavy Sour	6,181		9.84
Mesa-30	Venezuela	VEN	30	0.88	Medium Sour	5,826		9.62
Lagunillas Heavy	Venezuela	VEN	17	2.2	Heavy Sour	6,181		16.30
Bach Ho	Vietnam	VNM	40.2	0.04	Light Sweet	5,547	2.3	2.05
Su Tu Den	Vietnam	VNM	36.2	0.05	Medium Sweet	5,657		1.00
Chim Sao	Vietnam	VNM	38.5	0.03	Light Sweet	5,594		1.20
Bunga Orkid	Vietnam	VNM	55	0.3	Light Sweet	5,143		1.12
Masila	Yemen	YEM	31.4	0.54	Medium Sour	5,789	2.57	2.54

Determination of $CI_{crude\ trans}$

For $CI_{crude\ trans}$, emissions of crude oil transportation across different regions, crude can be transported through ocean tanker, pipeline, and rail, so different emission factors for each mode and corresponding distance need to be included. Similar to $CI_{crude\ oil}$ calculation in Equation 4, weighted average CI for crude transportation need to be used when crude oil is transported from multiple sources to the refinery. If the LCAF producer cannot access operational/measurement data, Table 2 needs to be used to determine $CI_{crude\ trans}$ based on source and destination countries.

Table 2 provides the CI lookup table for crude oil transportation from a source region to the destination region (i.e., location of the refinery)[19]. Note that the CI values in Table 2 account for the different mode of transport, the distance between source and destination, and the crude oil & infrastructure properties (e.g., crude oil API, pipeline diameter, crude tanker vessel type). A fuel producer can use the table to determine the crude transportation CI values associated with each of its purchased MCONs.

In the case of a crude oil transportation configuration missing from the table, an LCAF producers can use the closest configuration presented in the table. If such a configuration does not exist and/or is considered not to be representative of the actual configuration, then an additional value for this configuration will need to be added to this document before an L_{CEF} value can be assigned.

Table 2 – CI Lookup Table for Crude Oil Transportation across Different Regions

Source Country	Destination Country	Crude Transportation CI (gCO_2e/MJ)
Kuwait	South Korea	0.61
Kuwait	Kuwait	0.04
Kuwait	Singapore	0.69
Kuwait	Taiwan	0.41
Kuwait	United States	2.55
Kuwait	China	0.88
Kuwait	Japan	0.66
Kuwait	India	0.48
Kazakhstan	China	2.59
Kazakhstan	Germany	1.20
Kazakhstan	France	1.08
United States	United States	1.78
United States	Canada	2.23
Turkmenistan	Turkmenistan	0.04
Nigeria	India	0.97
Nigeria	Brazil	1.53
Colombia	United States	1.36
Colombia	China	2.82
Argentina	Argentina	0.46
Ecuador	United States	2.10
Venezuela	United States	0.69
Venezuela	China	1.33
Venezuela	India	2.61

[19] Fuel producers purchase various MCON from different source countries transported via different modes of transportation, such as pipelines, rails, barges, and shipping. Between international imports or domestic supply of crude oil, there is an important variation in CI. The CI values are the averaged CI combining the different modes of transportation based on 2015 refinery crude intakes and mapping the distances from the source countries to their destination.

