Life Cycle Impact Assessment Methodology for PCR Modules for Roundwood and Pulp/Paper

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Period of Validity

The final version of this PCR will be valid for five (5) years from the date of its issue.

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Introduction

This document specifies the life cycle impact assessment (LCIA) methodology requirements for the Product Category Rule (PCR) modules for roundwood and pulp/paper. It is intended to be used in conjunction with these two documents, which provide details on scoping, data collection, and other aspects of LCA. Use of these three documents allows for the establishment of LCAs and Environmental Product Declarations (EPDs) for roundwood and pulp/paper products.

The LCA methodology contained in these documents is intended to provide standardized protocols for addressing all relevant environmental and human health impacts from wood and paper production. These relevant impacts are based on the observable alterations compared to preindustrial conditions for many impact categories of environmental change, all of which can be linked back to anthropogenic activities related to logging and/or pulp/papermaking. In order to practically and consistently assess the degree of change within these impact categories in different instances, these protocols also contain detailed algorithms and data requirements for each type of evaluation. These algorithms are intended to provide results which are of a high enough precision and accuracy to be useful in decision making, product comparisons, improvement in environmental conditions, and in other applications of LCA in this context. Users of this PCR module are encouraged to become familiarized with the applicable PCR module for which they are developing an LCA or EPD. In this LCIA methodology document, references are made to this document where necessary.

This document can be used as the basis of the LCIA for product categories besides pulp/paper which use roundwood as a material input, like dimensional lumber, viscose fiber, wood pellets, and doors and windows made from wood. In the future, additional PCR modules for these other product categories should be developed which are consistent with this PCR module and the LCIA methodology document. This will allow for the development of complete and accurate EPDs for these other product categories.

1 Scope

This document provides rules and guidance for LCIA for roundwood, pulp, and paper products, with requirements conformant to the N505 document,[1] draft LEO-S-002,[2] ISO 14025, 14040 and 14044 standards.

Throughout this document, default LCIA approaches are presented. These default approaches are generally based on conservative assumptions which will result in upper-bound estimates which provide baseline LCA results, which could be improved by performing site specific modeling with higher temporal and geographical representativeness. However, it is recommended that specific data be used

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[1] The N505 document was submitted by representatives from the US Technical Advisory Group to the ISO TC 207 as a formal set of revisions for the ISO 14044 LCA standard. The document contains requirements pertaining to LCA which are applicable in this document and in these PCR modules. Available at: https://www.scsglobalservices.com/resource/technical-review-of-life-cycle-impact-assessment-phase

[2] LEO-S-002, Second Public Comment Version, Available July 2016 at http://www.leonardoacademy.org/programs/standards/life-cycle.html

to assess results, rather than default data, which can provide an assessment which has better temporal and geographical representativeness.

2 Normative References

The references in the roundwood and pulp/paper PCR modules also apply to this document. In addition, the following documents are normative:

- Roundwood PCR Module.
- Market Pulp/Paper PCR Module.

3 Terms and Definitions

The terms and definitions from the PCR Modules also apply here. The following additional terms and definitions are used:

Term	Definition
Annual unit of analysis	The unit of analysis is defined on a year-by-year basis within the timeframe of analysis, and so is referred to as the “annual unit of analysis.”
Biomass	Organic material, such as wood and wood products (e.g., black liquor, hog fuel), agricultural crops or wastes, source separated biogenic components of municipal solid wastes containing biogenic materials like food waste, leaves, wood, grass clippings, etc., and any non-plant organic material such as fungi and invertebrates.
Biotic Resource	A resource deriving recently from living biomass.
Black carbon	The light-absorbing component of carbonaceous aerosols. Black carbon contributes to roughly 1 W/m^2 of global radiative forcing[3], and is the second most important forcing agent after carbon dioxide.
Black liquor	The waste product from the kraft pulping process when digesting pulpwood into paper pulp removing lignin, hemicelluloses and other extractives from the wood to free the cellulose fibers. Often combusted to generate energy.
Brown carbon	The component of organic carbon which absorbs ultraviolet radiation from the sun. Co-emitted with the carbonaceous aerosols black and organic carbon.
Category Indicator	Quantifiable representation of an impact category [Ref. ISO-14044] (Also referred to as “Impact Category Indicator,” or simply, “Indicator.”)
Characterization Data	Any data used in the LCIA phase to calculate results. Examples include meteorological data used in dispersion modeling and data on ecological conditions used to calculate forest disturbance.
Climate Pollutant	An emission which can be linked to positive or negative climate forcing (i.e., both warming and cooling are considered).
Coated free sheet	Coated paper from predominately chemically pulped or recycled furnish.
Confidence Bound	A value representing the upper or lower end of a confidence interval.
Confidence Interval	An estimated range of values which is expected to include the actual value of a data point, defined by a lower confidence bound and an upper confidence bound. A confidence interval is the probability that a value will fall between an upper and lower bound of a probability distribution.
Core Impact Category	An impact category in which at least one unit process in the product system under study contributes measurably to observed midpoints or endpoints in the stressor-effects network. Defined independently by product system.

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[3] Bond, T.C., S.J. Doherty, D.W. Fahey, P.M. Forster, T. Berntsen, O. Boucher, B.J. DeAngelo, M.G. Flanner, S. Ghan, B. Karcher, D. Koch, S. Kinne, Y. Kondo, P.K. Quinn, M.C. Sarofim, M.G. Schultz, M. Schulz, C. Venkataraman, H. Zhang, S. Zhang, N. Bellouin, S.K. Guttikunda, P.K. Hopke, M.Z. Jacobson, J.W. Kaiser, Z. Klimont, U. Lohmann, J.P. Schwarz, D. Shindell, T. Storelvmo, S.G. Warren and C.S. Zender, Bounding the role of black carbon in the climate system: A scientific assessment, J. Geophys. Res., in press, DOI: 10.1002/jgrd.50171, 2013.

Term	Definition
Cradle-to-gate	A scope which includes the life cycle stages from raw material extraction through production of a product.
Cradle-to-grave	A scope which includes all life cycle stages from raw material extraction through end-of-life.
Disturbance	Average deviation in overall ecological conditions in a terrestrial ecoregion, freshwater body or wetlands, when compared to undisturbed conditions (i.e., unaffected by anthropogenic activities since the pre-industrial era) and fully disturbed conditions (i.e., representing maximally disturbed areas) in an area within the same terrestrial ecoregion, freshwater body or wetland type. This document specifies the ecological conditions which are included in the deviation measurement for each type of forest disturbance in Section 5.5.
Environmental Mechanism	System of physical, chemical, radiological, and biological processes for a given impact category, linking stressor(s) to midpoints and to category endpoints. *[Based on 14044]*
Environmental Relevance	The degree of linkage between a category indicator result and the category endpoint(s). *[Ref. ISO 14044, § 4.4.2.2.2]*
Exceedance of threshold	For a given impact category, represents the surpassing of a threshold (defined below).
FIA Evaluation Year (or FIA Evaluation Group)	Each FIA plot is analyzed once every 5 or 10 years, depending upon the region. An FIA Evaluation Year includes data from a full sample cycle of FIA plots, i.e. it will contain plot data from the last 5 or 10 years, depending on the region.
Fiber Basket	Region supplying pulpwood to a pulp or paper mill.
Forest Analysis Unit	An area of timberland used to represent forest ecosystem impacts resulting from forestry operations within a region.
Forest Inventory and Analysis Database	Forest Inventory and Analysis (FIA) Database, provided by the US Forest Service.[4]
Forest Trend Monitoring (FTM) plan	Forest Trend Monitoring plan includes designing sampling plans to select sample sizes, sampling frequency, identify the forest inventory parameters to be measured and determine sampling strategies for measurements.
Forest Type	A classification of forest land based on the species that form a plurality of live-tree basal-area stocking. [5]
Forest Type Group	A classification of forest land based on the species forming a plurality of live-tree stocking. A combination of forest types that share closely associated species or site requirements are combined several major forest-type groups. [6]
Forest Land	Land that is at least 10 percent stocked with trees of any size, or that formerly had such tree cover and is not currently developed for a nonforest use. The minimum area for classification of forest land is one acre. The components that make up forest land are timberland and all noncommercial forest land. [7]
Freshwater Body	A freshwater component within a holistic ecosystem, a freshwater body is an interconnected biotic community, including watercourses, lakes, wetlands, and adjacent riparian areas, within specific watershed boundaries, defined by: salinity; turbidity; water temperature; sedimentation rates; sediment size distribution; flow rates; depths; channel contours; hydrology and hydraulics; water quality; watershed area; tributary areas; stream lengths; presence of large woody debris; riparian canopy cover; riparian zone vegetative species composition; climate; and geology. [Based on LEO-S-002]
Freshwater Indicator species, genera, and/or families	Freshwater indicator species, genera, and/or families, used to define Freshwater Properly Functioning Conditions: • Shall include the most abundant 5% of fish species and genera present in the freshwater body in an undisturbed condition; • Should include other common species, genera, and/or families present in the freshwater body in an undisturbed condition.
Freshwater Properly Functioning Conditions (FWPFC)	The Freshwater Properly Functioning Conditions (FWPFC) are at least 5 specific ecological conditions related to a set of at least 5 freshwater indicator species, genus, and/or family (i.e. freshwater indicator taxa). The FWPFC:

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[4] Available at FIA Datamart: http://apps.fs.fed.us/fiadb-downloads/datamart.html

[5] USFS. Northeastern Forest Inventory & Analysis, Methodology: Common Definitions Used in FIA. http://www.fs.fed.us/ne/fia/methodology/def_ah.htm

[6] Ibid.

[7] Ibid.

Term	Definition
	• Shall include at least 1 condition based upon taxonomic composition (e.g., number or relative abundance of taxa). • Shall include at least 1 condition based upon population characteristics of indicator taxa (e.g., abundance or relative proportions). • Shall include conditions related to: turbidity; sedimentation rates; biological oxygen demand and/or dissolved oxygen content; presence of hazardous environmental contaminants; water temperature; salinity; vegetative cover; plant structure (if plants are present). • Should include at least 1 condition based upon age composition of freshwater indicator species. • Should include at least 1 condition based upon percentage of diseased freshwater indicator species.
Freshwater Undisturbed Condition	The undisturbed condition of the freshwater body is the condition prior to the onset of significant human interventions in the watershed in which it is present. If data are unavailable regarding the undisturbed freshwater condition, data on undisturbed conditions in a representative watershed can be used which is within 100 kilometers of the freshwater body, and which has similar: area; hydrology; elevation; and climate. The ecological conditions defined in the Freshwater Undisturbed Condition are the same as those defined in the Freshwater Properly Functioning Condition, and are compared to the conditions in a given freshwater based on the approach described in Section 5.5.2.
Furnish	A mixture of cellulosic fibers, optional fillers, and water from which paper is made.
Impact Category	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned *[Ref: ISO-14044]*. The issues of concern are represented in a distinct environmental mechanism, which can be modeled with a stressor-effects network made up of observable stressors, midpoints, and endpoints.
Impact Group	Impact categories with similar endpoints and environmental mechanisms.
Key unit process	A unit process contributing over 15% to any indicator result.
Land use	The number of acres occupied for one year to produce a certain amount of timber (measured in cubic feet). The land use per cubic feet of timber is the inverse of the site productivity.
Midpoint Characterization Factor	A factor characterizing the temporal nature, spatial extent, severity, reversibility, and/or exceedance of thresholds, of impacts on a specific midpoint. [Adapted from LEO-S-002 definition for Environmental Characterization Factor and N505.]
Organic carbon	The scattering component of carbonaceous aerosols, these emissions lead to a modest cooling effect globally due to their negative radiative forcing.
Potency Potential Characterization Factor	A factor characterizing the relative potency of individual stressors which contribute to a common endpoint. Used to aggregate related stressors into a single category indicator[8]. [Adapted from LEO-S-002 definition for Stressor Characterization Factor and N505.]
Radiative Efficiency	The change in global mean radiative forcing for a change in the atmospheric abundance of species, expressed in $mWm^{-2}Tg^{-1}$.
Radiative Forcing	The net change in the energy balance of the Earth system due to some imposed perturbation, typically expressed in watts per square meter. Can be expressed as a global or regional mean.
Receiving Environment	The environment affected by stressor(s), including emissions, land use, or wastes.
Reference Concentration	An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a NOAEL, LOAEL, or benchmark concentration, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in EPA's noncancer health assessments. [US EPA][9]
Reference Dose	An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a NOAEL, LOAEL, or benchmark dose, with

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[8] The PP-CF is equivalent to the traditional midpoint characterization factors often used in LCA, for example, kg N-eq/kg emission. It is titled PP-CF to delineate that it treats an earlier state in the environmental mechanism than M-CFs, and is used in conjunction with M-CFs to establish indicator results.

[9] http://www.epa.gov/risk_assessment/glossary.htm#r

Term	**Definition**
	uncertainty factors generally applied to reflect limitations of the data used. Generally used in EPA's noncancer health assessments. [US EPA][10]
Regional Radiative Efficiency	The change in regional mean radiative forcing for a change in the atmospheric abundance of species, expressed in $mWm^{-2}Tg^{-1}$, evaluated within a climate hot spot.
Roundwood	A length of cut tree generally having a round cross-section, such as a log or bolt.[11]
Sub-watershed	The smallest watershed definition used in the National Watershed Boundary Dataset, identified with 12-digit hydrologic unit codes. There are roughly 160,000 sub-watersheds in the US, with an average size of roughly 25,000 acres.
Technically recoverable reserve base	The technically recoverable reserve base includes “the part of an identified resource reserve that could be commercially extracted at a given time”. The technically recoverable reserve base may encompass those parts of a resource that have a reasonable potential for becoming economically recoverable within planning horizons that extend beyond those which assume proven technology and current economics [12].
Terrestrial ecoregion	The terrestrial component of a holistic ecosystem, a terrestrial ecoregion is a biotic community in a specific terrestrial area, which is defined by conditions such as prevailing vegetation structure, leaf types, plant spacing, vegetative species composition, vegetative compositional structure, vegetative age structure, presence of large living trees and snags (if relevant), presence of biomass (above and below ground), soil conditions, connectivity, landscape heterogeneity, fragmentation, climate, and topography. [Ref. LEO-S-002]
Threshold	A recognized environmental condition that, when exceeded, is linked to significant increases in negative impacts to environment or human health.
Timberland	Forest land producing or capable of producing crops of industrial wood (more than 20 cubic feet per acre per year) and not withdrawn from timber utilization (formerly known as commercial forest land).[13]
Time Horizon	A specified timeframe.
Ton	Metric ton (1,000 kilograms or 2,204.6 pounds).
Uncertainty Analysis	Systematic procedure to quantify the uncertainty introduced in the results of a life cycle assessment due to the cumulative effects of model imprecision, input uncertainty and data variability.
Undisturbed Reference Area	Area of forest/other wooded land against which measurements of ecological conditions in a Forest Analysis Unit are compared. Measurements are evaluated within plots and transects according to the requirements for sampling plans defined in Section 6.5.3.1 of the Roundwood PCR Module. The Undisturbed Reference Area shall be chosen to be representative of the forest ecosystem in the Forest Analysis Unit against which it is compared, if significant human interventions were absent for a time period sufficient for mature forest ecosystem characteristics to become established. The Undisturbed Reference Area: • Shall include an area which has not been subject to significant human interventions (i.e., logging, intensive hunting, non-timber extraction, agriculture, mining, fire suppression, or other activities[14]) for the longest time possible, which is not less than 80 years. An area can qualify as undisturbed if it has experienced disturbance events consistent with a natural regime within the last 80 years, including wildfires, severe storms, or pest outbreaks. • Shall be located in a region with similar climate, elevation, rainfall, and soil conditions, to the forest ecosystem in the Forest Analysis Unit against which it is compared. • Shall be located as close as possible to the Forest Analysis Unit against which it is compared, and never farther away than 800 kilometers. • Shall include the largest possible contiguous area in the region satisfying these requirements, which is no less than 5,000 hectares.

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[10] http://www.epa.gov/risk_assessment/glossary.htm#r

[11] Stokes, Bryce J.; Ashmore, Colin; Rawlins, Cynthia L.; Sirois, Donald L. 1989. Glossary of Terms Used in Timber Harvesting and Forest Engineering. Gen. Tech. Rep. SO-73. New Orleans, LA: U.S. Dept of Agriculture, Forest Service, Southern Forest Experiment Station. 33 p.

[12] LEO-SCS-002 Standard Draft Dated June 2014. Leonardo Academy. http://www.leonardoacademy.org/programs/standards/life-cycle.html

[13] USFS. Northeastern Forest Inventory & Analysis, Methodology: Common Definitions Used in FIA. http://www.fs.fed.us/ne/fia/methodology/def_qz.htm

[14] Some stakeholders have proposed defining some human interventions as being “restorative” in nature; however, there is no suitable definition which could be used in this PCR. Areas subjected to “restorative” forest management practices are not included in the URA definition.

Term	Definition
	Areas managed primarily for conservation purposes (e.g., national parks) should be used where available. If no Undisturbed Reference Area is available in the region meeting these requirements, then ecological conditions in the undisturbed reference can be specified by a panel of at least three independent experts in local ecology. This shall include defined values for all ecological conditions listed in Section 5.5.1.2 of the LCIA Methodology (i.e., forest compositional structure, forest size structure, relative measurements of biomass in the forest, surveys of the vertebrate and invertebrate species communities, and spatial forest structure).
Unit of analysis	A unit of analysis (also referred to as declared unit) is defined in lieu of a functional unit for products for which the function is not specified, due to its potential use in multiple applications.
Unit risk estimate	The upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 microgram per cubic meter (µg/m^3) in air. The interpretation of the URE would be as follows: if the URE = 1.5 x 10^{-6} per µg/m^3, 1.5 excess tumors are expected to develop per 1,000,000 people if they were exposed daily for a lifetime to 1 microgram of the chemical in 1 cubic meter of air. Unit risk estimates are considered upper bound estimates, meaning they represent a plausible upper limit to the true value. (Note that this is usually not a true statistical confidence limit.) The true risk is likely to be less, but could be greater.[15]
Watershed	A watershed is the area of land where all of the water that falls in it and drains off of it goes into the same place.[16]
Wetland	A wetland is a biotic community within a given geographic region. A specific wetland is defined by: acidity; salinity; turbidity; water quality; sedimentation rates; sediment size distribution; flow rates; depths; hydrology; vegetative cover; plant structure (if plants are present); bottom particle composition and structure; channel connectivity; channel complexity; tidal action (for saltwater wetlands); wave action (for saltwater wetlands); and climate. [Ref. LEO-S-002]
Wetland Indicator Species	Wetland indicator species, genera, and/or families, used to define WPFC: • Shall include the most abundant 5% of fish species and genera present in the undisturbed wetland condition number or relative abundance of taxa). • Should include other common species, genera, and/or families present in the undisturbed wetland.
Wetland Properly Functioning Conditions (WPFC)	The Wetland Properly Functioning Conditions (WPFC) are at least 5 specific ecological conditions related to a set of at least 5 freshwater indicator species, genus, and/or family (i.e. freshwater indicator taxa). The WPFC: • Shall include at least 1 condition based upon taxonomic composition (e.g., number or relative abundance of taxa). • Shall include at least 1 condition based upon population characteristics of indicator taxa (e.g., abundance or relative proportions). • Shall include conditions related to: turbidity; sedimentation rates; biological oxygen demand and/or dissolved oxygen content; presence of hazardous environmental contaminants; water temperature; salinity; vegetative cover; plant structure (if plants are present). • Should include at least 1 condition based upon age composition of wetland indicator species • Should include at least 1 condition based upon percentage of diseased wetland indicator species.
Wetland Undisturbed Conditions	The undisturbed condition of the wetland is its condition prior to the onset of significant human interventions in the watershed in which it is present. If data are unavailable regarding the undisturbed condition, data on undisturbed conditions can be used from a representative wetland which is within 100 kilometers of the wetland, and which has similar: area; hydrology; flow conditions; salinity; elevation; silt load; and climate.

