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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

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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

CORSIA METHODOLOGY FOR CALCULATING ACTUAL LIFE CYCLE EMISSIONS VALUES

1. ACRONYMS

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
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DOC	Degradable organic carbon
DOC_F	Fraction of degradable organic carbon dissimilated
GHG	Greenhouse gas
GWP	Global warming potential
ILUC	Induced land use change
LCA	Life cycle assessment
LEC	Landfill emissions credit
LFG	Landfill gas
LFGCE	Landfill gas collection efficiency
LMP	Land management practice
LUC	Land use change
LS_f	Life cycle emissions factor for a CORSIA eligible fuel in gCO_2e/MJ
MCF	Methane correction factor
MSW	Municipal solid waste
N_2O	Nitrous oxide
REC	Recycling emissions credit
SAF	Sustainable aviation fuel
SCS	Sustainability certification scheme

2. CORSIA METHODOLOGY FOR CALCULATING ACTUAL LIFE CYCLE EMISSIONS VALUES

An Aeroplane Operator seeking benefits from the use of CORSIA eligible fuels (CEF) in terms of reductions in CORSIA CO_2 offsetting requirements will have to provide documentation to their State on the life cycle emissions values (LS_f) and sustainability. An Aeroplane Operator will need to work with a CEF supplier to obtain this information.

1. An Aeroplane Operator may use an actual core life cycle value – described in paragraphs 3 and 6 – as part of an accepted fuel sustainability certification process if a fuel producer can demonstrate lower core life cycle emissions compared to the default core 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 core life cycle value. If the Aeroplane Operator chooses to use an actual core life cycle value, then the Aeroplane Operator shall 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 below. The results of the actual core life cycle value analysis shall be added to the appropriate ILUC value from the ICAO document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels" to calculate the total Life Cycle Emissions Value (LS_f). The SCS shall ensure that the methodology has been applied correctly and that relevant information on GHG emissions is transmitted through the chain of custody. SCS shall record detailed information about the calculation of actual values within their system and provide this information to ICAO on request.

2. If a fuel was produced from a feedstock that is defined as a waste, residue, or by-product according to Section 4, then the actual core LCA value shall be the total LS_f. If the feedstock is not a waste, residue, or by-product, then a default core LCA value and an ILUC value will need to be added to the ICAO document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels" before the fuel 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 the CORSIA Supporting Document "CORSIA Eligible Fuels - Life Cycle Assessment Methodology".

3. The system boundary of the core LCA value calculation shall include the full supply chain of CEF production and use. As such, emissions associated with the following life cycle stages of the CEF supply chain must be accounted for: (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; and (7) fuel combustion in an aircraft engine.

4. For life cycle stages 1-6 described in paragraph 3, carbon dioxide equivalent (CO_2e) emissions of CH_4, N_2O and non-biogenic CO_2 from these activities shall be calculated on the basis of a 100-year global warming potential (GWP). CO_2e values for CH_4 and N_2O shall be based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (28 and 265, respectively). Only non-biogenic CO_2 emissions from fuel combustion shall be included in the calculation of CO_2e emissions.

5. The functional unit for final LS_f results shall 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).

6. The calculated LS_f values shall include emissions generated during on-going operational activities (e.g., operation of a fuel production facility, feedstock cultivation), as well as emissions associated with the material and utility inputs to 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) shall not be included.

7. In many cases, the CEF supply chain of interest will result in the co-production of multiple commodities. These co-products may include non-CEF liquid fuels, chemicals, electricity, steam, hydrogen, and/or animal feed. Energy allocation shall 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 shall not be allocated to waste, residues and by-products that result from the CEF supply chain of interest.

8. CEF feedstocks can be broadly categorized into three groups - primary or co-products, by-products, and wastes and residues. Further information on how feedstocks are categorized in these groups for the purposes of CORSIA can be found in Section 4.

9. 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 shall 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”.

10. 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 shall be met to obtain these reductions can be found in Section 5. The ILUC value of zero shall be used in place of the default ILUC value to calculate total LS_f. If the Aeroplane Operator chooses to claim emissions reductions from the implementation of land use change-risk mitigation practices, then the Aeroplane Operator shall 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 Section 5.

11. Waste, residue, and by-product feedstocks are assumed to incur zero emissions during the feedstock production step of the lifecycle. Emissions generated during the collection, recovery, extraction, and processing of these wastes, residues, and by-products, however, shall be included (life cycle stages 2-7 described in paragraph 3).

12. The production of sustainable aviation fuels (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 LS_f. If the Aeroplane Operator chooses to use a SAF that would generate such an emission credit, then the Aeroplane Operator shall 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 shall 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 must 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; avoid double counting (including double issuance[1] or double claiming[2]) of such credits; and exceed emissions reductions that would otherwise occur in a business-as-usual scenario.