Source Country	Destination Country	Crude Transportation CI (gCO_2e/MJ)
Venezuela	Venezuela	0.41
Venezuela	Curacao	0.19
Algeria	Algeria	0.18
Thailand	Thailand	0.11
Indonesia	Indonesia	0.13
Russian Federation	South Korea	0.55
Russian Federation	China	0.71
Russian Federation	Japan	0.55
Russian Federation	Germany	0.68
Russian Federation	Italy	0.78
Russian Federation	Greece	0.90
Russian Federation	Russian Federation	0.47
Russian Federation	Poland	0.43
Russian Federation	Bulgaria	1.16
Russian Federation	Lithuania	0.41
Russian Federation	Belarus	0.50
Russian Federation	Hungary	0.82
Russian Federation	Slovakia	1.55
Russian Federation	Sweden	0.47
Russian Federation	Finland	0.36
Russian Federation	Belgium	0.53
Russian Federation	Netherlands	0.52
Norway	Germany	0.19
Norway	Netherlands	0.07
Norway	United Kingdom	0.19
Saudi Arabia	South Korea	0.95
Saudi Arabia	Singapore	0.87
Saudi Arabia	Taiwan	0.61
Saudi Arabia	United States	2.37
Saudi Arabia	China	1.02
Saudi Arabia	Japan	0.76
Saudi Arabia	India	0.66
Saudi Arabia	France	0.89
Saudi Arabia	Thailand	1.31
Saudi Arabia	Belgium	1.42
Saudi Arabia	Netherlands	1.40
Oman	China	0.91
Angola	China	1.14
Iraq	South Korea	1.87
Iraq	United States	3.06
Iraq	China	1.74
Iraq	India	0.89
Iraq	Italy	0.85
Iraq	Greece	0.62
Brazil	Brazil	0.45
United Kingdom	United Kingdom	0.30
India	India	0.30
United Arab Emirates	South Korea	0.60
United Arab Emirates	Japan	0.70
United Arab Emirates	India	0.27
United Arab Emirates	Thailand	0.66
Iran	China	0.36

Source Country	Destination Country	Crude Transportation CI (gCO_2e/MJ)
Qatar	Singapore	0.59
Congo	China	1.05
Mexico	United States	0.53
Mexico	India	0.86
China	China	0.48
Azerbaijan	Italy	1.12
Canada	United States	2.10
Canada	Canada	1.53
Norway	Norway	0.02
Saudi Arabia	Saudi Arabia	0.43
Saudi Arabia	Bahrain	0.53
Denmark	Denmark	0.01
Oman	Oman	0.66
Iraq	Turkey	0.58
Iraq	Iraq	0.13
Brazil	Chile	0.89
United Arab Emirates	United Arab Emirates	0.11
Iran	Iran	0.49
Vietnam	Vietnam	0.36
Mexico	Mexico	1.95
Mexico	Spain	1.17
Egypt	Spain	0.28
Egypt	Egypt	0.12
Azerbaijan	Israel	1.01
Azerbaijan	Azerbaijan	0.11

Determination of $CI_{refinery}$

For $CI_{refinery}$, one of the two methods can be used: a) reporting-value method or b) estimation method. Both methods aim to estimate GHG emissions per MJ jet fuel production using "process-level, energy allocation" approach in accordance with Section 2.2. Since each refinery product goes through different processes (e.g., jet goes through less processes than gasoline and diesel in refineries), process-level energy allocation provides higher resolution of emission effects of given products for calculating jet fuel specific $CI_{refinery}$. Detailed process inputs/output flows are needed for process-level energy allocation.

a) Reporting-value method: LCAF producers can collect key energy input and emission values for crude refining and enter them into an LCA tool such as ICAO-GREET to calculate crude refining GHG emissions for jet fuel. For refining emissions, the data include the amount of crude and energy inputs (e.g., electricity, H_2, natural gas), yields of the process units, parts of the main supply chain of interest and the associated CIs. Emissions from crude oil refining include three main parts: a) upstream emissions of energy inputs (such as electricity generation), b) combustion of process fuels, and c) process emissions (e.g., steam methane reforming [SMR] of natural gas).

b) Estimation method: Refinery models such as PRELIM[20] may be used to estimate GHG emissions of crude refining to jet fuel. Jet-specific refinery CIs should be calculated using

[20] PRELIM: The Petroleum Refinery Life Cycle Inventory Model, University of Calgary (https://ucalgary.ca/energy-technology-assessment/open-source-models/prelim); Abella, J. P.; Bergerson, J. A. Model to Investigate Energy and Greenhouse Gas Emissions Implications of Refining Petroleum: Impacts of Crude Quality and Refinery Configuration. Environ. Sci. Technol. 2012, 46 (24), 13037−13047.

process-level energy-based allocation among petroleum products when refinery models are used.

Determination of $CI_{jet\ trans}$

For $CI_{jet\ trans}$, LCAF producers will provide data on transportation distance from their facilities to their customers, transportation modes, and GHG emission factors of transportation modes for SCS to calculate $CI_{jet,\ trans}$.