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[15] http://www.epa.gov/airtoxics/natamain/gloss1.html

[16] USGS: What is a Watershed? http://water.usgs.gov/edu/watershed.html

4 Abbreviations

The abbreviations from the PCR modules apply. The additional abbreviations are used in this document:

µg	microgram
a.i.	Active ingredient
AR5	Fifth Assessment Report
TDF	Terrestrial Disturbance Factor
CH_4	Methane
CO_2	Carbon dioxide
CPC	Central Product Classification
EIA	Energy Information Administration
EPD	Environmental Product Declaration
eq.	equivalent
ERF	Exposure Risk Factor
FAU	Forest Analysis Unit
FIA	Forest Inventory Analysis
FTM	Forest Trend Monitoring
FWAU	Freshwater Analysis Unit
FWPFC	Freshwater Properly Functioning Conditions
FWTM	Freshwater Trend Monitoring Sites
FWTP	Freshwater Trend Monitoring Plan
GFP	Global Forcing Potential
GHG	Greenhouse gas
GJ	Gigajoule
GLO	Ground level ozone
H_2CO_3	Carbonic acid
HAAC	Hazardous Ambient Air Contaminant
HI	Hazard Index
HQ	Hazard Quotient
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
M-CF	Midpoint Characterization Factor
NATA	National Air Toxics Assessment
NOx	Nitrogen oxides
PCR	Product Category Rule
PM	Particulate matter
PM2.5	Particulate matter 2.5
ppb	parts per billion
PP-CF	Potency Potential Characterization Factor
RE	Radiative Efficiency
RRE	Regional Radiative Efficiency
RF	Radiative Forcing
RfC	Reference Concentration
SLCP	Short-lived climate pollutant
SO_2	Sulfur dioxide
URA	Undisturbed reference area
URE	Unit risk estimate
US	United States
US EPA	US Environmental Protection Agency
USGS	US Geological Survey
VOC	Volatile Organic Compound
WAU	Wetland Analysis Unit
WHO	World Health Organization
WPFC	Wetland Properly Functioning Conditions
WTM	Wetland Trend Monitoring Sites

5 Approach for Evaluating Category Indicator Results, by Impact Category

The core impact categories which must be considered for each process step of roundwood production, virgin pulp & paper production, and recycled pulp & paper production are described in the PCR Modules. This supplement provides a description of the following:

- The category indicators used to represent results for each impact category, including terminology and disclosure requirements for each. For some impact categories, multiple category indicators are reported.

- The requirements and guidance for characterization models which establish Potency Potential Characterization Factors (PP-CFs) and Midpoint Characterization Factors (M-CFs).

The characterization models used to generate indicator results are given in the sections below. Each involves the application of characterization data to generate PP-CFs and M-CFs and then produce results. Based upon the nature of the environmental mechanism for each impact category, characterization data required, characterization models used, and PP-CF and M-CF values all differ. All of the characterization modes referenced are based on the N505 and LEO-S-002 requirements, and all characterization models shall conform to these standards. This supplement provides the requirements and supplemental guidance for assessing results for roundwood, pulp, and paper products.

5.1 Biotic/Abiotic Resource Depletion Impacts

5.1.1 Non-renewable Energy Resource Depletion

This impact category considers the drawdown of non-renewable energy resources. The only energy consumption included in this indicator are fossil fuels, uranium, and wood products that are used in a non-sustainable fashion (i.e., wood that is harvested in a non-sustainable fashion, where harvest rates exceed rates of regrowth). “Non-renewable” consumption of a resource is defined as a case where the consumption rate of the resource exceeds the accretion rate. This includes consumption of:

- All fossil fuels (natural gas, oil, and coal).

- Uranium.

- Forest wood resources (including wood and wood products such as black liquor and hog fuel), used for all purposes, if the rate of harvest has exceeded the rate of regrowth over the last 10 years.[17,18]

The PP-CF is the energy content of the resource, using the lower (net calorific) heating value. The PP-CF should be specific to the region and timeframe where the resource is extracted, using data from the International Energy Agency. The PP-CFs in Table 1 can be used as default.

Table 1. Default heat content of fossil fuels,[19] uranium,[20] and wood.[21]

Resource	Heat content Net calorific value	Unit	Data Source
Coal	27.2	GJ per metric ton	US EIA (2014)
Crude oil	44.8	GJ per metric ton	US EIA (2014)
Natural gas	37.4	GJ per m^3	US EIA (2014)
Uranium	427,000	GJ per metric ton uranium	OECD / IAEA
Wood	20.8	GJ per metric ton	US DOE

> NOTE. This impact category only considers non-renewable consumption of elemental flows consumed from the providing environment. However, the energy content of certain intermediate products of wood (e.g., black liquor, paper pellets) will be needed to evaluate final results for energy consumption of wood. The combustion of these products is accounted for in this result, if the wood consumed is harvested in excess of regrowth rates. Alternatively the Total Energy Use can be reported as optional information (see Section 7.4 of Roundwood PCR Module). An average heat content of black liquor of 11.758 Million Btu per short ton can be used as a default in these calculations.[22]

The M-CF represents the fraction of the technically recoverable reserve base of the nonrenewable energy resource which will be depleted over the next 25 years. The M-CF therefore provides a relative weighting of the projected scarcity of different nonrenewable resources.

The M-CF shall be specific to production of non-renewable energy resources supplying the market from which the energy resource is extracted, and shall be as recent as possible.

> ***FOR EXAMPLE.*** The US Energy Information Administration has estimated that in the next 25 years, between 90-99% of natural gas and coal consumed in the United States will be produced domestically, while consumption of crude oil and uranium in is dependent in large part on global supplies.[23] For unit processes in the US, M-CFs reflective of domestic production for natural gas and coal, and global production for oil and uranium, shall be used. Conversely, consumption of natural gas in Europe relies on imports from

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[17] This period of 10 years is a typical period of time used to evaluate the sustainability of harvest rates in a given forest management regime.

[18] This determination shall be completed using the same data sources as required to evaluate site harvest productivity. See Section 6.5.3 of the Roundwood PCR Module.

[19] International Energy Agency. 2014 Key World Energy Statistics. Chapter 9: Conversions. http://www.iea.org/publications/freepublications/publication/KeyWorld2014.pdf

[20] Appendix 5 of OECD Nuclear Energy Agency and the International Atomic Energy Agency. Uranium 2009: Resources, Production and Demand.

[21] US DOE Office of Energy Efficiency and Renewable Energy, from: http://cta.ornl.gov/bedb/appendix_a/Heat_Content_Ranges_for_Various_Biomass_Fuels.xls

[22] US Energy Information Administration. *Table 1.10: Average heat content of selected biomass fuels. http://www.eia.gov/renewable/annual/trends/pdf/table1_10.pdf*

[23] US Energy Information Administration. *Annual Energy Outlook 2012.*

Russia and other sources. The M-CF for unit processes in Europe must consider the production characteristics of the market from which they purchase fuels.

The M-CF values from Table 2 can be used as a default.

Table 2. M-CF values for a 25-year time horizon (from 2010 to 2035).

Reserve	Unit	Total Production 2010-2035	Technically Recoverable Reserves (2012 Data)	M-CF	Data Source
Oil	billion barrels of oil	953	2,036	0.47	EIA International Energy Outlook 2011, USGS 2012[24]
Natural Gas	Trillion cubic feet	3,634	18,903	0.19	EIA International Energy Outlook 2011, USGS 2012
Coal	Quadrillion BTU	4,570	20,131	0.23	EIA International Energy Outlook 2011, USGS 2012
Uranium	Thousand tonnes U	2,647	6,306	0.42	OECD / IAEA 2009
Wood	Where relevant, the M-CF depends upon the regional harvest rate of wood compared to the total stock of valuable wood resources in the region, which shall be evaluated by FAU. Consistent with the M-CF for other energy resources. For consistency, it shall be calculated as: Net difference in harvest and growth over 10 years in the FAU, divided by the total standing stock in the FAU, times 2.5.				

**Includes both anthracite and bituminous coal.*

Total energy use can also be reported in additional environmental information.

The result for Nonrenewable Energy Resource Depletion, in GJ eq., is calculated according to the equation below, for a given year in the timeframe of analysis. As this is an accumulated midpoint, the indicator result is calculated as an accumulation over the total number of years in the timeframe of analysis.

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[24] US Geological Survey. *National Assessment of Oil and Gas Project: Continuous Gas Resources.* Updated August, 2012. Retrieved on 10/17/2012 from http://certmapper.cr.usgs.gov/data/noga00/natl/tabular/2012/Summary_12_Final.xls

Equation 1. Result for Nonrenewable Energy Resource Depletion.

Nonrenewable Energy Resource Depletion (GJ eq.), in year i =

$$\sum_i \sum_j \sum_k \text{Energy Input}_{i,j,k} \times \text{PP-CF}_k \times \text{M-CF}_{i,k})$$

Where:

- *Energy Input is the consumption of non-renewable energy resources required to produce the annual unit of analysis in a given year*
- *i is the total number of years since the beginning of the Timeframe of analysis (for this accumulated midpoint)*
- *j is the total number of unit processes in the scope*
- *k represents the total number of types of non-renewable energy resources consumed (at least including natural gas, crude oil, coal, and uranium)*
- *PP-CF is the equivalent energy content between energy resources*
- *M-CF represents the fraction of the technically recoverable reserve base of the nonrenewable energy resource which will be depleted over the next 25 years*

5.1.2 Net Freshwater Consumption

This impact category considers the net consumption of freshwater. In general, net freshwater consumption includes the water withdrawn from surface water or groundwater source and not directly returned.[25] Consumption of saltwater is not included. The result for Net Freshwater Consumption, in thousand cubic meters, is calculated according to the equation below, for a given year in the Timeframe of analysis.

NOTE. In some LCAs, “regionalized” approaches to treatment of water consumption have been proposed, which are intended to reflect differing levels of water scarcity in different parts of the world. However, the data available to evaluate measures such as water scarcity is inconsistent globally, and often variable seasonally and year-to-year, making most data sources unreliable. Additionally, there is no single accepted definition of “water scarcity” which is applicable globally. For these reasons, the approach here is limited to assessment of net freshwater consumption.

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[25] King, C. W., & Webber, M. E. (2008). Water intensity of transportation. Environmental Science & Technology, 42(21), 7866-7872.

Equation 2. Result for Net freshwater consumption.

$$\text{Net Freshwater Consumption (thous. m}^3\text{), in a given year} =$$

$$\sum_i \left(\text{Freshwater Consumed}_i - \text{Freshwater Returned}_i \right)$$

Where:

- *Freshwater consumed includes water withdrawals necessary to produce the annual unit of analysis in the year at the unit process i*
- *Freshwater returned includes water returned to the same receiving source at unit process i*
- *i is the total number of unit processes in the scope*

5.1.3 Minerals and Metals Resource Depletion

This impact category is not relevant to this industry sector.

5.1.4 Wood Resource Depletion

This impact category assesses the depletion of valuable wood resources resulting from timber harvesting (relevant only to virgin roundwood production). Impacts are assessed over an entire roundwood or fiber basket using Forest Analysis Units, defined according to the requirements of Section 6.5.3.1 of the PCR modules.

> NOTE: This impact category does not consider the effects on forest ecosystems, which are treated in the impact category group of Terrestrial and Freshwater Ecosystem Impacts (i.e., Forest, Freshwater, Wetland, and Species impacts). Nor does it consider losses of forest carbon (also treated in other impact categories), which is linked to loss of wood resources but nevertheless a distinct category of impact. This impact category considers the loss of valuable wood resources which can result from drawdown in resources.

In modeling foregone growth's effects on standing biomass and carbon, the requirements of Section 5.2.1.1 apply, and the same default assumptions are to be used.

In order to calculate wood resource depletion impacts from foregone growth in a given year, impacts from foregone growth must be assessed relative to the production of roundwood and then the annual unit of analysis. The equation below is used to calculate these impacts relative to the production of 1,000 cubic meters of roundwood production for a single FAU.

> ***NOTE.*** Wood resource depletion is an accumulated impact, and impacts in a given year are affected by foregone growth across all previous years in the timeframe of analysis.

This is integrated into final results relative to the annual unit of analysis by using a production-weighted average of wood resource depletion from foregone growth across all FAUs in the roundwood or fiber basket.

Equation 3. Equation to calculate the Wood Resource Depletion in a given year relative to the production of one thousand cubic meters of roundwood in a single FAU.

$$\text{Wood Resource Depletion in a given year n, in a single FAU} = \frac{(\text{Wood}_{\text{no harvest}} \text{ in year n} - \text{Wood}_{\text{harvest}} \text{ in year n}) \times \text{FAU}_{\text{area}}}{\text{Total FAU Timber Production over } n \text{ years (in thousand cubic meters)}}$$

Where:

- $\text{Wood}_{\text{no harvest}}$ and $\text{Wood}_{\text{harvest}}$ are the volume of valuable wood resources per hectare in the No Harvest and Harvest scenarios (evaluated as average across the FAU).
- FAU_{area} is the area, in hectares, of the FAU.
- Total FAU Timber Production over n years is all production of roundwood from the beginning of the timeframe of analysis to the year n.

This equation is assessed individually by each FAU included in the roundwood or virgin fiber basket. If multiple FAUs are included in the roundwood or virgin fiber basket, a production-weighted average of the result in each FAU is used to determine results relative to the declared unit.

5.2 Global and Regional Climate System Impacts

5.2.1 Global Climate Impacts

This impact category addresses endpoints linked to Global Climate Change. All results are calculated based on radiative forcing (RF) metrics in terms of thousand tons of carbon dioxide equivalent (thousand tons CO_2 e) for 20 years and 100 years.

There are two radiative effects to be considered, depending on the product system:

(1) *RF from Emissions*: The emissions such as carbon dioxide (CO_2), methane and other greenhouse gases, short-lived climate pollutants occurring from industrial machinery (e.g., emissions from transportation, energy generation, burning biomass in paper mills) and forest carbon fluxes (e.g., net forest regrowth, decomposition of belowground biomass), and

(2) *RF from foregone growth*: carbon storage losses resulting from foregone growth resulting from logging.

To calculate results for Global Climate Change, in units of tons carbon dioxide equivalent (CO_2e), relative to the annual unit of analysis in a given year, Equation 4 is used.

> ***NOTE.*** Global climate change from GHGs is an accumulated impact, and impacts in a given year are affected by emissions and foregone growth occurring in all previous years in the timeframe of analysis. This accumulation is integrated into the terms RF_{EM} and RF_{FG} in Equation 4 and the results for Global Climate Change are obtained in terms of carbon dioxide equivalent by dividing the integrated RF_{EM} and RF_{FG} with the RF of carbon dioxide emission in a given year.

Equation 4. Indicator results for Global Climate Change in year n of the timeframe of analysis, in units of thousand tons carbon dioxide equivalent (thousand tons CO_2 e).

$$\text{Global Climate Change (thousand ton } CO_2 \text{ equivalent), in a given year} =$$

$$[RF_{EM} \text{ (in a given year)} + RF_{FG} \text{ (in a given year)}]/RE_{CO2} * 1000$$

Where:

- *RF_{EM} is the radiative forcing from emissions, calculated based on the approach in Section 5.2.1.1.*
- *RF_{FG} is the radiative forcing from foregone growth, calculated based on the approach in Section 5.2.1.2.*
- *RE_{CO2} is the radiative efficiency of carbon dioxide with a value of 0.001772 mW m^{-2} Tg^{-1}as indicated in Table 4.*

5.2.1.1 Calculating RF from emissions (RF_{EM} in Equation 4)

From both industrial and forest-related emissions sources, all climate pollutants emitted over the timeframe of analysis, including all greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs), shall be included in calculations of RF_{EM} in Equation 4. Different species (GHGs, SLCPs) have different radiative efficiencies and remain resident in the atmosphere for varied time periods. Equation 5 provides the term RF_{EM} needed to calculate Equation 4, including from all emissions of climate pollutants occurring *n* years after the beginning of the timeframe of analysis.

Equation 5. RF_{EM} in Equation 4: Radiative forcing for emissions occurring 'n' years after the beginning of the timeframe of analysis, in units of milliwatts per square meter (mW/m^2). The three terms calculate RF from GHG emissions, SLCP, and NOX emissions, respectively. RF_{NOX} is calculated using Equation 8.

RF_{EM} in Equation 4 ($mW\ m^{-2}$) in a given year n =

$$= \sum_{i=GHGs}^{All\ GHGs} \sum_{t=1}^{n} Ei_t \times REi \times Ri_{(n-t+1)} + \sum_{i=SLCPs}^{All\ SLCPs} Ei_n \times REi + RF_{NOx}$$

Where:

- *n is the number of years between the year in which RF_{EM} is assessed and the beginning of the timeframe of analysis*
- *Ei_t is the pulse emission of species 'i' (in Tg or million tons of GHGs, SLCP emitted) required to produce the annual unit of analysis in year 't'*
- *RE_i is the radiative efficiency ($mWm^{-2}Tg^{-1}$) of species 'i'. See Section 5.2.1.1.1.*
- *Ri is the fraction of species remaining in the atmosphere after (n-t+1) years. See Section 5.2.1.1.1.*
- *Refer to the Table 3 , Table 4,*
- *Table 5 for the respective REi and Ri values for GHGs, SLCPs.*
- *RF_{NOx} is calculated according to Equation 8.*

5.2.1.1.1 Calculating Radiative Forcing from Greenhouse Gases in Equation 5

For GHGs except CO_2 listed in Table 3, Ri (n-t+1) (i.e., the atmospheric concentration function) presented in Equation 5 is calculated using the exponential decay function in Equation 6.

Equation 6. General equation for a pulse emission of a GHG (except for CO_2). Where (n-t+1) = the number of years after the pulse emission, τ = atmospheric lifetime of the climate pollutant. Refer to Table 3. for atmospheric lifetimes of different GHGs.

$$Ri_{(n-t+1)} = e^{-(n-t+1)/\tau}$$

However, for CO_2, the fraction of species remaining at a given year cannot be represented by a simple exponential decay. The Ri for CO_2 following a pulse emission after time (n-t+1) years, is approximated by a sum of exponentials shown in Equation 7.