During the pilot phase of CORSIA, and until additional requirements and guidance have been developed to (a) ensure that emission credits for SAF generated under CORSIA are of an equivalent quality and quantity to emission units and (b) resolve concerns regarding double counting, after the subtraction of the LEC and/or REC applicable to a SAF, the total LS_f value cannot be smaller than 0 gCO_{2e}/MJ.

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

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). With regard to the life cycle steps, Section 2, paragraph 3 states: "The system boundary of the core LCA value calculation shall include the full supply chain of CEF production and use. As such, emissions associated with the following life cycle stages of the CEF supply chain must be accounted for: (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; and (7) fuel combustion in an aircraft engine."

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 according to the MSW crediting methodology in Section 6 on "Emissions Credits".

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, paragraph 3, 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

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.

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 residues, wastes or by-products

Residues
Agricultural residues:
- Bagasse
- Cobs
- Stover
- Husks
- Manure
- Nut shells
- Stalks
- Straw
Forestry residues:
- Bark
- Branches

- Cutter shavings
- Leaves
- Needles
- Pre- commercial thinnings
- Slash
- Tree tops
Processing residues:
- Crude glycerine
- Forestry processing residues
- Empty palm fruit bunches
- Palm oil mill effluent
- Sewage sludge
- Crude Tall Oil
- Tall oil pitch
Wastes
- Municipal solid waste
- Used cooking oil
By-products
- Palm Fatty Acid Distillate
- Tallow
- Technical corn oil

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:

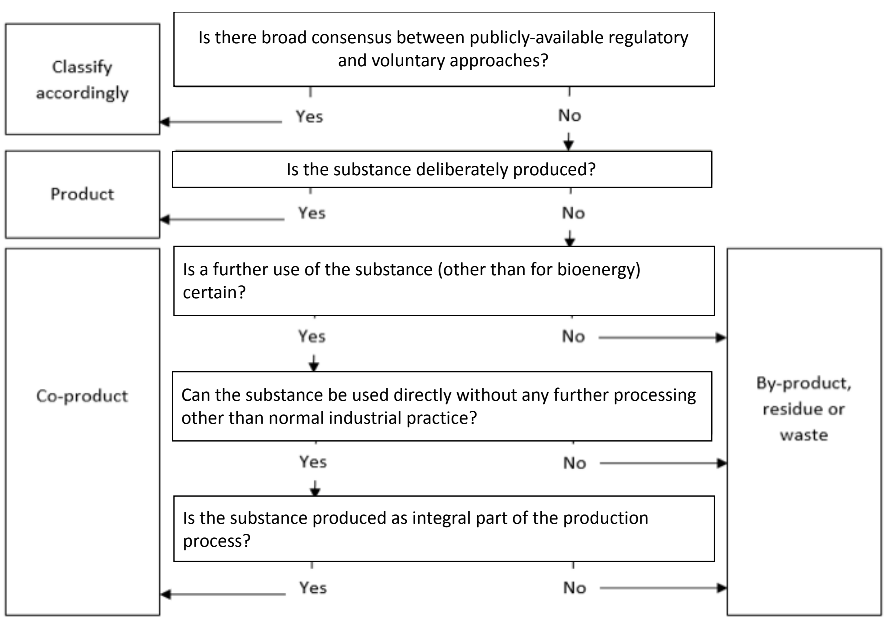

Figure 1. Guidance for inclusion of additional materials in positive list

5. LOW LAND USE CHANGE (LUC) RISK PRACTICES

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 should 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.

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 must be open, documented, and publicly communicated. Feedstocks designated under the Low LUC Risk Practices approach during the CORSIA pilot phase 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.

In all cases, this methodology should consider that, for a specific project to be eligible for recognition as a low LUC risk practice, the practice must 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.

This methodology is applicable during the pilot phase of CORSIA only.

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 should 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).

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.

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

1) The average amount of feedstock available historically, from 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. 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).

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.

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 services from that land onto different and equivalent amounts of land elsewhere.

Note. – services refer to products obtained from ecosystems such as food, animal feed, or bioenergy feedstocks.

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

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). The value of the LEC shall 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[3] (% 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)[4]

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

[3] 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/sites/production/files/2016-03/documents/warm_v14_management_practices.pdf

[4] 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 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]

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)[5]

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.

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[5] 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 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.[4]

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]

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

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]

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

where:

LHV_{CH4}	*= lower heating value of CH_4, 0.0139 MWh / kg*
η	*= 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 CO2e / 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]

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

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. The emissions avoided for additional recycling of plastics and metals, calculated separately, are summed to generate a total REC value. REC shall 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[6]

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

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.

[6] 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 6: REC associated with additional recycled plastic [g CO2e / 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[7]

Material	Emission factor for virgin metal production (*CI*)	Specific electricity consumption for metal recycling (SEC_{rec})
	[g CO_{2e}e / t]	*[MWh / t]*
Aluminium	8.40×10^6	0.66
Steel	1.27×10^6	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) [gCO₂e / 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.

Equation 7: REC associated with additional recycled metal [g CO2e / 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]*

[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 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 [gCO2e/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.*

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