Determination of $CI_{combustion}$

The carbon intensity of jet fuel combustion, $CI_{combustion}$, is set to 74 gCO_{2e}/MJ jet.

7.3 Facility actual CI values after deploying mitigation measures beginning at Year 1 and beyond: CP

CP is determined with emissions reductions (ER) of the adopted measures by LCAF producers as provided in Equation 5.

Equation 5: Facility actual CI value after deploying mitigation measures

$$CP = CO - \sum_{j} ER_j$$

where:

CP	*= facility actual CI after deploying mitigation measures (gCO_2e/MJ)*
CO	*= facility actual CI before deploying mitigation measures (gCO_2e/MJ)*
j	*= the type of (non-VFF) emissions reductions (from crude oil recovery and processing) measures*
ER	*= Emissions reductions by individual mitigation measures (gCO_2e/MJ)*

All the terms in the equation exclude VFF emissions.

Mitigation measures and their ER values need to be certified and verified. Sample mitigation measures could include CCS, renewable and low carbon intensity hydrogen (H_2), and renewable and low carbon intensity electricity. Note that VFF emission mitigation measures are excluded from CP.

In the case that a newly developed crude is used by an LCAF producer as a potential mitigation measure, the CI reduction enabled by this can also be included as an ER term. The difference between the CI of the three-year average crude mix for the LCAF producer prior to Year 1 of LCAF production and the CI value for the newly developed crude will be used as the emissions reductions of the newly developed crude.

7.4 Industry average VFF emissions value from crude oil recovery and processing: MA

The global industry average VFF value of 4.9 gCO_2e/MJ from Masnadi et al. 2018[21] is used for MA. The value of 4.9 gCO_2e/MJ is the sum of CH_4 emissions of 2.6 gCO_2e/MJ and flaring emissions of 2.3 gCO_2e/MJ.

7.5 Facility actual VFF emissions values beginning at Year 1 and beyond: MP

LCAF producers need to evaluate actual VFF emissions from oilfields (crude oil recovery and processing) at Year 1 and compare to the 4.9 g/MJ MA value.

VFF emissions are presented in terms of gCO_2e/MJ jet, which include CH_4 emissions (g CH_4/MJ crude) mainly from vented gas from oil wells, leakage from gathering pipelines and compressors, and leakage during separation (heaters, separators, and dehydrators). CH_4 emissions are converted to CO_2e emissions using the conversion factor presented in Section 2.2. Also, flaring emissions (gCO_2e/MJ crude) through CH_4 combustion need to be included.

For LCAF producer to determine the MP values of its crude intake mix, the fuel producer needs the VFF CI value of each of its intake crude oil type. LCAF producers need to provide reported or estimated VFF emissions presented in terms of MJ jet fuel production for crude volumes. The average MP of the crude mix of an LCAF producer is the energy-weighted VFF CIs of all crude types used by the producer (as in Equation 6). The average of crude mix of the 3 years prior to Year 1 of LCAF production will be used as the crude mix of the LCAF producer. If the LCAF producer does not control production of a specific crude type and is not provided with the actual VFF value by the crude oil supplier, a global average VFF of 4.9 gCO_2e/MJ is used for the crude type in MP calculation.

Equation 6: Facility actual VFF emissions values

$$MP = \sum_i [VFF_i \times E_i]$$

where:

MP	*= facility actual VFF emissions after deploying VFF mitigation measures (gCO_2e/MJ jet)*
VFF_i	*= VFF emissions of crude type i after deploying VFF mitigation measures (gCO_2e/MJ crude)*
E_i	*= energy share (%) of crude type i used by an LCAF producer (average crude mix of the 3 years prior to Year 1).*

The value of MP cannot be negative. With the global average MA value being set at 4.9 gCO_2e/MJ and not allowing a negative value of MP, the maximum credit for VFF is capped at 4.9 gCO_2e/MJ (assuming an LCAF producer could reach zero VFF emissions).

[21] Masnadi, M.S. et al. Global carbon intensity of crude oil production. Science. 361, 851-853 (2018).