Equation 7. The atmospheric concentration function for CO_2 from the IPCC Fifth Assessment Report.

$$\boldsymbol{R_{CO2}}^{26} = \mathbf{0.2173} + \left(\mathbf{0.2240} \times \boldsymbol{e}^{-\frac{(n-t+1)}{394.4}}\right) + \left(\mathbf{0.2824} \times \boldsymbol{e}^{-\frac{(n-t+1)}{36.54}}\right) + (\mathbf{0.2763} \times \boldsymbol{e}^{-\frac{(n-t+1)}{4.304}})$$

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[26] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing Supplementary Material. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Available from www.climatechange2013.org and www.ipcc.ch.

Equation 6 and Equation 7 can be used together with the default data in Table 3 in order to calculate RF from GHGs in Equation 5. These data are based on the IPCC Fifth Assessment Report and shall not be used if more recent data are available.

Table 3. Default Radiative Efficiencies (REi) and Atmospheric lifetimes for GHG pollutants.

Pollutant	Radiative Efficiency (REi)	Atmospheric Lifetime[27]
Carbon Dioxide (CO_2)	0.001772 $mW\ m^{-2}\ Tg^{-1}$	Refer to Equation 7
Methane (CH_4)	0.267 $mW\ m^{-2}\ Tg^{-1}$	12.4 years
Nitrous Oxide (N_2O)	0.357 $mW\ m^{-2}\ Tg^{-1}$	121 years
Sulfur Hexafluoride (SF_6)	21.939 $mW\ m^{-2}\ Tg^{-1}$	3200 years
HFC-134a	8.886 $mW\ m^{-2}\ Tg^{-1}$	13.4 years
Nitrogen Trifluoride (NF_3)	16.219 $mW\ m^{-2}\ Tg^{-1}$	500 years

5.2.1.1.2 Calculating Radiative Forcing from Short-Lived Climate Pollutants in Equation 5

Short-lived climate pollutants (SCLPs) include black carbon, organic carbon, sulfur dioxide, and ozone precursors (NOx), and have a relatively short atmospheric lifetime (few days to a few weeks). Since SLCPs have an atmospheric residence time of weeks or less, they are not evenly distributed in the global atmosphere and can vary regionally, depending on the location and source of emission.

> NOTE: SLCPs are emitted at many stages during wood and paper production. For example, NOx is emitted in almost all cases where combustion occurs, so is linked to transportation, black liquor and fossil fuel consumption at paper mills, and to other processes. Sulfur dioxide is primarily emitted by coal fired plants and so will be linked to coal use in pulp/paper mills but also in electricity generation which may power mills and other processes. Black carbon will mainly be linked to diesel transportation.

For short-lived climate forcers, the fraction of the species remaining in the atmosphere one year after emission is assumed to be zero. Table 4 provides the REi values for different SLCPs to be inserted in the SLCP summation term presented in Equation 5. RE for nitrogen oxides is based on a more detailed calculation, which is discussed in Equation 8 in the next section.

Table 4. Default Radiative Efficiencies (REi) for SCLPs. If more specific data are available, they should be used.

Pollutant	Radiative Efficiency (REi)
Black Carbon[28] [29]	107 $mW\ m^{-2}\ Tg^{-1}$
Organic Carbon[30]	-1.6 $mW\ m^{-2}\ Tg^{-1}$
Sulfur Dioxide (SO_2)	-7.3 $mW\ m^{-2}\ Tg^{-1}$

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[27] Ibid.

[28] Bond, T., et al. Quantifying immediate RF by black carbon and organic matter with the Specific Forcing Pulse. Atmos. Chem. Phys., 11, 1505-1525, 2011. Value is based on the highest SPF value for black carbon.

[29] Bond, T. C., et al. (2013), Bounding the role of black carbon in the climate system: A scientific assessment, J. Geophys. Res. Atmos., 118, 5380–5552, doi:10.1002/jgrd.50171.

[30] Ibid. Value is based on the highest SPF value for organic carbon (i.e., lowest in magnitude).

5.2.1.1.3 Calculating Radiative Forcing from Nitrogen oxides in Equation 5

NOx is highly reactive and can participate in several chemical reactions in the atmosphere. NOx is an ozone precursor and can form ozone in the presence of sunlight and sufficient concentrations of VOCs, leading to short-term impacts on RF. Ozone, in turn, reacts with methane to form CO_2. The breaking down of methane has longer-term effects on RF. Increased ozone can also disrupt plant photosynthesis, resulting in reduced uptake of CO_2, which generates longer-term RF effects. NOx can react with sulfate aerosols to break them down, giving short-term impacts on RF. NOx can also generate ammonium nitrate aerosols in regions of high ammonia abundance, adding additional short-term RF effects.

Accordingly, the multiple effects of NOx on RF include formation of ozone, perturbation of sulfate formation, generation of ammonium nitrate aerosols, change in methane lifetime[31], and disruption of plant respiration (from increased surface ozone)[32,33]. These effects are summed to calculate the net radiative forcing resulting from pulse emissions of NOx in Equation 5 using Equation 8.

Equation 8. RF for NOx emissions 'n' years after the beginning of the timeframe of analysis. RE_{O3}, RE_{SO4}, RE_{Ni}, RE_{CH4}, RE_{CO2}, are respectively the Radiative Efficiencies of ozone, sulfate, nitrate, methane, and carbon dioxide, and k is equal to the tons of methane oxidized per ton of NOx emitted. Default values are given in Table 5 below. $\Delta CO2_{n\text{-}t+1}$ can be calculated using default values in Table 6.

$$RF_{NOX}(n) = E_{NOXt} \times [RE_{O3} + RE_{SO4^{-2}} + RE_{Ni}] + \sum_{t=1}^{n} E_{NOXt} \times [\left(RE_{CH4} \times e^{\frac{n-t+1}{12.4}} \times k\right)$$

$$+ (RE_{CO2} \times \Delta CO2_{n-t+1})]$$

Table 5. Radiative efficiency and k value for different effects of NOx which shall be used as a default. These values result in a conservatively high RF estimate for NOx.

Radiative Efficiency (mW m-2 Tg -1)					***k***
SO_4^{2-}	**O_3[34]**	**Ni[35]**	**CH_4[36]**	**CO_2**	
-0.4827	4.2823	-2.0	See Table 3.	See Table 3.	-1.71

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[31] Collins, W. J., M. M. Fry, H. Yu, J. S. Fuglestvedt, D. T. Shindell, and J. J. West. "Global and Regional Temperature-change Potentials for Near-term Climate Forcers." Atmospheric Chemistry and Physics Atmos. Chem. Phys. 13.5 (2013): 2471-485.

[32] Collins, W. J., S. Sitch, and O. Boucher (2010), How vegetation impacts affect climate metrics for ozone precursors,J. Geophys. Res., 115, D23308, doi:10.1029/2010JD014187.

[33] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Chapter 8, Anthropogenic and Natural Radiative Forcing. Section 8.3.3.1: Tropospheric Ozone. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[34] Fry, Meridith M., Vaishali Naik, J. Jason West, M. Daniel Schwarzkopf, Arlene M. Fiore, William J. Collins, Frank J. Dentener, Drew T. Shindell, Cyndi Atherton, Daniel Bergmann, Bryan N. Duncan, Peter Hess, Ian A. Mackenzie, Elina Marmer, Martin G. Schultz, Sophie Szopa, Oliver Wild, and Guang Zeng. "The Influence of Ozone Precursor Emissions from Four World Regions on Tropospheric Composition and Radiative Climate Forcing." *Journal of Geophysical Research: Atmospheres J. Geophys. Res.* 117.D7 (2012).

[35] Collins, W. J., M. M. Fry, H. Yu, J. S. Fuglestvedt, D. T. Shindell, and J. J. West. "Global and Regional Temperature-change Potentials for Near-term Climate Forcers." Atmospheric Chemistry and Physics Atmos. Chem. Phys. 13.5 (2013): 2471-485.

[36] Fry, Meridith M., Vaishali Naik, J. Jason West, M. Daniel Schwarzkopf, Arlene M. Fiore, William J. Collins, Frank J. Dentener, Drew T. Shindell, Cyndi Atherton, Daniel Bergmann, Bryan N. Duncan, Peter Hess, Ian A. Mackenzie, Elina Marmer, Martin G. Schultz, Sophie Szopa, Oliver Wild, and Guang Zeng. "The Influence of Ozone Precursor Emissions from Four World Regions on Tropospheric Composition and Radiative Climate Forcing." *Journal of Geophysical Research: Atmospheres J. Geophys. Res.* 117.D7 (2012).

ΔCO2 term in Equation 8 is derived using data from literature[37]. Emissions of NOx can increase ground level ozone concentrations, which in turn can disrupt plant uptake of CO_2.

> NOTE. The effect of ozone on the suppression of CO_2 uptake in land plants could account for 0.2 to 0.4 W/m^2, or 10-20% of the total RF resulting from excess atmospheric CO_2. This is a major RF driver and very important to account for in the ozone precursors.[38]

This term is included for unit processes if emissions could transport to regions where the ambient ozone concentration exceeds 40ppb for at least once per year.[39] As a default, it can be assumed that all unit processes are in locations where this threshold is exceeded. In these regions, the change in land carbon is converted to the change in CO_2 using a molar mass ratio of 44/12. Default values for ΔCO2 for 50 years are given in Table 6 below, from Collins et al., which calculated the change in land carbon resulting from a pulse emission of NOx over a 50 year period. More specific data can be used if available.

Table 6. ΔCO2 values for calculating longer-term RF effects from reduced uptake of CO_2.

Years After Pulse Emission *i*	**ΔCO_2** (kg CO_2 / kg NOx)	**Years After Pulse Emission *i***	**ΔCO_2** (kg CO_2 / kg NOx)	**Years After Pulse Emission *i***	**ΔCO_2** (kg CO_2 / kg NOx)
1	843.525	21	146.7	41	61.430625
2	770.175	22	137.53125	42	58.68
3	696.825	23	128.3625	43	55.929375
4	623.475	24	119.19375	44	53.17875
5	550.125	25	110.025	45	50.428125
6	506.115	26	106.3575	46	47.6775
7	462.105	27	102.69	47	44.926875
8	418.095	28	99.0225	48	42.17625
9	374.085	29	95.355	49	39.425625
10	330.075	30	91.6875	50	36.675
11	308.07	31	88.936875		
12	286.065	32	86.18625		
13	264.06	33	83.435625		
14	242.055	34	80.685		
15	220.05	35	77.934375		
16	207.825	36	75.18375		
17	195.6	37	72.433125		
18	183.375	38	69.6825		
19	171.15	39	66.931875		
20	158.925	40	64.18125		

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[37] Collins, W. J., S. Sitch, and O. Boucher (2010), How vegetation impacts affect climate metrics for ozone precursors,J. Geophys. Res., 115, D23308, doi:10.1029/2010JD014187.

[38] Sitch, et al. *Indirect radiative forcing of climate change through ozone effects on the land-carbon sink.* Nature, 448, 791-794.

[39] Levels of ozone exceeding this concentration may cause leaf injury and plant damage, and suppress the absorption of CO_2 by plants. Ashmore, M.R. *Assessing the future global impacts of ozone on vegetation.* Plant Cell Environ., 28, 949-965 (2005).

5.2.1.2 Modeling Foregone Growth Impacts (RF_{FG} in Equation 4)

In modeling foregone growth's effects on biomass and carbon, the following requirements apply[40]:

- The data used and vegetative growth models shall at a minimum include the following carbon pools in the total carbon estimates: carbon in live trees over 1" in diameter, including both aboveground and belowground carbon; carbon in standing dead trees (at least 5" in diameter); carbon in litter; carbon in downed dead trees; and aboveground carbon in understory. Soil carbon should be included if possible.

- The foregone growth model should be peer reviewed in a process that 1) primarily involves reviewers with necessary technical expertise (e.g., modeling specialists and relevant fields of biology, forestry, ecology, etc.,), and 2) is open and rigorous.

- The foregone growth model should be parameterized for the specific conditions of the FAU and URA.

- The model is applied to a scope of analysis applicable to a situation for which the model was developed and evaluated.

- The foregone growth model should be clearly documented with respect to the scope of the model, the assumptions, known limitations, embedded hypotheses, assessment of uncertainties, and sources for equations, data sets, factors, or parameters.

- A sensitivity analysis should be conducted to assess model behavior for the range of parameters for which the foregone growth model is applied.

- The basis of this modeled harvest scenario shall be provided, describing:

    - A description of the silvicultural methods which will be used, i.e.: description of trees retained (by species group if appropriate) at harvest; the harvest frequency (years between harvests) for each silviculture method; and assumptions about regeneration.

    - A list of all legal constraints and constraints of other types (e.g., water quality best management practices of a voluntary nature or forest management certifications) that affect forest management activities in the FAU. This list must identify and describe the legal constraint, how the legal constraint affects the project area, and the silviculture methods that will be projected to ensure the constraint is respected.

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[40] These requirements are adapted from the Climate Action Reserve Quantification Guidance for Use with Forest Carbon Projects, January 21, 2014].

  - A description of the model used and explanation of how the model was calibrated for local use.

- The model shall output the periodic harvest, inventory, and growth estimates for the FAU as total tons of carbon and carbon tons per acre in each scenario.

The following growth models shall be assumed to meet these requirements and can be used to assess foregone growth's impacts on biomass/carbon, provided they are applied in the correct region and have appropriate data inputs: CACTOS (California Conifer Timber Output Simulator); CRYPTOS (Cooperative Redwood Yield and Timber Output Simulator); FVS (Forest Vegetation Simulator); SPS (Stand Projection System); FPS (Forest Projection System); FREIGHTS (Forest Resource Inventory, Growth, and Harvest Tracking System); CRYPTOS Emulator; and FORESEE.

Additionally, projections may be made using a stand table projection. In this modeling approach, the measured carbon storage per acre in different stand age classes present today is used to estimate the change in forest carbon storage over time.

In many cases, use of vegetative growth models will not be possible. In these cases, default assumptions for the growth trajectory of each scenario as follows shall be used:

- Harvest scenario. Levels of stored forest biomass per hectare shall be assumed to begin with the current levels in the FAU, changing in the future at a linear rate based on the average change in the change in the FAU over the past 10 years. If complete data are not available on the trend over the past 10 years, estimates may be made regarding the trend.

- No-harvest scenario. It shall be assumed that the level of forest biomass recovers to a level equivalent to the URA within 50 years at most, according to a fixed recovery rate of 2% of the total URA storage per acre per year (i.e., a linear recovery rate over the 50 year time period).

- The average site productivity is assumed to be the same in the future as for the past 10 years.

In order to calculate RF_{FG} in a given year for use in Equation 4, RF from foregone growth must be assessed relative to the production of roundwood in each FAU using Equation 9. Equation 9 calculates RF from foregone growth relevant to the production of 1,000 cubic meters of roundwood production for a single FAU, in units of tons mW m^{-2} per 1,000 m^3. Equation 9 and Equation 10 are then used together to calculate RF_{FG} in Equation 4.

Equation 9. Equation to calculate the radiative forcing from foregone growth in a given year relative to the production of one thousand cubic meters of roundwood in a single FAU.

Radiative Forcing from Foregone Growth in a given year n, in a single FAU =

$$\frac{(\text{Carbon}_{\text{no harvest}} \text{ in year n} - \text{Carbon}_{\text{harvest}} \text{ in year n}) \times \text{FAU}_{\text{area}} \times \text{RE}_{\text{CO2}} \times 44/12}{\text{Total FAU Timber Production over } n \text{ years (in thousand cubic meters)}}$$

Where:

- $\text{Carbon}_{\text{no harvest}}$ and $\text{Carbon}_{\text{harvest}}$ are the carbon storage per hectare in the No Harvest and Harvest scenarios.
- FAU_{area} is the area, in hectares, of the FAU.
- RE_{CO2} is the radiative efficiency of CO_2 (see Table 3).
- 44/12 is the ratio of the molar masses of CO_2 to carbon.
- Total FAU Timber Production over n years is all production of roundwood from the beginning of the timeframe of analysis to the year n.

RF from foregone growth in Equation 4 is calculated by assessing this relative to the annual unit of analysis by using a production-weighted average of RF impacts from foregone growth across all FAUs in the roundwood or fiber basket, using Equation 10.

Equation 10. Equation used to calculate RF_{FG} in Equation 4.

RF_{FG} in Equation 4 =

$$\textstyle\sum_i(\text{ RF in FAU}_i \text{ in year n} \times \text{Fraction of Roundwood Consumed from FAU}_i \text{ in year n}))$$

$$\times\ 1000 \text{ cubic meters} \div \text{Annual unit of Analysis (year n)}$$

Where:

- n is the years since the beginning of the timeframe of analysis.
- i is the total number of FAUs in the scope.
- RF in FAU_i in year n is calculated using Equation 9.
- Fraction of Roundwood Consumed from FAU_i in year n is the roundwood consumed in production of the unit of analysis from FAU_i, divided by the total amount of roundwood required to produce the unit of analysis.

5.2.2 Climate ‘Hot Spot’ Impacts

These impact categories address the impacts from emissions of aerosols and aerosol precursors on “climate hot spots”. In these hot spots, local emissions have altered the climate in excess of what has been caused by the background warming induced by long-lived GHGs. The following “climate hot spots” identified by UNEP shall be included[41].

- Arctic
- East Asia.
- South Asia.
- Southeast Asia.
- Indonesia/Malaysia.
- South America.
- Central Africa.

These impacts are relevant only if product operations are located in these regions, and if those operations result in the emissions of black carbon, organic carbon, nitrogen oxides, sulfur dioxide, or other pollutants contributing directly (or indirectly through secondary aerosol formation) in these local climate hot spots.

> NOTE. Aerosols such as black carbon, absorb solar and infra-red radiation, resulting in a net addition of heat to the atmosphere. On the other hand, aerosols such as organic carbon and aerosol precursors such sulfates and nitrates, scatter solar energy back into space, which results in cooling of the atmosphere. Both these absorbing and scattering aerosols block solar radiation so that it does not hit the Earth’s surface, causing surface dimming[42], and can even in some regions result in surface cooling. In addition to other local impacts on the climate, this leads to reduction in evaporation of water vapor from the surface, impacting the hydrological cycle and (in some regions) reducing precipitation. For example, studies have shown that over the last few decades, precipitation in the monsoon regions in Asia has been largely altered due to increased aerosol loading within climate “hot spots”[43, 44,45]. The climate impacts within “hot spots” are distinct in nature and would still occur, even in the absence of increased GHG concentrations and radiative forcing and therefore are accounted for in separate indicators.

The result for a single climate hot spot, in tons of aerosol loading, is calculated using Equation 11, for a given year in the timeframe of analysis. Equation 11 is calculated using PP-CFs (see Table 7) which

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[41] Ramanathan, V., et al., (2008), Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia. Published by the United Nations Environment Programme, Nairobi, Kenya.

[42] Ramanathan, V., et al., (2008), Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia. Published by the United Nations Environment Programme, Nairobi, Kenya.

[43] Das, S., Dey, S., & Dash, S. K. (2016). Direct radiative effects of anthropogenic aerosols on Indian summer monsoon circulation. *Theoretical and Applied Climatology*, *124*(3-4), 629-639.