8 CORSIA METHODOLOGY FOR CALCULATING DIRECT LAND USE CHANGE EMISSIONS VALUES

8.1 Introduction

This section describes the methodology for calculating Direct Land Use Change (DLUC) emissions for an economic operator aiming at producing a feedstock for CORSIA Sustainable Aviation Fuel (SAF). It applies in the event where feedstocks were sourced from land obtained through land use conversion after 1 January 2008. The methodology first outlines the required data and then defines the steps to calculate DLUC.

8.2 Required data

The following data items are required for DLUC calculation:

- The type and locations of the feedstock production.

- The types of lands converted to feedstock production will be determined using the IPCC definitions[22]. The reference date for initial land cover is 1 January 2008, even if land conversion occurred after this date. Any land use change to a feedstock plantation for bioenergy production will be considered as land conversion. Within cropland, cultivation of unused[23] land and conversion of annual to perennial crops, from perennial to annual, and between perennial crops will also be considered as land conversion.

  The area of each reference type of land $\boldsymbol{j}$ converted to feedstock cultivation measured in hectares is expressed below as $\boldsymbol{L_j}$. Total area of land used for CORSIA eligible fuel feedstock production per year is noted $L = \sum_j L_j$.

- The yield of feedstock for each type of converted land, $\boldsymbol{y_j}$, will be determined in tonnes per hectare per year.

- The energy outputs of the main sustainable aviation fuels (E_{SAF}) and production of other types of co-products such as marketable road biofuels, electricity, or feed meals ($E_{coproducts}$), all expressed in energy terms measured in Megajoules (MJ) per year. The lower heating value will be used to calculate the energy output, including for non-energy co-products.

Notes:

1) *Within cropland, crop rotations will not be considered as land conversion, except for pathways using lignocellulosic energy crops.*

[22] Chapter 3, Volume 4 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

[23] Unused land is specified in Sections 5.2. of ICAO Document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values".

2) *If more than one crop are produced in each crop year and only one of these is used as feedstock for SAF, then the additional crops in the annual rotation will be considered as co-product and their energy output will be included in the calculation of $E_{coproduct}$, using their lower heating value.*

3) *It is recommended to choose the suitable level of land description in accordance with IPCC classification guidelines to perform the relevant carbon stock accounting, based on the local conditions. At minimum, the six main IPCC land categories (forest land, cropland, grassland, wetlands, settlements, and other land) will be clearly distinguished, and idle land and perennial crops considered separately. Higher level of refinement may be advised to properly capture the landscape heterogeneity.*

8.3 DLUC calculation

Step 1.

Determine land use emission factors, $\boldsymbol{F_j}$, for each reference type of land converted to bioenergy feedstock production after 1 January 2008. This variable will be measured in grams of CO_2 equivalent per hectare (gCO_2e /ha). Emission factors will reflect terrestrial carbon fluxes due to land conversion including changes in soil organic carbon, in living vegetation carbon stock, and in dead organic matter and litter carbon pools in accordance with the IPCC guidelines[24]. In addition to CO_2 emissions, the land use emission factors will include the relevant non-CO_2 emissions associated with the Land Use Land Use Change and Forestry (LULUCF) sources of the IPCC, including emissions from biomass burning through land clearing and N_2O emissions from mineralisation associated with the loss of soil organic carbon. Section 8.4 provides the formulas and default parameters for the calculations of non-CO_2 emissions.

For emissions from the conversion of land type *j* to feedstock production, the emission factor will be calculated using the following equation:

$$F_j = 44/12 * \left[CS_j^R - CS_j^A\right] + F_j^{nCO2},$$

Where CS_j^R is the carbon stock of land type *j* measured in gC/ha for the reference *(R)* (1 January 2008),
CS_j^A is the carbon stock of land type *j* measured in gC/ha for actual *(A)* land uses,
F_j^{nCO2} is the emission factor for non-CO_2 emissions measured in gCO_2e /ha.

The carbon stocks for the reference and actual land uses are defined as:

$$CS_j^K = \left[SOC_j^K + CVEG_j^K\right], \text{ for } K = R \text{ or } A,$$

where ***SOC*** stands for the soil organic carbon measured in grams/ha,
CVEG stands for the above and below ground vegetation carbon stock measured in grams/ha, including dead wood and litter.