[44] Bollasina, M. A., Ming, Y., & Ramaswamy, V. (2011). Anthropogenic aerosols and the weakening of the South Asian summer monsoon. *science*,*334*(6055), 502-505.

[45] Burney, J., & Ramanathan, V. (2014). Recent climate and air pollution impacts on Indian agriculture. *Proceedings of the National Academy of Sciences*, *111*(46), 16319-16324

characterize ‘Hot Spot Aerosol Loading’. The PP-CF characterizes the potential release of aerosol and aerosol precursors.

Table 7. Default PP-CFs for calculating results for Climate Hot Spot Impacts

Pollutant	**PP-CF**
Black Carbon	1
Organic Carbon	1
Sulfur Dioxide (SO_2) *	0.36
Nitrogen Oxides (NOx)*	0.1

**PP-CFs for SO_2 and NOx are same as PP-CFs used for PM2.5 Inhalation Impacts in Table16.*

Equation 11. Result for climate hot spots.

Climate Hot Spot Impacts (tons aerosol loading) in a given year =

$$\sum_i \sum_j \text{Short-Lived Climate Pollutant Emissions}_{i,j} \times \text{PP-CF}_j$$

Where:

- *Short-Lived Climate Pollutant Emissions are tons resulting for the annual unit of analysis in the year, including: black carbon, nitrogen oxides, sulfur dioxide, and organic carbon, contributing to the local climate hot spot.*
- *i is the total number of unit processes in the scope*
- *j represents the total number of aerosols and aerosol precursors emitted*
- *PP-CF values from Table 8.*

5.3 Ocean Ecosystem Impacts

5.3.1 Ocean Acidification

This impact category represents the degree to which CO_2 emissions lead to decreases in the pH of the ocean through the formation of carbonic acid, negatively impacting coral reefs and other marine life by lowering both the aragonite and calcite saturation levels. Ocean acidification represents an increasing risk of disruption of the global ocean ecosystem. Acting along with other ocean stressors, including ocean warming, increases in eutrophication on a large scale, trash, chemical releases such as mercury, overfishing, and other stressors, ocean acidification is contributing to increasing risk to the ocean biosphere.

The only considered emissions are carbon dioxide (CO_2) and methane (CH_4). The conversion of these substances into carbonic acid (H_2CO_3) in the world’s oceans is considered. There are two sources of oceanic H_2CO_3 to be considered, depending on the product system: (1) The emissions of CO_2 and CH_4 occurring from industrial machinery operations and from forest carbon fluxes (e.g., net forest regrowth, decomposition of belowground biomass), and (2) carbon storage losses resulting from foregone growth resulting from logging.

For roundwood products, all emissions caused by forest carbon fluxes in the FAU described in Section 5.2.1 shall be included using the same assumptions. From both industrial and forest-related emissions sources, all emissions of CO_2 and CH_4 are considered. For these emissions, the PP-CF represents the potential amount of H_2CO_3 formed from an emission, and the M-CF represents the amount absorbed into the oceans (for current emissions, approximately 25% of emitted CO_2 is absorbed into the oceans each year.[46, 47]). The PP-CF and M-CF to be used are in Table 8.

Table 8. PP-CF and M-CFs for Ocean Acidification, for emissions of CO_2 and CH_4.

	PP-CF (ton H_2CO_3 per ton emitted)	**M-CF (fraction absorbed)**	**PP-CF x M-CF (ton H_2CO_3 absorbed per ton emitted)**
CO_2	1.41	0.25	0.3524
CH_4	3.87	0.25	0.9675

In addition to emissions, forestry activities involved in production of roundwood prevent storage of forest carbon through forest recovery, and can reduce standing levels of forest carbon. This impact from foregone growth is calculated using an approach which is consistent with requirements of Section 5.3.1.1 and Section 6.5.3.2 of the Roundwood PCR Module.

To calculate results for Ocean Acidification, in units of tons of H_2CO_3 absorbed, relative to the annual unit of analysis in a given year, Equation 12 is used.

Equation 12. Indicator results for Ocean Acidification in year n of the timeframe of analysis.

$$\text{Ocean Acidification (tons } H_2CO_3\text{), in a given year} =$$

$$\sum_i \sum_j \text{CO2 Emissions}_{i,j} \times \text{PP-CF}_{CO2} \times \text{M-CF} + \sum_i \sum_j CH_4 \text{ Emissions}_{i,j} \times \text{PP-CF}_{CH4} \times \text{M-CF} + OA_{FG} \text{ (in a given year)}$$

Where:

- *CO_2 and CH_4 emissions are respectively the tons of carbon dioxide and methane emissions linked to production of the unit of analysis in the year*
- *i is the total number of years since the beginning of the timeframe of analysis (for this accumulated midpoint)*
- *j is the total number of unit processes in the scope*
- *PP-CF and M-CF values are from Table 11.*
- *OA_{FG} is the ocean acidification resulting from foregone growth (see Section 5.3.1.1).*

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[46] Global Carbon Project. *Global Carbon Budget. http://www.globalcarbonproject.org/carbonbudget/12/data.htm*

[47] National Oceanic and Atmospheric Administration: PMEL Carbon Program. *Ocean Acidification: The Other Carbon Dioxide Problem. http://www.pmel.noaa.gov/co2/story/Ocean+Acidification*

5.3.1.1 Modeling Foregone Growth Impacts on Ocean Acidification (OA_{FG} in Equation 12)

In modeling foregone growth's effects on standing biomass and carbon, the requirements of Section 5.2.1.1 apply, and the same default assumptions are to be used.

In order to calculate ocean acidification impacts from foregone growth in a given year (OA_{FG} in Equation 12), impacts from foregone growth must be assessed relative to the production of roundwood in each FAU using Equation 13. Equation 13 calculates ocean acidification impacts relative to the production of 1,000 cubic meters of roundwood production for a single FAU, in units of tons H_2CO_3 per 1,000 m^3. Equation 13 and Equation 14 are used together to calculate OA_{FG} in Equation 12.

> ***NOTE.*** Ocean acidification is an accumulated impact, and impacts in a given year are affected by emissions and foregone growth occurring in all previous years in the timeframe of analysis.

Equation 13. Equation to calculate the ocean acidification impacts from foregone growth in a given year relative to the production of one thousand cubic meters of roundwood in a single FAU. This equation is used to calculate $OA_{\text{foregone growth}}$ in Equation 12.

Ocean Acidification Impacts from Foregone Growth in a given year n, in a single FAU =

$$\frac{(\text{Carbon}_{\text{no harvest}} \text{ in year n} - \text{Carbon}_{\text{harvest}} \text{ in year n}) \times \text{FAU}_{\text{area}} \times 44/12 \times \text{PP-CF} \times \text{M-CF}}{\text{Total FAU Timber Production over } n \text{ years (in thousand cubic meters)}}$$

Where:

- $\text{Carbon}_{\text{no harvest}}$ and $\text{Carbon}_{\text{harvest}}$ are the carbon storage per hectare in the No Harvest and Harvest scenarios.
- FAU_{area} is the area, in hectares, of the FAU.
- PP-CF and M-CF values are from Table 11.
- 44/12 is the ratio of the molar masses of CO_2 to carbon.
- Total FAU Timber Production over n years is all production of roundwood from the beginning of the timeframe of analysis to the year n.

OA_{FG} in Equation 12 is calculated by assessing this relative to the annual unit of analysis by using a production-weighted average of ocean acidification impacts from foregone growth across all FAUs in the roundwood or fiber basket, using Equation 14.

Equation 14. Equation used to calculate OA_{FG} in Equation 12.

$$OA_{FG} \text{ in year n for Equation 12} =$$

$$\sum_i (\text{ OA impact in } FAU_i \text{ in year n x Fraction of Roundwood Consumed from } FAU_i \text{ in year n}))$$

$$\text{x 1000 cubic meters} \div \text{Annual unit of Analysis (year n)}$$

Where:

- *n* is the years since the beginning of the timeframe of analysis.
- *i* is the total number of FAUs in the scope.
- OA impact in FAU_i in year n is calculated using Equation 13.
- Fraction of Roundwood Consumed from FAU_i in year n is the roundwood consumed in production of the unit of analysis from FAU_i, divided by the total amount of roundwood required to produce the unit of analysis.

5.3.2 Ocean Warming

This impact category addresses the warming of the world's oceans. Of the total excess heat trapped by climate pollutants since 1750, over 90% has been absorbed by the oceans. This has led to major impacts such as changes in populations of species in different regions, decreases in vertical mixing, and other effects.

Ocean warming is linked to global climate change effects, but the scale and timeframe of impacts justifies its treatment as a separate impact category. However, at this time, there is no metric available to assess the effect of climate pollutants on ocean warming. There is no PP-CF or M-CF. This impact category shall be included as relevant and listed in final results, with results listed as "No data". As methods become available to characterize this impact category, this PCR will be revised to include results.

5.3.3 Marine Disturbance

This impact category is not relevant to this industry sector.

5.3.4 Marine Eutrophication

This impact category addresses marine eutrophication impacts, including eutrophication in estuaries, bays, or other marine ecosystems. Marine eutrophication usually occurs when nutrients (biologically available nitrogen and phosphorus) are added beyond a receiving water body's ability to process them.

This impact will also be relevant for mills discharging effluent to marine water bodies which are impaired, and will likely only be relevant if effluent is unregulated or regulations are not enforced. For example, pulp mills on the coast may discharge effluents which can cause localized impacts and impair water quality in the region. Unless pulp mills are located on the coast, this impact is not likely to be relevant. It shall be considered relevant if a mill is located on the coast and discharges eutrophying substances into receiving waters which are impaired. The definition of "impaired" which is used can be based on local governmental regulatory frameworks, or from a more conservative framework. If marine eutrophication is relevant, an approach similar to Freshwater Eutrophication addressed in Section 5.4.4 shall be used to calculate results.

> NOTE. The most common driver of this type of impact category is fertilizer runoff from agricultural systems. The contribution of eutrophying emissions from across the entire supply chain is minor, and the most likely contribution are pulp mills as described above. For this reason, it is not treated as a core impact which must be reported in all LCAs and EPDs. However, results for all supply chain eutrophying emissions, occurring regardless of source or receiving environment, can be reported optionally (see Section 7.4 of Roundwood PCR Module).

5.3.5 Marine Key Species Loss

This impact category is not relevant to this industry sector.

5.3.6 Persistent, Bioaccumulative, and Toxic Chemical Loading

This impact category considers the impacts of persistent, bioaccumulative, and toxic (PBT) chemicals which, if emitted into the environment, can transport to the oceans and lead to persistent contamination of receiving environments on many scales. These PBTs, if contamination exceeds safe thresholds, can lead to risks of impacts to flora and fauna. PBTs are emitted into air, soil or water, and can affect many types of ecosystems, including freshwater, marine, and terrestrial. This impact category considers impacts on marine systems.

Generally, the impact associated with production of roundwood and pulp/paper is mercury emissions. Although the impact category is different in scale, reflecting accumulation of methylmercury in the world's oceans, the same category indicator is used as in the assessment of Freshwater Ecotoxicity Impacts. Contamination of receiving environments by methylmercury and other compounds of mercury occurs around the world. When emitted to air as a gas (the most common form of emission), elemental mercury stays in the atmosphere for long periods of time and may be transported around the world.[48] Only one result is reported for mercury's emissions effects on these two impact categories.

> NOTE. Mercury is emitted by many unit processes involved in production of roundwood and pulp/paper, and usually results from combustion of fuels containing trace amounts of mercury, which subsequently transports in the atmosphere.

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[48] United Nations Environment Programme. *Global Mercury Assessment 2013: Sources, Emissions, Releases, and Environmental Transport.* http://www.unep.org/PDF/PressReleases/GlobalMercuryAssessment2013.pdf

The result for Mercury Emissions, in kilograms of elemental mercury, is calculated according to Equation 15, for a given year in the timeframe of analysis. As this is an accumulated midpoint, the indicator result is calculated as an accumulation over the total number of years in the timeframe of analysis. The PP-CF is the kilograms of elemental mercury emissions per kilogram emitted.

Equation 15. Result for Mercury Emissions.

$$\text{Mercury Emissions (kg Hg), in year i} =$$

$$\sum_i \sum_j \sum_k \text{Mercury Compound Emitted}_{i,j,k} \text{ x PP-CF}_k)$$

Where:

- *Mercury Compound Emission is the emission of mercury compounds required to produce the unit of analysis in year i*
- *i is the total number of years since the beginning of the timeframe of analysis (for this accumulated midpoint)*
- *j is the total number of unit processes in the scope*
- *k represents the total number of types of mercury compounds emitted*
- *PP-CF is the equivalent mass of elemental mercury emitted, considering molar mass of emitted mercury compounds*

NOTE. There is no M-CF used to characterize this indicator result. Currently, models suitable for use in LCA are not available to characterize the site specific fate and transport of mercury as it transits between different receiving environments. Results shall be expressed using Equation 15; however, optionally, alternative LCIA methodologies can be used to express results (see Section 7.4 of Roundwood PCR). Once they become available, methods enabling site specific evaluation of mercury impacts in LCA will be included in future PCR versions.

5.3.7 Cumulative Plastic Loading

This impact category is not relevant to this industry sector.

5.4 Terrestrial & Freshwater Ecosystem Impacts (from Emissions)

5.4.1 Regional Acidification

This impact category addresses impacts caused primarily from acid rain on terrestrial and freshwater ecosystems. Some regions are much more sensitive to acid deposition than others. The indicator characterizes the fraction of acidifying emissions which deposit into sensitive soils. Sensitive soils are defined based on the methodology detailed in literature[49], utilizing a global soils database (i.e., the Harmonized World Soil Database) to characterize the spatial variation of soil types (and sensitivities). A GIS approach for processing these data is typically required.

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[49] Kuylenstierna, J.C.I., Henning Rodhe, Steve Cinderby and Kevin Hicks. Acidification in Developing Countries: Ecosystem Sensitivity and the Critical Load Approach on a Global Scale. Ambio, Vol. 30, No. 1 (Feb., 2001), pp. 20-28.

The PP-CF expresses the potential release of hydrogen ions per kilogram of an emission, compared to SO_2, in units of SO_2 equivalent (SO_2e). PP-CF values are in Table 9.

Table 9. Potential for release of hydrogen ions per kilogram of substance, compared to potential for release of hydrogen ions per kilogram of sulfur dioxide. *Source: EDIP97.*[50]

Substance	Formula	kg SO_2e / kg substance
Ammonia	NH_3	1.88
Hydrochloric acid	HCl	0.88
Hydrofluoric acid	HF	1.60
Hydrogen sulfide	H_2S	1.88
Nitric acid	HNO_3	0.51
Nitric oxide	NO	1.07
Nitrogen dioxide	NO_2	0.70
Phosphoric acid	H_3PO_4	0.98
Sulfur dioxide	SO_2	1.00
Sulfuric acid	H_2S0_4	0.65

The M-CF is the fraction of an emission which deposits into sensitive regions, which are defined as regions in Sensitivity Classes 1-4 (plus fresh water) according to the Harmonized World Soil Database.[51] The soil sensitivity classes should be derived from the soil base saturation and cation exchange coefficient, following the approach Kuylenstierna, et al. Inland (fresh) water bodies should be included, where such data is available, and considered “sensitive” for the classification. Classes 1-4 (plus fresh water) are considered sensitive for the soil classification.

The M-CF differs by the locations of processes in the supply chain. To determine the fraction of emissions which deposit into sensitive soils, dispersion modeling shall be used, where a dispersion plume is modeled and deposition rates assessed for each region in a grid across all regions, relative to the total emission[52]. The deposition rate in each grid cell is then overlaid onto soil sensitivity maps (i.e., the Harmonized Soil Database). The M-CF is the total emission which the dispersion model indicates deposit in sensitive soils, divided by the total emission.

This dispersion modeling should use mathematical and numerical techniques to simulate the physical and chemical processes that affect substances that may disperse and react in the atmosphere, based on inputs of meteorological data and source information. The dispersion model which is selected for use

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[50] Environmental Design of Industrial Products (EDIP), in Danish UMIP. 1996.

[51] Kuylenstierna, J.C.I., Henning Rodhe, Steve Cinderby and Kevin Hicks. Acidification in Developing Countries: Ecosystem Sensitivity and the Critical Load Approach on a Global Scale. Ambio, Vol. 30, No. 1 (Feb., 2001), pp. 20-28. http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html.

[52] The total deposition of emissions (wet and dry deposition) is calculated by summing the hourly deposition rates, as estimated using dispersion modeling, to obtain a spatial distribution of the annual deposition of acidifying emissions for a unit process. Spatial analysis tools (i.e., GIS tools) are then used to identify regions of sensitive soils into which acidifying emissions deposit. Chemicals depositing into non-sensitive soils are not included in the calculations.

should be publicly available, and derived from peer-reviewed work.[53] Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) dispersion model is one model which can be used. [54]

NOTE: Ideally, LCI data on emissions used in the dispersion modeling would be hourly throughout the year. Generally this level of information is not available for LCA studies. As a default, annual average emission data can be used, assuming for continuous emissions sources that the level of emissions are roughly constant throughout the year. Given there is in fact variability, it should be assumed as a default that the use of annual average data introduces an additional uncertainty of +/-20% which shall be included in final results using principles of error propagation.

NOTE: A challenge in the calculation of the regionalized results based in air dispersion is the lack of site-specific emissions data. Generally, even if proprietary data on emissions levels in the supply chain are not available, the locations of emissions sources can be identified through publicly available data sources. Some of these data sources even include information sufficient to calculate specific emissions levels. In the US, for example, the US EPA provides location and emissions data in the TRI and NEI databases for many facilities. Similar inventories exist in Canada, and in many countries in Europe, including Sweden and Germany, through local regulatory bodies. If this data is not available or is insufficient, secondary data on emissions from LCI databases (e.g., Ecoinvent) can be used, with locations specified using public data or other data sources.

Assessment of M-CFs should not be completed for all operations in the supply chain, as this is impractical. Instead, M-CFs should be assessed using the following specific approach, in order to minimize the effort required:

- After the initial LCI model is completed, LCA results shall be assessed using PP-CFs with no M-CFs. No regionalization is required.

- The key unit processes (i.e., processes contributing over 15% to results) should be identified based on results using PP-CFs.

- M-CFs should then be evaluated using dispersion modeling for the key unit processes defined based upon PP-CFs.

- For non-key unit processes, all M-CFs should be assumed to be 1. LCA results should then be re-calculated. If any of the contribution of non-key unit processes at this stage make up a significant contribution to final results for this indicator, or could influence results significantly if

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[53] Dispersion models which can be used include those used in regulatory applications by air quality management agencies and by other organizations, such as those used in the United States to determine compliance with National Ambient Air Quality Standards. The US Environmental Protection Agency provides guidance and support for the use of numerous air quality models through the Technology Transfer Network at the Support Center for Regulatory Atmospheric Modeling. This guidance is periodically updated and revised to ensure the new model developments or expanded regulatory requirements are incorporated. Access to the descriptions of air dispersion models routinely used in air quality management studies can be found at the website of the US EPA's Support Center for Regulatory Atmospheric Modeling.

[54] National Oceanic and Atmospheric Administration: Air Resources Laboratory. HYSPLIT - Hybrid Single Particle Lagrangian Integrated Trajectory Model. http://ready.arl.noaa.gov/HYSPLIT.php

its M-CF were less than 1, then dispersion modeling should be completed for these non-key unit processes and LCA results should be re-calculated.[55]

- This process should continue until there are no remaining non-key unit processes for which an M-CF of less than 1 could affect results. Generally this will not require more than two or three iterations.
- With this approach, typically 5-10 M-CFs need to be evaluated for each supply chain in order to assess results of acceptable data quality.
- For the processes for which M-CFs are not established, conservative estimates can be used to establish results. Uncertainty and data quality analysis can further assist in the effort to minimize the number of M-CFs which are established.

NOTE. The set of key unit processes should be re-evaluated once final indicator results are calculated using M-CFs based on Equation 16.

If it is not possible to assess M-CFs, then results cannot be reported for this category indicator. The fraction of acid emissions depositing in sensitive soils varies from 5-95% around the world, and results expressed without considering these differences can be very misleading.

The result for Regional Acidification, in tons SO_2 equivalent, is calculated according to the equation below, for a given year in the timeframe of analysis.

Equation 16. Result for Regional Acidification.

$$\text{Regional Acidification (tons } SO_2 \text{ eq.) in a given year} =$$

$$\sum_i \sum_j \text{Acid Emission}_{i,j} \times \text{PP-CF}_j \times \text{M-CF}_i$$

Where:

- *Acid emissions is the tons of acidifying substance emissions linked to production of the unit of analysis in the considered year*
- *i is the total number of unit processes in the scope*
- *j represents the total number of types of acids emitted (e.g., substances from Table 9)*
- *PP-CF is the potential release of hydrogen ions per kilogram of an emission, compared to SO_2, from values in Table 12.*
- *M-CF is the fraction of an emission which deposits into sensitive regions for the unit process i*

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[55] Although these processes contribute relatively less to the total acidifying emissions, a relatively large fraction of these emissions may deposit into sensitive soils, making them important to include with more accurate dispersion data.

5.4.2 Stratospheric Ozone Depletion

This impact category is generally not relevant to this industry sector. If LCI results indicate that ozone depleting chemical emissions, calculated using Ozone Depletion Potentials from the CML LCIA Methodology, exceed 100 kilograms per year, per 1,000 tons of wood or pulp/paper product, then the sources of these emissions in the supply chain should be identified and validated. If found to be correct and accurate, this impact category can be reported as relevant.

> NOTE. Generally LCA model outputs indicate ozone depletion potential results at the level of micrograms or nanograms even for large scales of production. Ozone Depleting Chemicals have been banned worldwide except for a very small number of applications which are unrelated to wood or pulp/paper production. The Ozone Depletion results usually reported in LCAs are typically modeling artifacts caused by older datasets for which ozone depleting chemical emissions may have been linked, but for which are not currently contributing. Results defined as relevant in this impact category should be carefully examined to understand if the LCI data indicating an ODC emission is reliable.

5.4.3 Freshwater Ecotoxicity Impacts

This impact category considers releases of hazardous environmental contaminants which can lead to risks of exposure to flora and fauna at unsafe levels. These contaminants are emitted into air, soil or water, and can affect many types of ecosystems, including freshwater, marine, and terrestrial.

Generally, three distinct impacts within this impact category can be associated with production of roundwood and pulp/paper: mercury emissions; dioxin emissions; and emissions of other ecotoxic contaminants. Mercury is emitted by many unit processes involved in production of roundwood and pulp/paper, and usually results from combustion of fuels containing trace amounts of mercury, which subsequently transports in the atmosphere. Dioxins are emitted by some pulp mills as a side effect of bleaching with elemental chlorine. Both emitted chemicals have different levels of persistence, mobility, and toxicity, and are treated separately.

5.4.3.1 Mercury Loading

Mercury is an elemental substance which will persist in the environment for very long periods of time. The most toxic form of mercury is methylmercury, which forms through microbial processes after other forms of mercury are deposited into aquatic environments, soil, and sediments. Methylmercury is highly bioaccumulative.[56] Because of the risk that mercury can accumulate in the environment over time and space, even if not found to be present at unsafe levels in the receiving environment, emissions shall be considered relevant in all cases where they occur at pulp mills. Although the impact category is different in scale, the same category indicator is used as in the assessment of Persistent, Bioaccumulative, and Toxic Chemical Loading. Only one result is reported for mercury's emissions effects on these two impact categories. Mercury Emissions are calculated according to Equation 15 in Section 5.3.6.

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[56] In one study focused on American alligators (Alligator mississippiensis), BCFs for adult alligators of 39.9x10(7) and 32.9x10(7) were found in liver and kidneys, respectively. From B. Khan, and B. Tansel. *Mercury bioconcentration factors in American alligators (Alligator mississippiensis) in the Florida everglades.* Ecotoxicol Environ Saf. 2000 Sep;47(1):54-8.

5.4.3.2 Emissions of Dioxins and Dioxin-Like Compounds

Emissions of dioxins occur at pulp mills as a by-product of the elemental chlorine bleaching process. The ability of dioxins and dioxin-like compounds to persist and accumulate in receiving environment and bioaccumulate in organisms, coupled with their ability to cause adverse health impacts in organisms even at low doses, means that even small levels of emissions can eventually lead to negative ecosystem impacts. [57] Because of the long-term nature of these risks and high sensitivity of ecosystems, emissions shall be considered relevant in all cases where they occur at pulp mills.

If results are relevant for a given pulping mill, a separate indicator result shall be reported in the indicator results describing the affected water body. The name of the affected water body shall be included in the indicator result. The PP-CF is the grams of dioxins (including dioxins-like substances) emitted per kilogram of emission. All emissions of dioxins from mills are included, and no environmental characterization required; the indicator result only expresses the amount of dioxins emitted. There is no M-CF needed to establish results. The result for Dioxin and Dioxin-Like Compound emissions, in grams of dioxins, is calculated according to the equation below, for a given year in the timeframe of analysis. As this is an accumulated midpoint, the indicator result is calculated as an accumulation over the total number of years in the timeframe of analysis.

Equation 17. Result for Emissions of Dioxin and Dioxin-Like Compounds.

Dioxin and Dioxin-Like Compounds Emissions (kg), in a given year =

$$\sum_i \sum_j \sum_k \text{Dioxin and Dioxin-Like Compound Emitted}_{i,j,k} \text{ x } \text{PP-CF}_k)$$

Where:

- *Dioxin and Dioxin-Like Compound Emitted are the emissions required to produce the unit of analysis in year i*
- *i is the total number of years since the beginning of the timeframe of analysis (for this accumulated midpoint)*
- *j is the total number of unit processes in the scope*
- *k represents the total number of types of dioxin and dioxin-like compounds emitted*
- *PP-CF is the grams of dioxins (including dioxins-like substances) emitted per kilogram of emission*

NOTE. There is no M-CF used to characterize this indicator result. Currently, models suitable for use in LCA are not available to characterize the site specific fate and transport of dioxins. Results shall be expressed using the equation above; however, optionally, alternative LCIA methodologies can also be used to express results (see Section 7.4 of Roundwood PCR). Once they become available, methods enabling site specific evaluation of mercury impacts in LCA will be included in future PCR versions.

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[57] *Evaluation of the Health Implications of Levels of Polychlorinated Dibenzo-p-Dioxins (dioxins) and Polychlorinted Dibenzofuans (furans) in Fish from Maine Rivers*: 2008 Update. Environmental and Occupational Health Programs, Maine Center for Disease Control, Maine Department of Health and Human Services. January, 2008.

5.4.3.3 Emissions of Other Ecotoxic Contaminants

There are a number of other contaminants which are emitted as a result of different life cycle stages associated with pulp and paper production. These contaminants are emitted in sufficient volume, and are sufficiently persistent and toxic, to present a risk to flora and fauna in the receiving environment. They can be emitted at many different stages of roundwood, pulp, and paper production and use. As a default, the substances listed in Sediment Quality Guidelines (SQG) established by the US National Oceanic and Atmospheric Administration (NOAA) shall be included.[58,59]

The PP-CF for a given Ecotoxic contaminant is the relative toxicity of the contaminant compared to lead. This toxicity shall be established using Effects Range Low (ERL) values or a similar measure. The substances, ERL values, and PP-CF values, from Table 10, shall be used in calculation of this indicator as a default.

Table 10. Substances included in this indicator, along with ERL values and PP-CF values to be used. *Source: NOAA.*[60]

Substance	ERL (µg/kg)	PP-CF (g Pb eq. / g)	Substance	ERL (µg/kg)	PP-CF (g Pb eq. / g)
As	8200	5.7	**Benzo(a)pyrene**	430	108.6
Cd	1200	38.9	**Dibenzo(a,h)anthracene**	63.4	736.6
Cr	81000	0.6	**Chrysene**	384	121.6
Cu	34000	1.4	**Fluoanthene**	600	77.8
Pb	46700	1.0	**Pyrene**	665	70.2
Hg	150	311.3	**HMW PAHs**	1700	27.5
Ni	20900	2.2	**Total PAHs**	4022	11.6
Zn	150000	0.3	**p,p-DDD**	2	23,350
Acenaphthene	16	2,918,750	**p,p-DDE**	2.2	21,227
Acenaphthylene	44	1,061,364	**p,p-DDT**	1	46,700
Anthracene	85.3	547,479	**Total DDT**	1.58	29,557
Fluorene	19	2,457,895	**Chlordane**	0.5	93,400
Naphthalene	160	291,875	**Dieldrin**	0.02	2,335,000
Phenanthrene	240	194,583	**Endrin**	0.02	2,335,000
LMW PAHs	552	84,601	**Lindane**	0.32	145,938
B(a)Anthracene	261	178,927	**Total PCBs**	22.7	2,057

The result for Emissions of Other Ecotoxic Contaminants, in mass of lead equivalent, is calculated according to the equation below, for a given year in the timeframe of analysis. As this is an accumulated midpoint, the indicator result is calculated as an accumulation over the total number of years in the timeframe of analysis.

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[58] NOAA. Sediment Quality Guidelines Developed for the National Status and Trends Program. Released 6/12/99.

[59] MacDonald, D.D., C.G. Ingersoll, T.A. Berger. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. Arch. Environ.

[60] Retrieved from Table 1 and Table 4 of https://www.researchgate.net/publication/225126804_Sediment_quality_criteria_in_use_around_the_world

Equation 18. Result for Emissions of Other Ecotoxic Contaminants.

Emissions of Other Ecotoxic Contaminants, in a given year =

$$\sum_i \sum_j \sum_k \text{Ecotoxic Substances Emitted}_{i,j,k} \text{ x PP-CF}_k)$$

Where:

- *Ecotoxic Substances Emitted are the emissions required to produce the unit of analysis in year i*
- *i is the total number of years since the beginning of the timeframe of analysis (for this accumulated midpoint)*
- *j is the total number of unit processes in the scope*
- *k represents the total number of types of Ecotoxic substances emitted*
- *PP-CF is from Table 10*

5.4.4 Freshwater Eutrophication

This impact category addresses eutrophication of freshwater systems. Freshwater eutrophication usually occurs when nutrients (biologically available nitrogen and phosphorus) are added beyond a receiving water body's ability to process them, leading to increases in primary productivity of algae, which in turn leads to multiple and complex changes to aquatic ecosystems, including blooms of microscopic and macroscopic algae, and increased turbidity in the water column. These effects are often called the "primary symptoms" of eutrophication, and are herein referred as such.

Increased decay as a result of increased algae formation will eventually deplete levels of dissolved oxygen, leading to hypoxia and anoxia; this depletion in oxygen levels leads to major disruptions to local ecosystems as organisms that require oxygen cannot survive. These effects are sometimes called the "secondary symptoms" of eutrophication, and are herein referred as such.

In the production of roundwood, freshwater eutrophication can be linked to runoff soil erosion, which can lead to an increased amount of nutrients entering local watercourses. In the production of pulp and paper, eutrophication can be caused by mill discharges of substances which contain phosphorus or nitrogen compounds (e.g., nitrates, ammonia), or suspended solids (e.g. wood particles in effluent).

The impact of eutrophying emissions from these processes on freshwater eutrophication is highly site variable, depending on the conditions of receiving water bodies and character of emissions affecting them. Both PP-CF and M-CF values can vary based on these factors, and results should only be included if unit processes discharge eutrophying emissions to impaired waters. However, site-specific evaluation of PP-CF and M-CF values should not be completed for all operations in the supply chain, as this is impractical. Instead, the following approach shall be used to evaluate freshwater eutrophication:

- After the initial LCI model is completed, LCA results shall be assessed using PP-CFs from Table 11 with no M-CFs. No regionalization is required. LCA results shall be evaluated separately for potential to contribute to primary symptoms and secondary symptoms, by separate evaluation of nitrogen and phosphorus compounds and COD/BOD emissions.

- The potential key unit processes (i.e., processes contributing over 15% to these preliminary results) are identified for emissions potentially contributing to primary and secondary symptoms, based on results using these PP-CFs. This screening identifies which processes could affect freshwater eutrophication. Results for potential contribution to primary and secondary symptoms of eutrophication shall be determined separately.

Table 11. PP-CFs used in the initial stages of the LCA to determine the major potential contributors to freshwater eutrophication across the supply chain. These PP-CF values characterize the Redfield ratio in environments with underdetermined limiting nutrients. *Source: Table 6.1, Danish Guidelines*[61]

Substance	Formula	PP-CF, Undetermined Limiting Nutrient
Primary Symptoms		**kg NO_3- eq. / kg substance**
Ammonia	NH_3	3.64
Nitrate	NO_3-	1.00
Nitrite	NO_2-	1.35
Cyanide	CN	2.38
Total Nitrogen	N	4.43
Phosphate	PO_4^{3-}	10.45
Pyrophosphate	$P_2O_7^{2-}$	11.41
Total Phosphorus	P	32.03
Secondary Symptoms		**kg COD or BOD / kg substance**
Chemical Oxygen Demand*	COD*	1*
Biological Oxygen Demand*	BOD*	1*

**Evaluated in a separate category indicator from phosphorus and nitrogen compounds.*

- For each potential key unit process identified, it shall be determined if the water body receiving emissions from the process is impaired due to eutrophication. Receiving water bodies are considered impaired based upon water column measurements of mean productivity, chlorophyll-a concentrations, algal biomass, concentrations of total phosphorus or nitrogen, or dissolved oxygen. The definitions of impaired in a given instance shall be based upon those provided by local regulatory frameworks, or from a more conservative framework. In the US, the definitions used by US EPA or local agencies shall be used. In the US, the US EPA list of impaired waters shall be used as a starting point for this determination.[62]

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[61] M. Hauschild and Potting, J., 2003.Spatial differentiation in Life Cycle impact assessment - The EDIP2003 methodology. Institute for Product Development Technical University of Denmark.

[62] US EPA. Impaired Waters and Total Maximum Daily Loads. http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm

- If the receiving water body for a potential key unit process is impaired, the symptom of eutrophication shall be determined (i.e., if the water body is impaired solely due to algal blooms, it is the primary symptoms; if due to oxygen depletion, secondary symptoms).

- If the receiving water bodies are impaired due to primary symptoms of eutrophication, the next step is to determine whether the eutrophied water bodies are nitrogen- or phosphorus-limited. This shall be determined based on whether the impairment results from contamination by nitrogen-containing, or phosphorus-containing, compounds. Nitrogen-limited water bodies are impaired by nitrogen compounds, phophorus-limited water bodies are impaired by phosphorus compounds.

- LCA results shall be re-calculated using Equation 20, using PP-CF and M-CF values determined using Table 12, Table 14, and Equation 19. Eutrophication from primary and secondary symptoms shall be reported in separate indicators, even in situations where a water body is experiencing both symptoms.

Table 12. PP-CF and M-CF values to be used in evaluating freshwater eutrophication for key unit processes for primary symptoms. ***PP-CF Source: Table 6.1, Danish Guidelines***[63]

Type of Emission	**Non-key processes**	**Key unit processes**		
			Primary Symptoms	
		Not Impaired	**N-limited***	**P-limited***
Nitrogen compounds	M-CF = 1 PP-CF using Table 11.	M-CF = 0 No PP-CF	M-CF using Equation 19 PP-CF using Table 14	M-CF = 0 No PP-CF
Phosphorus compounds	M-CF = 1 PP-CF using Table 11.	M-CF = 0 No PP-CF	M-CF = 0 No PP-CF	M-CF using Equation 19 PP-CF using Table 14

**In cases where it is not possible to determine the limiting nutrient in the eutrophied water bodies, the PP-CF specified for undetermined limiting nutrient in Table 11 shall be used.*

Table 13. PP-CF and M-CF values to be used in evaluating freshwater eutrophication for key unit processes, considering secondary symptoms.

Type of Emission	**Non-key processes**	**Key unit processes**	
		Secondary symptoms	
		Not Impaired	**Impaired**
COD / BOD	M-CF = 1 PP-CF using Table 11.	M-CF = 0 No PP-CF	M-CF using Equation 19 PP-CF using Table 11.

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[63] M. Hauschild and Potting, J., 2003.Spatial differentiation in Life Cycle impact assessment - The EDIP2003 methodology. Institute for Product Development Technical University of Denmark.

Table 14. PP-CF, characterizing the Redfield ratio in environments with different limiting nutrients.

Substance	Formula	PP-CF, Nitrogen-Limited Water Body	PP-CF, Phosphorus-Limited Water Body	PP-CF, Undetermined Limiting Nutrient
		kg N. eq. / kg substance	**kg P eq. / kg substance**	**kg NO_3- eq. / kg substance**
Nitrogen Compounds				
Ammonia	NH_3	0.82	0	3.64
Nitrate	NO_3-	0.23	0	1.00
Nitrite	NO_2-	0.30	0	1.35
Cyanide	CN	0.54	0	2.38
Total Nitrogen	N	1.00	0	4.43
Phosphorus Compounds				
Phosphate	PO_4^{3-}	0	0.33	10.45
Pyrophosphate	$P_2O_7^{2-}$	0	0.35	11.41
Total Phosphorus	P	0	1.00	32.03

Equation 19. The M-CF for freshwater eutrophication, calculated separately for each key unit process, characterizes the fraction of emitted eutrophying discharges which transport to impaired waters. "Total eutrophying discharges" include all the eutrophying discharges released from the unit process each year. "Eutrophying discharges transporting to impaired waters" include those discharges depositing in the impaired water body during the periods of year when it is experiencing symptoms of eutrophication (e.g., emissions in wintertime to an impaired water periodically experiencing eutrophication only in summer are not included).

$$M - CF = \frac{Eutrophying\ Discharges\ Transporting\ to\ Impaired\ Water\ (tons/yr)}{Total\ Eutrophying\ Discharges\ from\ Unit\ Process\ (tons/yr)}$$

- If any of the contribution of what had been classified as non-key unit processes at this stage make up over 15% of re-calculated results for this indicator, then they should be re-classified as potential key unit processes. The process outlined above should be repeated, re-calculated LCA results with the new classified potential key unit processes.