Notes:

[24] Volume 4 of the IPCC guidelines (2006) and their 2019 Refinement.

1) *Calculations will always respect the IPCC guidelines principles. These define different methods depending on the data availability and quality (Tier 1, Tier 2, and Tier 3, where the last one is the most comprehensive tier) and provides decision trees to help determine the relevant methodology to be applied. It is recommended that economic operators apply these decision trees to choose the methodology applied for the DLUC calculation based on data availability at reasonable cost. In the case where there is ambiguity in the magnitude of a DLUC value, compared to ILUC, due to uncertainty in the choice of Tier 1 coefficients, economic operators will use Tier 2 or Tier 3 approaches.*

2) *More detailed guidance compatible with the IPCC methodology have been developed in some regions and may be used to facilitate the calculation of land carbon stocks and emission factors*[25].

3) *If calculation of DLUC leads to a negative value, due to enhancement in carbon stocks associated with the land use conversion (e.g., soil organic carbon sequestration, sequestration in agricultural plantation biomass), the contribution of negative sources will be verified against the same criteria as for CORSIA Emissions Units. SCSs will submit methodologies to CORSIA SCS Evaluation Group to account for negative DLUC sources. Only approved methodologies for CORSIA will be used to account for negative emissions or carbon stock variations leading to a negative DLUC value. Calculation based on these methodologies will be performed even if the negative DLUC is ultimately lower than ILUC and the negative ILUC applies.*

4) *If the feedstock production affects the average crop biomass of the feedstock production area, it will be calculated as part of:* $CVEG_j^K$*. For example, converting a piece of land which has been used for soybeans to oil palm plantation could increase the average crop biomass of the feedstock production area. In this case, the average palm tree above and below ground biomass over the plantation life time.*

5) *Non-*CO_2 *emissions from biomass burning are to be accounted only if the necessary information on area burnt is available.*

Step 2.

Apply the following formula to calculate $DLUC_j$ for land type j, in gCO_2e/MJ:

$$DLUC_j = \frac{L_j * F_j}{T * E * l_j}$$

where L_j is the land area in hectares, as identified in the data collection from Section 8.2,
F_j is the associated emission factor measured in gCO_2e/ha, as defined in Step 1,
$E = E_{SAF} + E_{coproducts}$ are the energy outputs measured in MJ, as identified in Section 8.2,
T = 25 is the number of years for amortization of the emissions in CORSIA,
l_j is the land use share of type j defined as $l_j = \frac{L_j * y_j}{\sum_j L_j * y_j}$.

If $DLUC_j$ + core LCA does not satisfy CORSIA Sustainability Criterion 1, then the land type j will be classified as ineligible.

[25] For instance, European Commission guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC, *notified under document C(2010) 3751, 2010/335/EU, Official Journal of the European Union.).*

Note: Economic operators are expected to discriminate land types at the level of detail needed so that the exclusion criterion above is respected.

Step 3.

Apply the following formula on all types of eligible land of step 2 to calculate *DLUC* in gCO_2e/MJ:

$$DLUC = \sum_j DLUC_j * l_j$$

Note: If only one type of land is converted to cropland for feedstock production, then the simplified expression can be used: $DLUC = \frac{L * F}{T * E}$

8.4 Accounting of non-CO_2 emissions

The emission factor for non-CO_2 emissions, F_j^{nCO2}, will be calculated using the following equation:

$$F_j^{nCO2} = FF_J + FM_j$$

where FF_j represents non-CO_2 emissions due to biomass burning associated with clearing land type *j* measured in gCO_2e/ha,

FM_j represents non-CO_2 emissions due to soil mineralization associated with conversion of land type *j* measured in gCO_2e/ha.