- This process should be repeated until site-specific evaluation of non-key unit processes result will no longer significantly affect results over 15%. Generally this will not require more than two iterations. At this stage, the key unit processes are finalized with final PP-CFs and M-CFs applied with final results calculated using Equation 20.

The result for Freshwater Eutrophication for a single indicator, in tons N/P equivalent, is calculated according to Equation 20, for a given year in the timeframe of analysis.

Equation 20. Result for Freshwater Eutrophication.

Freshwater Eutrophication (tons N/P eq.) in a given year =

$$\sum_i \sum_j \text{Eutrophying Discharges}_j \times \text{PP-CF}_j \times \text{M-CF}_i)$$

Where:

- *Eutrophying discharges includes those discharges linked to production of the annual unit of analysis in the given year*
- *i is the total number of unit processes in the scope*
- *j represents the total number of types of eutrophying substances emitted*
- *PP-CF is the potential for emissions to contribute to eutrophication, calculated using Table 11, 12, 13, or 14, as appropriate*
- *M-CF is the fraction of emitted eutrophying discharges from unit process i which transport to impaired waters, calculated using Equation 19.*

5.4.5 Terrestrial Eutrophication

This impact category is not relevant to this industry sector.

5.5 Terrestrial & Freshwater Ecosystem Impacts (from Land Use and Conversion)

This group of impact categories accounts for logging and forest management associated with roundwood production, which leads to measurable physical disturbances to local terrestrial and freshwater ecosystems.

Four distinct impact categories shall be measured, which, when understood together, reflect four independent parameters of disturbance to ecosystems: terrestrial disturbance, freshwater disturbance, wetland disturbance, and loss of threatened species. The first three impact categories account for physical alterations in measurable ecological conditions of specific components of ecosystems, which are defined across specific spatial land areas and temporal scales. The fourth impact category addresses the loss of threatened species, which reflects effects to biodiversity.

Assessment of all results is inherently based on the comparison of ecological conditions of terrestrial, freshwater, and wetland components of an ecosystem, as well as threatened species habitats (or populations) within the considered roundwood or virgin fiber basket of the considered product. Therefore before analysis can begin, these baskets must be defined, based on the system boundary requirements of the respective PCR modules.

For any assessment of terrestrial and freshwater ecosystems impacts tied to logging and forest management:

- Primary data shall be used in the assessment.
- The data used shall be representative of the forest management and logging practices occurring across the entire region covered.
- Data may be calculated as an average of multiple years.

5.5.1 Terrestrial Disturbance

This impact category addresses disturbance to the terrestrial component of an ecosystem. The first step in assessing terrestrial disturbance (associated with roundwood production) is the identification of the terrestrial ecoregions within the roundwood or virgin fiber basket. The WWF Wildfinder Database[64] shall be used to determine which terrestrial ecoregions are impacted. All terrestrial ecoregions impacted by logging within the basket shall be included. The following steps are involved in determining which terrestrial ecoregions are affected:

- The specific geographical boundaries of the roundwood and fiber baskets in the scope of the LCA are defined.

> NOTE: The boundaries of the roundwood and fiber baskets should be defined using the best available data. Preferably, this is specific data provided by mill operators. If this is not available, public databases from government regulatory agencies (e.g., US Forest Service) often provide a level of information adequate to define the basket in a credible way. Reasonable assumptions can also be made, for example assuming that all wood is sourced from within 100 kilometers of a mill (as very rarely do transportation distances for significant amounts of timber for a mill's consumption exceed 100 or 200 kilometers.) The definition of the fiber basket should also consider whether data on ecological conditions will be available in FTM plots in defined FAUs.

- The terrestrial ecoregion(s) in which the roundwood and fiber baskets are located are identified from the WWF Wildfinder database. More geographically specific boundaries of the ecoregion can be defined if the Wildfinder definition is too broad in a region, based upon specific regional data (e.g., forest type, major tree species class).

Note. Other alternative datasets which could be used include those provided by organizations like the Global Forest Watch[65].

Indicator results are assessed per terrestrial ecoregion impacted. Results for Terrestrial Disturbance in a FAU, in units of equivalent fully disturbed acres, relative to the annual unit of analysis in a given year, are calculated using Equation 21. This equation provides results relative to the production of 1,000 cubic meters of roundwood production for a single FAU.

> ***NOTE.*** Terrestrial disturbance is an accumulated impact, and impacts in a given year are affected by foregone growth across all previous years in the timeframe of analysis.

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[64] https://www.worldwildlife.org/science/wildfinder/

[65] http://www.globalforestwatch.org/

This is integrated into final results relative to the annual unit of analysis by using a production-weighted average of impacts from foregone growth across all FAUs in the terrestrial ecoregions.

Equation 21. Equation to calculate the indicator result for Terrestrial Disturbance in a given year relative to the production of one thousand cubic meters of roundwood in a single FAU. This equation follows all requirements of Sections 5.5.1.1 and 5.5.1.2.

$$\text{Terrestrial Disturbance in a given year n, in a single FAU} = \frac{(\text{TDF}_{\text{no harvest}} \text{ in year n} - \text{TDF}_{\text{harvest}} \text{ in year n}) \times \text{FAU}_{\text{area}}}{\text{Total FAU Timber Production over } n \text{ years (in thousand cubic meters)}}$$

Where:

- $\text{TDF}_{\text{no harvest}}$ and $\text{TDF}_{\text{harvest}}$ are the Terrestrial Disturbance Factors (calculated according to requirements of Section 5.5.1.2) across the FAU in the No Harvest and Harvest scenarios (calculated according to requirements of Section 5.5.1.1).
- FAU_{area} is the area, in hectares, of the FAU.
- Total FAU Timber Production over n years is all production of roundwood from the beginning of the timeframe of analysis to the year n.

There are special reporting requirements for indicators in this impact category, described in Section 7.2 of the Roundwood and Pulp/Paper PCR Modules.

5.5.1.1 Modeling Foregone Growth

The result for an FAU is calculated using Equation 21, which requires the projection of TDFs under Harvest and No-Harvest scenarios. Currently, detailed growth models capturing all required elements of disturbance do not exist and must be established. Projections may be made using a stand table projection. In this modeling approach, the measured disturbance in different stand age classes present today is used to model change in disturbance levels over time.

Alternatively, the following default assumptions for the recovery trajectory of each scenario shall be used:

- Harvest scenario. The disturbance level shall be assumed to begin with the current disturbance level in the FAU, changing in the future at a linear rate based on the average change in the level of disturbance in the FAU over the past 10 years. If complete data are not available on the trend over the past 10 years, conservative estimates may be made regarding the trend in disturbance.

- No-harvest scenario. It shall be assumed that the forest recovers to conditions equivalent to the URA within 50 years, according to a fixed recovery rate of 2% per year (i.e., a linear recovery rate over the 50 year time period).

- The average site productivity is assumed to be the same in the future as for the past 10 years.

If growth models are used, effects on disturbance from foregone growth are modeled using the approach described in Section 6.5.3.2 of the Roundwood PCR Module, with the following supplemental requirements:[66]

- The growth model should be peer reviewed in a process that 1) primarily involved reviewers with necessary technical expertise (e.g., modeling specialists and relevant fields of biology, forestry, ecology, etc.), and 2) is open and rigorous.
- The growth model should be parameterized for the specific conditions of the FAU and URA.
- Limits use to the scope for which the model was developed and evaluated.
- The growth model should be clearly documented with respect to the scope of the model, the assumptions, known limitations, embedded hypotheses, assessment of uncertainties, and sources for equations, data sets, factors, or parameters.
- A sensitivity analysis should be conducted to assess model behavior for the range of parameters for which the growth model is applied.
- The basis of this modeled harvest scenario shall be provided, describing:
  - A description of the silvicultural methods which will be used, including: description of trees retained (by species group if appropriate) at harvest; the harvest frequency (years between harvests) for each silviculture method; and assumptions about regeneration.
  - A list of all legal constraints and constraints of other types (e.g., water quality best management practices of a voluntary nature or forest management certifications) that affect forest management activities in the FAU. This list must identify and describe the legal constraint, how the legal constraint affects the project area, and discuss the silviculture methods that will be projected to ensure the constraint is respected.
  - A description of the model used and explanation of how the model was calibrated for local use.
- The projections must consider all elements of disturbance used to calculate the initial level of disturbance in the projection as described in Section 5.5.1.2 of this document.
- The model shall output the periodic harvest, inventory, and disturbance estimates for the FAU as percent disturbance in each scenario.

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[66] These requirements are adapted from the Climate Action Reserve Quantification Guidance for Use with Forest Carbon Projects, January 21, 2014].

5.5.1.2 Calculation of Terrestrial Disturbance Factors

In assessing terrestrial disturbance using Equation 21, the terrestrial disturbance factor (TDF) in the current condition of the FAU shall be assessed in order to establish the initial level of disturbance. The TDF is established by first measuring multiple ecological conditions in the FAU and undisturbed reference area (URA), and then collecting and comparing them. (See Section 3 for definition of URA.) The ecological conditions included in the TDF calculation include those in the table below.

Table 15. Required and recommended ecological conditions for measurement in the evaluation of the Terrestrial Disturbance Factor. All measurements are evaluated as a comparison between the FAU and URA.

Category of Measurement	**Required Measurements**	**Recommended Measurements**
Forest Compositional Structure, including consideration of the species present in forest stands	• Abundance of the most common 5% of the known tree species in the URA (i.e., 5 out of 100 tree species, if 100 are present and where 5 are the most common)	
Forest Size Structure	• Tree diameter distribution (e.g., using Kolmogorov-Smirnov goodness-of-fit test) • Mean diameter of trees	
Relative Measurements of Biomass in the Forest	• Biomass in ground litter, downed (i.e., fallen) dead trees, live and dead understory, living trees, and standing dead trees. (The stored carbon in each pool can be used as a proxy for biomass.)	
Surveys of the Vertebrate and Invertebrate Species Communities	• Composite of censuses of all vertebrate species in the community, measured as individuals per kilometer of transect, by species; the number of species present. Vertebrate species which shall be included are small birds, small mammals, and herps (i.e., frogs, lizards, and snakes). If data are not available, by default it shall be assumed that each species and number of species present is reduced by 100%.	Censuses of invertebrate species in the community.
Spatial Forest Structure	• The percent of land in forested versus non-forest condition. Whether or not land is in a forested condition is evaluated based upon a quantitative measure of canopy cover (e.g., 30% of 50% canopy cover).	• Percentage of forest within 50 meters of a forest edge; the total length of the boundary of the forest divided by the area; and other measures of connectivity.

> NOTE: Existing databases can be used which contain measurements on ecological conditions in some regions, where they exist. In many countries, local governments publish very detailed data on some ecological conditions (e.g., the US Forest Inventory and Analysis, Swedish Forest Inventory, Canadian Forest Inventory). Global satellite datasets based in LANDSAT (e.g., Global Forest Watch) are also available for all regions.

Measurements shall be completed based upon a specified Forest Trend Monitoring (FTM) plan, satisfying all requirements of Section 6.5.3.1 of the Roundwood PCR Module.

In some cases, specific data may not be available for measurement of these conditions, however, reasonable estimates can be made based on known conditions in the FAU. Such reasonable estimates can be made provided they are conservative and a subject of the peer review.

> FOR EXAMPLE. A pulp plantation using a monoculture of non-native species replaces a mature forest in a region. In planted areas (excluding any set sides), it can be assumed that the abundance of the most prominent 5% of the known tree species is reduced 100%.

For each of these measurements, Equation 22 is used to calculate the deviation. The TDF should be calculated using the arithmetical average of all deviation measurements. Other approaches for assessing the TDF, based on the deviation measurements, can be used, provided the approach is based upon a methodology which is critically reviewed by a panel of at least three experienced forest ecologists.

Equation 22. Equation for assessing deviation in a condition in the FAU. Average measurements of conditions are evaluated across all FTM plots in the FAU. The deviation in a measurement has a minimum of 0%, when conditions in the URA are the same as in the FAU; and a maximum of 100%, when alteration in conditions between the URA and FAU is over 100%.

$$Deviation\ in\ a\ Condition = \left|\frac{Average\ measurement\ of\ condition\ in\ FAU - Average\ measurement\ of\ condition\ in\ URA}{Average\ measurement\ of\ condition\ in\ URA}\right|$$

5.5.2 Freshwater Disturbance

This impact category addresses disturbance to freshwater bodies within an ecosystem. Forest management and logging can contribute to freshwater disturbance in several ways, including: current forest management practices leading to ongoing excess sediment delivery into local watercourses; past forest management which has led to increased sediment in watercourses, due to historical sediment delivery; activities leading to direct physical changes in the channel shape, depth, and contour, of local watercourses; and harvests and other activities leading to direct impacts to riparian zones. The significance and impact of these stressors varies widely for the freshwater bodies in different regions. Furthermore, multiple freshwater bodies are usually affected. The following steps shall be used to determine the set of potentially impacted freshwater bodies:

- The locations of specific sites in the roundwood or virgin fiber basket(s) where harvests have occurred in the past 10 years shall be identified.

- Locations of logging roads and other infrastructure shall be identified to the extent possible.

- The watersheds in which harvest sites, roads, or other infrastructure are located shall be identified. In the US, the US Geological Survey's Watershed Boundary Dataset[67] shall be used to identify watersheds, based on 12-digit Hydrologic Unit Codes (i.e., sub-watersheds). For regions outside of the US, other datasets which provide watershed definitions at a spatial granularity of

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[67] http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/water/watersheds/dataset/

approximately 5,000-50,000 acres shall be used. If data at this granularity is not available, the HydroSheds dataset[68] shall be used.

- These are the watersheds which could potentially be affected by forestry practices.

Specific data from measurements of ecological conditions within a freshwater body can be used to evaluate disturbance levels within a freshwater body, and to determine if disturbance is relevant at all. Freshwater disturbance shall be evaluated using the following approach:

- Measurements of ecological conditions are collected at Freshwater Trend Monitoring (FWTM) sites within specifically defined Freshwater Analysis Units (FWAU) within the freshwater body.
- Measurements of the conditions are taken based on assessment of conditions across all FWTM sites within an FWAU.
- The deviation in the measurement of a specific ecological condition is evaluated by considering conditions across the entire FWAU in comparison to the Freshwater Properly Functioning Condition (FWPFC). The deviation is calculated based on the approach described in Section 5.5.2.1.
- The Freshwater Disturbance Factor (FWDF) is calculated based on the approach described in Section 5.5.2.1.

If the FWDF is a value larger than the expected uncertainty in measurement based on the standard deviation (i.e., the ecological conditions in the FWAU are different than in the FWPFC to a degree which is statistically significant), freshwater disturbance is relevant in the watershed. The trend of FWDF disturbance should also be evaluated based on examination of the trend in ecological conditions over at least a 10 year period. This can be reported as:

1. Recovering: The FWDF has decreased over the past 10 years.
2. Increasing Disturbance: The FWDF has increased over the past 10 years.
3. Stable Condition: The FWDF has not changed over the past 10 years.
4. Unknown: The condition of the FWDF is not known over the past 10 years.

NOTE. Projections of recovery are not allowed due to the inherent uncertainty and variability in recovery of freshwater bodies. Hence there is no calculation for foregone recovery in freshwater bodies.

Special reporting requirements apply to this impact category, as described in Section 7.2 of the Roundwood PCR Module.

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[68] HydroSheds model; http://www.fao.org/geonetwork/srv/en/main.home?uuid=9c52166f-2a8e-465d-a14a-f230f38d63f9

Specific requirements for the FWTM sites and FWTM plan are below.

5.5.2.1 Requirements for Freshwater Trend Monitoring and Calculating Freshwater Disturbance Factors

Measurements of ecological conditions within a freshwater body shall be gathered according to a Freshwater Trend Monitoring (FWTM) plan, which sets out requirements for monitoring completed at Freshwater Trend Monitoring (FWTM) sites. The FWTM sites shall cover a reasonable fraction of the lengths of fish-bearing (Class I) streams with clearly defined Freshwater Analysis Units (FWAUs) within the freshwater body, and should cover additional streams if possible. FWTM sites shall be located permanently in the same location in order to track trends in aquatic conditions over time. Measurements of ecological conditions at FWTM sites are measured and compared to the same conditions in the FWPC, using Equation 22. Sampling at each FWTM site within the FWAU shall include measurements of:

- At least 1 condition based upon taxonomic composition (e.g., number or relative abundance of taxa).
- At least 1 condition based upon population characteristics of indicator taxa (e.g., abundance or relative proportions).
- Water quality conditions, including: turbidity; biological oxygen demand and/or dissolved oxygen content; presence of hazardous environmental contaminants.
- Siltation and sedimentation rates;
- Water temperature;

The ecological conditions included in the BDF calculation should include:

- At least 1 condition based upon the age composition of freshwater indicator species.
- At least 1 condition based upon percentage of diseased freshwater indicator species.
- Conditions related to: Channel dimensions; particle size of the stream bed surface and subsurface; pool characteristics; large woody debris characteristics.

Measurements of ecological conditions are evaluated according to the requirements of the FWTM Plan, and compared to conditions based on the FWPFC for the freshwater body.

> NOTE. As part of local regulatory requirements, logging operations may have established plans for freshwater trend monitoring satisfying the guidance of this PCR.[69]

In calculating the Freshwater Disturbance Factor (FWDF), measurements of ecological conditions within the FWAU are assessed considering measurements at all FWTM sites in the FWAU. The deviation in each measurement of ecological condition for a freshwater body is calculated using Equation 23. The FWDF

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[69] An example of a conforming ATM plan can be found here: http://www.hrcllc.com/wp-content/uploads/2012/01/2014-ATM-Report-w_ApdxA-for-website.pdf

should be calculated using the arithmetical average of all deviation measurements. Other approaches for assessing the FWDF, based on the deviation measurements, can be used, provided the approach is based upon a methodology which is critically reviewed by a panel of at least three experienced ecologists.

Equation 23. Equation for assessing deviation in a condition in the FWAU. Average measurements of conditions are evaluated across all FWTM plots in the FWAU. The deviation in a measurement has a minimum of 0%, when conditions in the FWPFC are the same as in the FWAU; and a maximum of 100%, when alteration in conditions between the FWPFC and FWAU is over 100%.

$$Deviation\ in\ a\ Condition = \left| \frac{Average\ measurement\ of\ condition\ in\ FWAU - Average\ measurement\ of\ condition\ in\ FWPFC}{Average\ measurement\ of\ condition\ in\ FWPFC} \right|$$

Alternative approaches for evaluating the deviation for a given measurement of an ecological condition can be used, provided the methodology is critically reviewed by a panel of at least three experienced forest ecologists.