Formulas to calculate these emission factors are provided in the following

Calculation of emission factor for biomass burning (FF_j)

The emission factor for biomass burning, FF_j, will be measured using the following equation:

$$FF_j = \alpha_j \times \beta_j \times \frac{CVEGABOV_j \times \left[G_j^{CH4} \times GWP_{CH4} + G_j^{N2O} \times GWP_{N20} + G_j^{NOX} \times GWP_{NOX}\right]}{1000} / \theta,$$

Where α_j is the fraction of area of land type *j* cleared due to biomass burning, varying between 0 and 1,

β_j is the combustion factor for land type *j*, selected from Table 7,

$CVEGABOV_j$ represents the above ground biomass carbon stock plus litter and deadwood for land type *j* measured in gC/ha, as determined by the economic operator,

G_j^{CH4} is the CH_4 biomass burning emission factor for land type *j* before land conversion, measured in kg per tonne of dry matter,

G_j^{N2O} is the N_2O biomass burning emission factor for land type *j* before land conversion, measured in kg per tonne of dry matter,

G_j^{NOX} is the NO_x biomass burning emission factor for land type *j* before land conversion measured in kg per tonne of dry matter,

GWP_{CH4} is the IPCC global warming potential associated with CH_4 emissions, equal to 25,

GWP_{N2O} is the IPCC global warming potential associated with N_2O emissions, equal to 298,

GWP_{NOX} is the IPCC global warming potential associated with NO_x emissions, equal to $298 \times \left(\frac{44}{28}\right) \times 0.01$,

θ is the woody biomass carbon fraction, equal to 0.47 based on IPCC.

Table 7: Biomass burning default emission and combustion factors by land type and latitude

	Emission factor *Gj* (kg per tonne dry matter)			Combustion factor β_j
Land type	**CH_4**	**N_2O**	**NO_x**	
Tropical forest	6.8	0.2	1.6	0.55
Temperate forest	4.7	0.26	3	0.45
Boreal forest	4.7	0.26	3	0.34
Grassland/Savanna	2.3	0.21	3.9	0.755

Source : IPCC guidelines 2006, Volume 4, Chapter 2, Table 2.5 & 2.6.

Calculation of soil mineralization due to land conversion (FM_j)

These emissions are composed of two components: direct emissions FM_j^{Direct} and indirect emissions $FM_j^{Indirect}$ from volatilization and leaching/run-off, as follows:

$$FM_j = FM_j^{Direct} + FM_j^{Indirect}$$

Based on the 2019 Refinements to the IPCC guidelines (Equations 11.2 and 11.8 of chapter 11, Vol. 4), direct emissions for soil mineralization for land type *j* can be expressed as:

$$FM_j^{Direct} = \frac{44}{28} \mathrm{EF}_1 \times \mathrm{FSOM}_j \text{, where } \mathrm{FSOM}_j = 1000 * \Delta\mathrm{SOC}_j / \mathrm{R}$$

Where EF_1 is the emission factor for direct emissions, in kg N_2O-N. $(\text{kg N})^{-1}$, equal to 0.005 in dry climate and 0.006 in wet climate,

FSOM_j is the net amount of N mineralised in mineral soils and land type *j*, in kg N,

ΔSOC_j is the average loss of soil organic carbon in the land type *j*, in tonnes C,

R is the C:N ratio of the soil organic matter (15 for forest or grassland, 10 for cropland).

Based on IPCC guidelines (Equation 11.10 of Chapter 11, Vol. 4), indirect emissions from soil mineralization are exclusively associated to leaching and run-off and derived as follows:

$$FM_j^{Indirect} = \frac{44}{28} \mathrm{EF}_5 \times \mathrm{Frac}_{\mathrm{LEACH-(H)}} \times \mathrm{FSOM}_j$$