5.5.3 Wetland Disturbance

This impact category addresses disturbance to wetlands within an ecosystem. In forestry, there are several activities which can lead to stressors contributing to wetland disturbance, including: conversion of wetlands for the establishment of forestry operations; direct disturbances to existing wetlands; activities which alter the hydrology of watersheds; and activities leading to increased sediment input into watercourses. The significance and impact of these stressors varies widely for wetlands in different regions; however, consistent and credible site monitoring data are very rarely available to assess this wetland disturbance arising from each of these vectors of stress. The set of wetlands which could be impacted shall be the basis of this assessment. To make this identification, regional data on affected wetlands must be identified, and resulting wetland impacts linked to forestry. The specific affected wetlands shall be listed where results are reported.

Specific data from measurements of ecological conditions within a wetland can be used to evaluate disturbance levels within the region, and to determine if disturbance is relevant at all. Wetland disturbance shall be evaluated using the following approach:

- Measurements of ecological conditions are collected at Wetland Trend Monitoring (WTM) sites within specifically defined Wetland Analysis Units (WAU) within the wetland.

- Measurements of the conditions are taken based on assessment of conditions across all WTM sites within a WAU.

- The deviation in the measurement of a specific ecological condition is evaluated by considering conditions across the entire WAU in comparison to the Wetland Properly Function Condition (WPFC). The deviation is calculated based on the approach described in Section 5.5.3.1.

- The Wetland Disturbance Factor (WDF) is calculated based on the approach described in Section 5.5.3.1.

If the WDF is a value larger than the expected uncertainty in measurement based on the standard deviation (i.e., the ecological conditions in the WAU are different than in the WPFC to a degree which is statistically significant), wetland disturbance is relevant in the watershed. The trend of WDF disturbance should also be evaluated based on examination of the trend in ecological conditions over at least a 10 year period. This can be reported as:

1. Recovering: The WDF has decreased over the past 10 years.

2. Increasing Disturbance: The WDF has increased over the past 10 years.

3. Stable Condition: The WDF has not changed over the past 10 years.

4. Unknown: The condition of the WDF is not known over the past 10 years.

NOTE. Projections of recovery are not allowed due to the inherent uncertainty and variability in recovery of wetlands. Hence there is no calculation for foregone recovery in wetlands.

Special reporting requirements apply to this impact category, as described in Section 7.2 of the Roundwood PCR Module.

Specific requirements for the WTM sites and WTM plan are below.

5.5.3.1 Requirements for Wetland Trend Monitoring and Calculating Wetland Disturbance Factors

Measurements of ecological conditions within a wetland shall be gathered according to a Wetland Trend Monitoring (WTM) plan, which sets out requirements for monitoring completed at Wetland Trend Monitoring (WTM) sites. The WTM sites shall cover a reasonable portion of the area of the wetland with clearly defined Wetland Analysis Units (WAUs) within the wetland. WTM sites shall be located permanently in the same location in order to track trends in conditions over time. Measurements of ecological conditions at WTM sites are measured and compared to the same conditions in the WPFC, using Equation 24. Sampling at each WTM site within the WAU shall include measurements of:

- At least 1 condition based upon taxonomic composition (e.g., number or relative abundance of taxa).

- At least 1 condition based upon population characteristics of indicator taxa (e.g., abundance or relative proportions).
- Conditions related to: turbidity; sedimentation rates; biological oxygen demand and/or dissolved oxygen content; presence of hazardous environmental contaminants; water temperature; salinity; vegetative cover; plant structure (if plants are present).

The ecological conditions included in the WDF calculation should include:

- At least 1 condition based upon age composition of wetland indicator species.
- At least 1 condition based upon percentage of diseased wetland indicator species.

The WTM plan shall specify the sampling frequency at each WTM site within the WAU. The WTM plan should specify that sampling be completed after significant precipitation events or storms which could affect wetland conditions.

Measurements of ecological conditions are evaluated according to the requirements of the WTM Plan, and compared to conditions based on the WPFC for the wetland. See Terms and Definitions for definition of the WPFC.

In calculating the Wetland Disturbance Factor (WDF), measurements of ecological conditions within the WAU are assessed considering measurements at all WTM sites in the WAU. The deviation in each measurement of ecological condition for a wetland is calculated using Equation 24. The WDF should be calculated using the arithmetical average of all deviation measurements. Other approaches for assessing the WDF, based on the deviation measurements, can be used, provided the approach is based upon a methodology which is critically reviewed by a panel of at least three experienced ecologists.

Equation 24. Equation for assessing deviation in a condition in the WAU. Average measurements of conditions are evaluated across all WTM plots in the WAU. The deviation in a measurement has a minimum of 0%, when conditions in the WPFC are the same as in the WAU; and a maximum of 100%, when alteration in conditions between the WPFC and WAU is over 100%.

$$\begin{aligned}&Deviation\ in\ a\ Condition\\&= \left|\frac{Average\ measurement\ of\ condition\ in\ WAU - Average\ measurement\ of\ condition\ in\ WPFC}{Average\ measurement\ of\ condition\ in\ WPFC}\right|\end{aligned}$$

Alternative approaches for evaluating the deviation for a given measurement of an ecological condition can be used, provided the methodology is critically reviewed by a panel of at least three experienced forest ecologists.

5.5.4 Threatened Species Habitat Disturbance

This impact category addresses the loss of threatened species, using separate category indicators to characterize impacts to each threatened species. Included are all threatened categories of species affected by roundwood or pulp/paper production, based upon the definition of the "threatened categories" according to the IUCN Red List Categories and Criteria Version 3.1 Second Edition (or latest final version of these criteria). This includes species meeting the categories of Critically Endangered, Endangered, or Vulnerable. All mammals, amphibians, reptiles, and birds shall be considered. Additionally, impacts to threatened species in other taxa including invertebrates and plants should be included.

In determining which threatened species are included, the first step is creating the list of potentially impacted species. To create this list, the following data sources shall be used to identify the threatened species which are present in the roundwood or virgin basket(s) considered:

1. Species classified as Critically Endangered, Endangered, or Vulnerable, in the affected ecoregions considered in the study scope, according to the WWF Wildfinder Database listing or entry in the IUCN Red List of Species, in the corresponding ecoregion.

2. Additional threatened species shall be included, where relevant, based on alternative data sources (e.g., governmental lists, environmental impact statements, peer reviewed literature), provided their status is Critically Endangered, Endangered, or Vulnerable, according to the IUCN Red List Categories and Criteria.

NOTE. Although alternative definitions exist for categorizing species as "threatened", use of different lists or different categorizations will lead to inconsistencies in comparisons in the number of threatened species in different regions. Accordingly, only the IUCN categorization is used.

NOTE. In many tropical regions, there may be a large number of threatened species affected by logging which are not included on these lists. There may additionally be many species for which very little data is available regarding threatened status or habitat conditions. The comprehensiveness of the data regarding threatened species available for the region shall be considered in disclosing results in LCAs and EPDs (see Roundwood PCR, Section 7.2).

After the potentially impacted list of threatened species is generated, the subset of this list of species with habitat or populations negatively impacted by local forestry are identified. The following screening considerations shall be used to exclude species:

- Whether the range (current or historic) of the species overlaps with the roundwood or virgin fiber basket.
- If present in the basket, the habitat type(s) used by the species in the region.
- Whether forestry in the basket adversely impacts regional populations, or regional habitats. (While some species will experience deleterious effects to habitat conditions and/or species populations, some may actually be favored by regional forest management.)

In this screening, databases which can be used include those provided by the US Fish and Wildlife Services,[70] local state governments, the International Union for the Conservation of Nature, and others.[71,72]

For many of these species, these data sources will note explicitly that local habitats and populations are impacted by forestry (for example, when logging has been identified as one of the primary threats to species populations, and regulatory actions may have been taken to limit species impacts from forest management). For some species, while timber harvests are not explicitly described as a significant threat, suitable habitat will clearly be impacted by forestry.

> ***FOR EXAMPLE.*** Species requiring contiguous mature forest habitats will be impacted by short-rotation even-aged forest management, which prevents forest maturation and can fragment forests.

Assumptions may be required to determine the relevance of forestry activities to impacts on habitat and populations. The following assumptions shall be made as a default, unless established to be false for a specific species:

- *For species occupying freshwater habitats (e.g., streams, rivers, creeks, lakes, and ponds).* Forestry can contribute to increased sediment yield (and other stressors) which can impact freshwater habitats. As a default, it shall be assumed that forestry will negatively impact species occupying these habitats. If it can be established that forest management practices have successfully mitigated sedimentation (e.g., as a result of Best Management Practices being followed in the US, or due to Federal and Provincial forestry laws and regulations in Canada that prevent sediment run-off and overharvesting of trees in riparian areas), then species occupying freshwater habitats do not need to be included.
- *For species occupying wetland habitats (e.g., swamps, bogs, and marshes).* The conversion and disturbance of wetlands resulting from forestry is well documented in many regions. As a default, it shall be assumed that forestry will negatively impact species occupying these habitats.
- *Species occupying riparian habitats (e.g., areas near freshwater and wetland habitats).* The same stressors which lead to the disturbance of wetland and freshwater habitats can also impact riparian habitats. As a default, it shall be assumed that forestry will negatively impact species occupying these habitats.
- *Species occupying grassland habitats (e.g. pastures, open meadows, and savannas).* Due to the complete differences in grassland and forest habitat, it shall be assumed that forestry causes disturbance to these habitats, as a default.
- *Species occupying habitats in forest edges, adjacent to grasslands or other types of non-forest habitat.* As a default, it shall be assumed that forestry has no net impact on habitats for these

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[70] US Fish and Wildlife Service. Species Environmental Conservation Online System.
[71] NatureServer Explorer: An Online Encyclopedia of Life.
[72] FishBase, 06/2014. http://www.fishbase.org/

species. Timber harvesting can remove habitat, but will also create habitat through the generation of forest edges.

Specific assessment of species populations can be used to determine whether the species is in fact affected negatively by logging.

FOR EXAMPLE. Threatened species may be the subject of specific Habitat Conservation Plans or other specific types of forest management practices which avoid negative effects. For given species in the region dependent upon intact forest core interiors, clear cutting may have negative effects, but single tree selection cutting may not. Or specific set aside areas may be put in place to preserve this intact forest. These could avoid negative effects of logging on the species.

In these cases, site monitoring of species populations will be required; impacts to species can only be excluded if populations are at similar levels to conditions in the URA, FWPFC, or WPFC (depending on habitats occupied by the species).

Assessment of habitat disturbance or population losses can be completed according to LEO-S-002 protocols. However, typically the effort required for this assessment across a large number of species is not practical in LCA. The results can be reported as the number of species affected by logging in each threatened classification (e.g. number of endangered species affected, number of threatened species affected, etc.).

> ***FOR EXAMPLE.*** An industry-wide EPD considered virgin paper sourced from integrated mills in Wisconsin, Maine, and Maryland. The number of endangered species affected was considered. For the Wisconsin, Maine, and Maryland mills, 21, 8, and 118 endangered species are affected by logging.

5.6 Human Health Impacts from Chronic Exposure to Hazardous Chemicals

The impact categories in this group address endpoints to human health. There are five impact categories in this group which are relevant to roundwood, pulp, and paper production:

- Ground Level Ozone (GLO) Inhalation Impacts
- PM2.5 Inhalation Impacts.
- Ambient Emission Inhalation Impacts.
- Ingestion Impacts.
- Dermal Exposure to Toxic Herbicides (for roundwood production).

These impact categories characterize hazardous chemical releases that present health risks to humans from exposure, and include carcinogens, and those that can lead to acute and non-cancerous chronic health effects.

Each of these impact categories represents a distinct environmental mechanism, based on the route and extent of exposure of humans of various hazardous substances. Aggregation of these emissions into just one or two category indicators is not allowed.

The first two impact categories (GLO Inhalation Impacts, and PM2.5 Inhalation Impacts) address exposure to ozone and particulate matter, which are the two most harmful components of urban smog. Urban smog is prevalent in almost all industrialized regions in the world and leads to the death of nearly 4 million people per year.[73]

The last three impact categories address three routes of exposure to humans linked to various steps in the supply chain of production of roundwood, pulp, and paper, arising from emissions of hazardous substances. Based on the LEO-S-002 standard, to be defined as "hazardous", a substance must satisfy two conditions: (1) there must be a documented route of exposure to humans, which leads to a measurable risk of exposure; and (2) exposures have been observed to result in toxic effects in humans.[74] Although a chemical may be inherently toxic if a human is exposed, if there is no route of exposure, no toxic endpoints can result. Chemicals only have risk when there is an exposure pathway and inherent toxicity has been documented.

5.6.1 Ground Level Ozone Inhalation Impacts

This impact category addresses the human health impacts which can occur when human populations are exposed to ground level ozone (GLO) at concentrations above the safe health threshold defined by the World Health Organization (WHO), 60 ppb over an 8-hour period. Unit processes are included if emissions could transport to regions where the ambient ozone concentration exceeds 60ppb as an average over an 8-hour period for at least once per year. As a default, it can be assumed that all unit processes are in locations where this threshold is exceeded.

Ozone is not emitted, but instead formed after emissions of NOx and VOCs undergo photochemical reactions in the atmosphere; the PP-CF represents the amount of ozone formed by the emission of an ozone precursor.

The relative ambient concentrations of NOx and VOCs determine the amount of ozone formed from each type of emissions and the PP-CF. In NOx- and VOC-limited receiving environments, additional emissions of NOx and VOCs respectively lead to increased formation of ozone. This means that in NOx-limited receiving environments, emissions of NOx lead to formation of GLO, while VOC emissions do not, and vice versa for VOC-limited receiving environments.

In practice, most receiving environments are NOx-limited. Unless determined otherwise with specific ambient monitoring data, it shall be assumed as default that local receiving environments are NOx-limited, with little or no incremental contribution to ozone formation occurring from emissions of VOCs.

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[73] World Health Organization. Global Health Observatory (GHO) data. Mortality from ambient air pollution. http://www.who.int/gho/phe/outdoor_air_pollution/burden_text/en/

[74] Hazardous chemicals may include those listed under: the US EPA, under the provisions of SARA Title III Section 313, Toxic Release Inventory (TRI), Clean Air Act (CAA) Section 112(r) substances; the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA); the International Agency for Research on Cancer (IARC) Monographs on the Evaluation of Carcinogenic Risks to Humans; and chemicals of concern in other countries where studies are conducted. These are listed, for instance, in US EPA, Office of Solid waste and Emergency Response's "List of Lists: Consolidated List of Chemicals Subject to the Emergency Planning and Community Right-To-Know Act (EPCRA) and Section 112(r) of the Clean Air Act ," EPA 550-B-01-003, October 2001.

NO_x are the only substances which contribute to ozone formation in these conditions, and are the only emissions included in results. This includes emissions to air of nitrogen dioxide, nitrogen oxide, and unspecified nitrogen oxides. While the specific conversion rate may vary, a PP-CF of 1.0 ton O_3/ ton emitted NOx shall be used as a default, based on global average conversion rates of NOx to ozone.[75]

The M-CF characterizes the exposure of humans to GLO at concentrations exceeding the 60 ppb threshold. The M-CF differs by process in the supply chain, which must be assessed using Geographic Information System tools and dispersion modeling. It is calculated by first assessing the Exposure Risk Factor for GLO (ERF_{GLO}), by grid cell, in the region of the operation. The ERF_{GLO} is calculated using Equation 25.

Equation 25. Calculation for the Exposure Risk Factor for GLO Inhalation Impact for a single grid cell. The ERF_{GLO} is in units of persons * ppb O_3 * hours.

$$ERF_{GLO}\ for\ a\ grid\ cell = \sum_{daylight\ hours}^{ozone\ season}\left(\frac{O_3\ ambient\ concentration\ (ppb)}{60\ ppb}\right) x$$

$$\sum_{hours}^{ozone\ season}(Population\ x\ \ O_3\ concentration\ (ppb)\ from\ dispersion)$$

> NOTE. The 60 ppb value represents the safe threshold level identified by the WHO. The ratio of annual ambient concentration to this value indicates the increase in concentrations over safe concentrations, characterizing the severity of exposure in relation to the 60 ppb threshold.[76]

The M-CF for an operation is then calculated as the sum of the ERF_{GLO} by grid cell across the dispersion domain for the operation, which is the region into which ozone formed from precursors emitted from the operation transit. The dispersion domain shall be calculated using air dispersion modeling. The most appropriate air dispersion model for characterizing modeling of O_3 should be applied to evaluate results. CMAQ and CAMx are suitable tools. The M-CF must be assessed using the same approach for all unit processes.

> NOTE: Ideally, LCI data on emissions used in the dispersion modeling would be hourly throughout the year. Generally this level of information is not available for LCA studies. As a default, annual average emission data can be used, assuming for continuous emissions sources that the level of emissions are roughly constant throughout the year. Given there is in fact variability, it should be assumed as a default that the use of annual average data introduces an additional uncertainty of +/-20% which shall be included in final results using principles of error propagation.

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[75] Fry, M.M. The influence of ozone precursor emissions from four world regions on tropospheric composition and radiative climate forcing.

[76] This approach of weighting by severity is similar to other LCIA methodologies treatment of this impact. See Sleeswijk, et al., 2010. GLOBOX: A spatially differentiated global fate, intake, and effect model for toxicity assessment in LCIA. Science of the Total Environment, Vol. 408 #14, 2010.

Assessment of M-CFs should not be completed for all operations in the supply chain, as this is impractical. Instead, M-CFs should be assessed using the following specific approach, in order to minimize the effort required:

- After the initial LCI model is completed, LCA results shall be assessed using PP-CFs with no M-CFs.
- The key unit processes (i.e., processes contributing over 15% to results) should be identified based on results using PP-CFs.
- M-CFs should then be evaluated using dispersion modeling based in Equation 25 for the key unit processes.
- With this approach, typically 5-10 M-CFs need to be evaluated for each supply chain in order to assess results of acceptable data quality. For the processes for which M-CFs are not established, conservative estimates can be used to establish results. Uncertainty and data quality analysis can assist in the effort to minimize the number of M-CFs which are established.

The result for GLO Inhalation Impacts, in persons * hrs * ppb O3 eq, is calculated according to the equation below, for a given year in the timeframe of analysis.

Equation 26. Result for Ground Level Ozone Inhalation Impacts.

$$\text{Ground Level Ozone Inhalation Impacts (prsns * hrs * ppb O3 eq) in a given year} =$$

$$\sum_i \sum_j \text{Ozone Precursors Emitted}_{i,j} \times \text{PP-CF}_j \times \text{M-CF}_i$$

Where:

- *Ozone precursors emitted include those emissions linked to production of the annual unit of analysis in the considered year*
- *i is the total number of unit processes in the scope*
- *j represents the total number of types of ozone precursor emitted*
- *PP-CF is the amount of ozone formed by the emission of an ozone precursor, in kilograms ozone per kilogram emission.*
- *M-CF is calculated using Equation 25.*

In cases where consistent GIS tools and data are unavailable for all key unit operations which are identified, regionalized results cannot be evaluated. In cases where full assessment is not possible, indicator results shall be reported using PP-CF values in units of kilograms of O_3. In this case, results shall be reported as “Emissions of Ozone Precursors”. In addition to this reporting, results can optionally be reported using alternative LCIA methodologies (see Section 7.4 of Roundwood PCR Module).

5.6.2 PM 2.5 Inhalation Impacts

This impact category considers health risks from inhalation of particles less than 2.5 microns in diameter ($PM_{2.5}$). For indicator results, all primary particulate emissions are included, as well as emissions which can convert into particulate matter in the atmosphere to form secondary particulates.

The PP-CF for this impact category characterizes the mass of $PM_{2.5}$ transported into the atmosphere as the result of an emission. This includes primary particulates, which are emitted directly from combustion sources, and secondary particulates, which form after the atmospheric oxidation of NOx and SO_2 emissions into particulates containing nitrate and sulfate. The PP-CF values which shall be used are in Table 16.

Table 16. PP-CFs used in calculation of category indicator results for $PM_{2.5}$.

Emission	PP-CF[77] *(ton PM2.5 eq. per ton emission)*
≤ PM 2.5	1
> PM 2.5	0
PM10 and unspecified PM	0.9
SO_2*	0.36
NO_x**	0.10

**Emissions of all oxides of sulfur are characterized with PP-CF for SO_2.*

***Emissions of all oxides of nitrogen are characterization with PP-CF for NOx. This includes emissions of nitrogen dioxide, nitrogen monoxide, and unspecified nitrogen oxides.*

The M-CF characterizes the exposure of humans to fine particulate matter, considering the local severity of health impacts linked to elevated levels of $PM_{2.5}$. The M-CF differs by process in the supply chain, which must be assessed using GIS tools and dispersion modeling. It is calculated by first assessing the Exposure Risk Factor for $PM_{2.5}$ ($ERF_{PM2.5}$), by grid cell, in the region of the operation. The $ERF_{PM2.5}$ is calculated using Equation 27.

Equation 27. Calculation for the Exposure Risk Factor for PM2.5 for a single grid cell.

$$ERF_{PM2.5}\ for\ a\ grid\ cell =$$

$$\frac{Annual\ average\ ambient\ \ concentration\ \left(\frac{\mu g\ PM_{2.5}}{m^3}\right)}{3\ \frac{\mu g\ PM_{2.5}}{m^3}}$$

$$x \sum_{hours}^{year} \left(Population\ x\ \ PM_{2.5}\ concentration\ from\ dispersion\ (\frac{\mu g\ PM_{2.5}}{m^3})\right)$$

NOTE. The value of $3\,\frac{\mu g\ PM_{2.5}}{m^3}$ in the above equation represents the typical ambient background concentration. The ratio of annual ambient concentration to this value indicates the increase in concentrations over typical background concentrations.

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[77] US EPA. *Compilation of Air Pollutant Emissions Factors: Appendix B.2, Generalized Particle Size Distributions.* http://www.epa.gov/ttn/chief/ap42/appendix/appb-2.pdf

M-CFs for an operation are then calculated as the sum of the $ERF_{PM2.5}$ by grid cell across the dispersion domain for the operation, which is the region into which $PM_{2.5}$ and $PM_{2.5}$ precursors emitted from the operation transit as shown in Equation 29. The dispersion domain shall be calculated using air dispersion modeling. The most appropriate air dispersion model for characterizing modeling of PM should be applied to evaluate results.

Equation 28. M-CF for a unit process calculated as the sum of the $ERF_{PM2.5}$ for 'n' grid cells, where 'n' is the number of grid cells across the dispersion domain for a unit process.

$$M - CF\ for\ a\ unit\ process = \sum ERF\ PM2.5\ for\ n\ grid\ cells$$

NOTE: Ideally, LCI data on emissions used in the dispersion modeling would be hourly throughout the year. Generally this level of information is not available for LCA studies. As a default, annual average emission data can be used, assuming for continuous emissions sources that the level of emissions are roughly constant throughout the year. Given there is in fact variability, it should be assumed as a default that the use of annual average data introduces an additional uncertainty of +/-20% which shall be included in final results using principles of error propagation.

M-CFs should be assessed using the following specific approach, in order to minimize the effort required:

- After the initial LCI model is completed, LCA results shall be assessed using PP-CFs with no M-CFs. No regionalization is required.
- The key unit processes (i.e., processes contributing over 15% to results) should be identified based on results using PP-CFs.
- M-CFs should then be evaluated only for the key unit processes, in order to assess final results.
- With this approach, typically 5-10 M-CFs need to be evaluated for each supply chain in order to assess results of acceptable data quality. For the processes for which M-CFs are not established, conservative estimates can be used to establish results.
- Uncertainty and data quality analysis can further assist in the effort to minimize the number of M-CFs which are established.

In cases where GIS tools and data are unavailable, results cannot be evaluated. Regional $PM_{2.5}$ concentrations and populations vary by multiple orders of magnitude even within single countries, and assessing results in terms of mass of emitted $PM_{2.5}$ or other modes can be misleading. In cases where full assessment is not possible, indicator results shall be reported as "No data".

The result for PM2.5 Inhalation Impacts, in prns * hrs * µg PM2.5e / m3, is calculated according to the equation below, for a given year in the timeframe of analysis.

Equation 29. Result for PM2.5 Inhalation Impacts.

$$\text{PM2.5 Inhalation Impacts (prsns * hrs * µg PM2.5e / m}^3\text{) in a given year} =$$

$$\sum_i \sum_j \text{Particulates and Particulate Precursors Emitted}_{i,j} \times \text{PP-CF}_j \times \text{M-CF}_i$$

Where:

- *Particulates and particulate precursors emitted include those emissions linked to production of the annual unit of analysis in the considered year*
- *i is the total number of unit processes in the scope*
- *j represents the total number of particulate size fractions and particulate precursors emitted*
- *PP-CF is the mass of $PM_{2.5}$ transported into the atmosphere as the result of an emission from Table 16.*
- *M-CF is calculated using Equation 27.*

5.6.3 Ambient Emission Inhalation Impacts

This impact category considers hazardous ambient air contaminants (HAACs) emitted to air which, if inhaled, may lead to toxic effects in humans. The only substances considered are those which contribute to the contamination of ambient air at concentrations over safe thresholds, which could subsequently expose humans through inhalation.

NOTE. The toxic effects which may be caused by some contaminants occur at essentially any concentration; for these contaminants, there is no safe threshold. For example, cancer effects have no safe threshold of exposure.

Separate category indicators are evaluated for toxic endpoints in humans resulting from HAAC exposure. This distinct accounting is important due to the differing level of risks, health impacts, and types of populations which can be affected. As a default, results shall be separately assessed for two indicators: characterization HAAC emissions with respiratory health impacts, and emissions of carcinogens. In regions where contaminants of pollutants are present at concentrations which can lead to other health endpoints, additional indicator results should be reported.

NOTE. In urban regions in the US and most industrial regions around the world, unsafe concentrations of HAACs which lead to these two toxic endpoints are very prevalent.[78]

The HAAC emissions and respective PP-CFs which shall be included are in Table 17. PP-CFs are based on the inhalation toxicity of each chemical relative to a reference chemical, based on the Reference Concentration (RfC). The HAACs in Table 17 are the main contributors to health risks from ambient air inhalation in many regions of the US[79].

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[78] https://www.epa.gov/national-air-toxics-assessment

[79] Ibid.

Table 17. The PP-CFs, by indicator, for this impact category. For emissions with respiratory and cancer health effects, PP-CFs are respectively the ratio of the RfC value of acrolein to the RfC of the substance in question,[80] and the ratio of the URE of the substance to the URE of hexavalent chromium.[81]

Emitted Substance	**CAS Number**	**PP-CF for Emissions with Potential Respiratory Health Effects** *(g acrolein eq. / kg emission)*	**PP-CF for Emissions of Carcinogens** *(g Cr VI eq. / kg emission)*
1,1,2,2-Tetrachloroethane	79345	Emission not relevant for this endpoint	4.833
1,1,2-Trichloroethane	79005	Emission not relevant for this endpoint	1.333
1,3-Butadiene	106990	Emission not relevant for this endpoint	2.5
1,3-Dichloropropene	542756	Emission not relevant for this endpoint	0.333
1,3-Propane Sultone	1120714	Emission not relevant for this endpoint	57.5
1,4-Dichlorobenzene	106467	Emission not relevant for this endpoint	0.917
2,4-Toluene Diisocyanate	26471625	286	Emission not relevant for this endpoint
4,4'-Methylenedianiline	101779	Emission not relevant for this endpoint	38.333
4,4'-Methylenediphenyl Diisocyanate (MDI)	101688	33	Emission not relevant for this endpoint
4-Dimethylaminoazobenzene	60117	Emission not relevant for this endpoint	108.333
Acetaldehyde	75070	2	0.183
Acetamide	60355	Emission not relevant for this endpoint	1.667
Acrolein	107028	1,000	Emission not relevant for this endpoint
Acrylamide	79061	Emission not relevant for this endpoint	13.333
Acrylic Acid	79107	20	Emission not relevant for this endpoint
Acrylonitrile	107131	Emission not relevant for this endpoint	5.667
Antimony Compounds	7440360	100	Emission not relevant for this endpoint
Arsenic Compounds	7440382	Emission not relevant for this endpoint	358.333
Benzene	71432	Emission not relevant for this endpoint	0.650
Benzidine	92875	Emission not relevant for this endpoint	8,933.333
Benzotrichloride	98077	Emission not relevant for this endpoint	308.333
Beryllium Compounds	7440417	1,000	200.0
Cadmium Compounds	7440439	Emission not relevant for this endpoint	150.0
Carbon Tetrachloride	56235	Emission not relevant for this endpoint	0.5
Chlorine	7782505	133	Emission not relevant for this endpoint
Chromium VI Compounds	18540299	Emission not relevant for this endpoint	1,000.0
Cobalt Compounds	7440484	200	Emission not relevant for this endpoint
Epichlorohydrin	106898	20	Emission not relevant for this endpoint
Ethyl Carbamate (Urethane) Chloride (Chloroethane)	51796	Emission not relevant for this endpoint	38.333
Ethylbenzene	100414	Emission not relevant for this endpoint	0.208
Ethylene Dibromide / Dibromoethane	106934	Emission not relevant for this endpoint	50.0
Ethylene Oxide	75218	Emission not relevant for this endpoint	7.333
Formaldehyde	50000	2	1.083
Hexamethylene Diisocyanate	822060	2,000	Emission not relevant for this endpoint
Hydrazine	302012	Emission not relevant for this endpoint	408.333
Hydrochloric Acid	7647010	1	Emission not relevant for this endpoint
Methyl Bromide	74839	4	Emission not relevant for this endpoint
Methyl Tert-Butyl Ether	1634044	Emission not relevant for this endpoint	0.022
Naphthalene	91203	7	2.833
Nickel Compounds	NA	222	26.0
Polycyclic Aromatic Hydrocarbons*		Emission not relevant for this endpoint	20.0
Propylene Dichloride	78875	Emission not relevant for this endpoint	1.583
Tetrachloroethylene	127184	Emission not relevant for this endpoint	0.492
Trichloroethylene	79016	Emission not relevant for this endpoint	0.167
Vinyl Chloride	75014	Emission not relevant for this endpoint	0.733

** USEPA data lists URE values for eight different classes of this substance, with PP-CFs from 1.3 to 13,000. This is the median value of these substances.*

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[80] RfCs are from the IRIS database and the Agency for Toxic Substances and Disease Registry.

[81] URE values from IRIS, the California Office of Environmental Health Hazard Assessment, and USEPA Office of Air Quality Planning and Standards.

PP-CFs are used to analyze results for the two indicators, with results listed separately, by key unit process. Results for key unit processes are only included if the process is in a region with unsafe concentrations. As a default, it shall be assumed that processes are located in regions with unsafe concentrations of HAACs, and shall be included in this impact category.

If there are key unit processes located in regions outside of the US, local ambient monitoring data shall be used to determine if additional HAACs not included in Table 17 are present at unsafe levels. If so, PP-CFs shall be evaluated for these HAACs using an approach identical to the process used to establish PP-CFs in Table 17, and they shall be included in the result.

There is not sufficient data at this time to establish M-CFs which characterize the geographically varying risk and population effects of HAAC exposure, and it is inappropriate to aggregate emissions at each key unit process based only on PP-CFs when impact levels vary dramatically for different regions. When reporting results, all key unit processes shall be reported separately without aggregation.

> ***FOR EXAMPLE.*** A mill produces recycled paper in Wisconsin; all key unit processes are located in the US. Results are reported as in Table 18.

Table 18. Results, by key unit process, for two category indicators for Ambient Emission Inhalation Impacts: Respiratory Effects and Carcinogens.

Key Unit Process	**Respiratory Effects**	**Carcinogens**
Recycled Paper	**g acrolein eq.**	**g chromium VI eq.**
Other Unit Processes	1,367	220
Ancillary Materials	0-650	191
Natural gas production (for consumption at papermaking mill)	0-650	43
Wastepaper Sourcing	0-650	145
Electricity generation (for consumption at pulp mill)	0-650	293
Electricity generation (for consumption at papermaking mill)	761	474
Papermaking mill	11,114	519

The result for Ambient Emission Inhalation Impact for a key unit process, in grams of reference contaminant equivalent (see Table 17), is calculated according to the Equation 30, for a given year in the timeframe of analysis.

Equation 30. Result for Ambient Emission Inhalation Impacts for a given unit process in a given year.

$$\text{Ambient Emission Inhalation Impacts (grams reference contaminant) in a given year} = \sum_j \text{HAAC Emitted}_j \times \text{PP-CF}_j$$

Where:

- *HAAC emitted include those emissions linked to production of the unit of analysis*
- j represents the total number of HAACs emitted which are considered in the same category indicator
- PP-CF is the inhalation toxicity of each chemical relative to a reference chemical, based on the RfC of the reference chemical (see Table 17).

5.6.4 Indoor Emission Impacts

The only impacts relevant to this industry sector include occupational exposure and, potentially, exposure to certain classes of products in use.[82] However, methods do not exist to determine relevance for a given product system, nor to characterize results. As research becomes available, this impact category may be included in future versions of this PCR.

5.6.5 Ingestion Impacts

This impact category considers releases of hazardous food or water contaminants that can result in risks of human exposure through ingestion. The potential routes of human exposure by ingestion usually include the contamination of drinking water or food supply (e.g., agricultural products, fish).

Generally, two distinct impacts can be associated with production of roundwood and pulp/paper: mercury emissions and dioxin emissions. Both emitted chemicals have different levels of persistence, mobility, and toxicity, and are treated separately.

Although this route of exposure and set of subsequent health impacts are distinct, the same category indicators are used to evaluate results as for Freshwater Ecotoxicity Impacts, for both impacts. See Section 5.4.3.

> ***NOTE*.** This means that in LCA results, one number is reported, which is described as affecting multiple impacts.

5.6.6 Dermal Exposure to Toxic Herbicides

In the production of roundwood, herbicides may be applied during forest management. These herbicides are generally not applied in sufficient volumes to contaminate local receiving environments, but can pose a risk of exposure to workers applying the chemicals. Herbicides are usually used in even-aged forest management to suppress undesirable species after clear cuts to optimize the regeneration of desired tree species, and at roadsides to control weed growth as part of regular maintenance. These chemicals can cause toxic effects if humans are exposed at levels exceeding safe thresholds. This impact category addresses the risk of exposure to humans caused by the use of these herbicides during forestry.

Three human health endpoints can occur following exposure to the most commonly used herbicides in forestry:

1. Acute toxic effects,
2. Carcinogenic effects, and
3. Endocrine disruption.

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[82] Walser and et al., 2013, Indoor Exposure to Toluene from Printed Matter Matters: Complementary Views from Life Cycle Assessment and Risk.

As a default, three category indicators are characterized, characterizing each of these toxic effects. The PP-CFs for some of the most commonly applied herbicides in forestry, by category indicator for this impact category, are shown in Table 19.

Table 19. The PP-CFs, by category indicator, for the impact category of Dermal Exposure to Toxic Herbicides.

Herbicide	**Acute Toxicity[83] PP-CF Values** *(kg 2,4-D eq. / kg applied)*	**Carcinogenicity[84] PP-CF Values** *(kg carcinogen)*	**Endocrine Disruption[85] PP-CF Values** *(kg endocrine disruptors)*
2,4-D	1.000	1	1
Glyphosate	0.100	Not classified	Not classified
Hexazinone	0.303	Not classified	Not classified
Imazapyr	0.004	Not classified	Not classified
Metsulfuron Methyl	0.040	Not classified	Not classified
Picloram	0.143	Not classified	1
Sulfometuron methyl	Not established*	Not classified	Not classified
Triclopyr	0.200	Not classified	Not classified

**RfD values for sulfometuron methyl have not been established. However, this herbicide is only slightly acutely toxic, according to USEPA, and is applied in very low volumes in forestry applications. This herbicide is not included in final results; however, its omission will have an effect on results which is not measurable, considering other sources of uncertainty.*

By default, it shall be assumed that these herbicides are used in forestry in conjunction across the entire area of any clear cuts that can occur each year. The ground application rates in Table 20 shall be used as a default. The amount of herbicides used is the inventory result for this indicator.

Table 20. Commonly used herbicides in forestry, and recommended ground application rate of active ingredient (a.i.). *Source: Bugwood.org.*[86]

Herbicide (active ingredient)	**Trade Names**	**Upper Bound of Recommended Ground Application Rate** ***(kg a.i. / acre)***
2,4-D	Tordon 101	4.2
Glyphosate	Rodeo, Accord	4.6
Hexazinone	Velpar	1.2
Imazapyr	Chopper	0.7
Metsulfuron Methyl	Escort	0.1
Sulfometuron methyl	Oust XP	0.12
Picloram	Tordon 101	0.2
Triclopyr	Garlon	4.0

These indicators can be excluded from LCA results if it can be shown that these herbicides are not being used on the site.

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[83] The PP-CF characterizes the relative toxicity of each applied herbicide compared to the toxicity of 2,4-D, using PP-CFs which are the ratio of the RfD of 2,4-D to the RfD of the applied herbicide.

[84] Only one of the most commonly used herbicides is a possible carcinogen: 2,4-D. There is no need to establish relative toxicity values, and this indicator characterizes the amount of the carcinogenic herbicide 2,4-D which is applied.

[85] Of the herbicides used most commonly in forestry, 2,4-D and picloram are potential endocrine disruptors. There is no data available to establish equivalencies in relation to this human health endpoint and the PP-CF characterizes the mass of endocrine disruptors which are applied.

[86] Moorhead, David J. *Forest Herbicides.* http://www.bugwood.org/2014ForestHerbicides.pdf

The result for Dermal Exposure to Toxic Herbicides, in kilograms of chemical (using equivalencies from Table 19), is calculated according to the equation below, for a given year in the timeframe of analysis.

Equation 31. Result for Dermal Exposures to Toxic Herbicides for a given year.

Dermal Exposure to Toxic Herbicides (kilograms of chemical) in a given year =

$$\sum_i \sum_j \text{Herbicide Applications}_j \text{ x } \text{PP-CF}_j)_i$$

Where:

- *Herbicide applications emitted include those applications linked to production of the unit of analysis*
- *i is the total number of unit processes in the scope*
- *j represents the total number of herbicides which are considered in the same category indicator*
- *PP-CF values are from Table 19.*