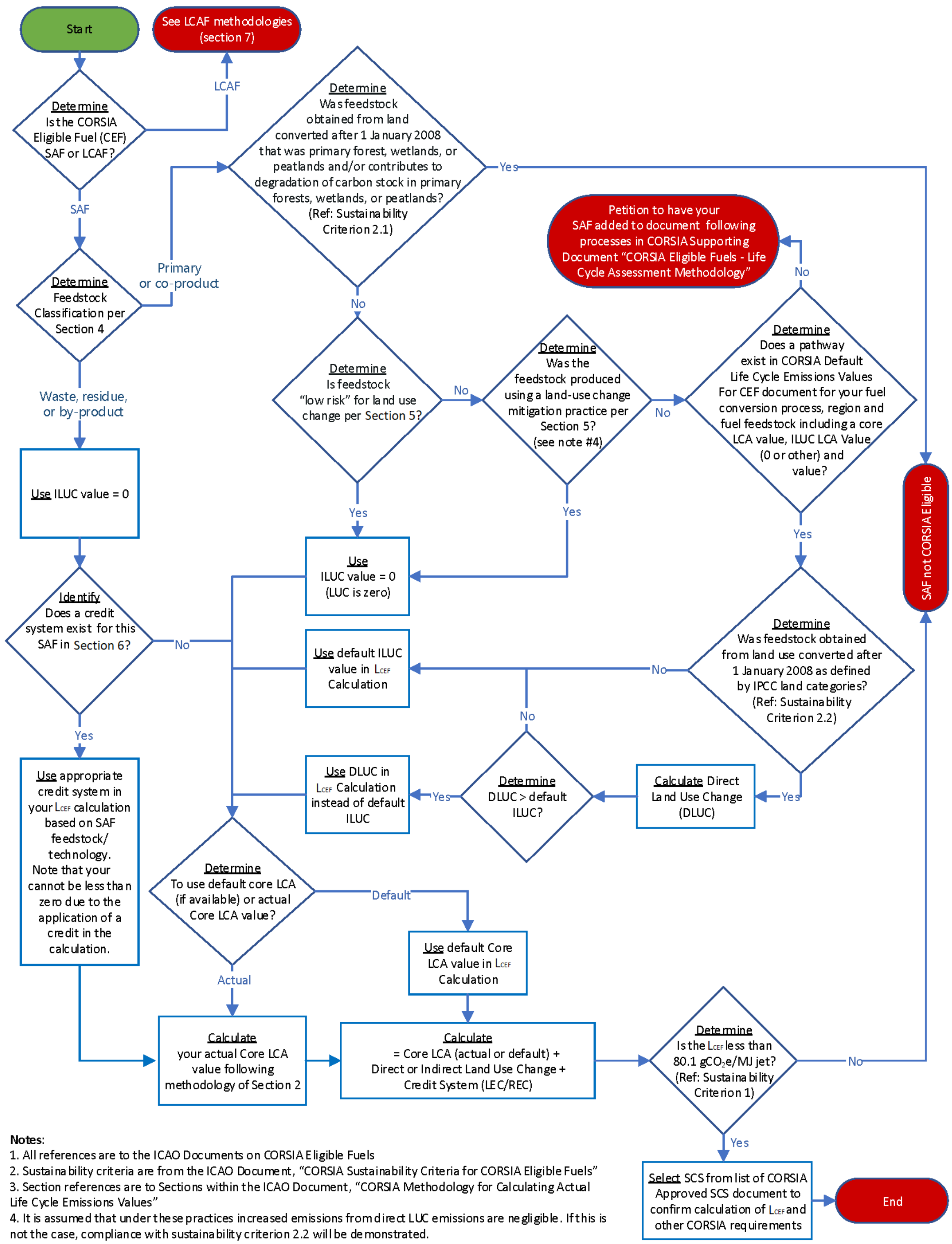
Where EF_5 is the indirect emission factor from N leaching and run-off, in kg N_2O-N. (kg N)$^{-1}$, equal to 0.011,

$Frac_{LEACH-(H)}$ is the fraction of N mineralized lost through leaching and run-off, in kg.kg^{-1}, equal to 0.24,

$FSOM_j$ is the net amount of N mineralized in mineral soils, in kg N, as defined above.

9 PROCESS TO DETERMINE L_{CEF}

The following flowchart describes the process for obtaining L_{CEF} for a given CORSIA Eligible Fuel.



Notes:
1. All references are to the ICAO Documents on CORSIA Eligible Fuels
2. Sustainability criteria are from the ICAO Document, "CORSIA Sustainability Criteria for CORSIA Eligible Fuels"
3. Section references are to Sections within the ICAO Document, "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values"
4. It is assumed that under these practices increased emissions from direct LUC emissions are negligible. If this is not the case, compliance with sustainability criterion 2.2 will be demonstrated.

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