Life Cycle Impact Assessment Methodology for Environmental Paper Network Paper Calculator v4.0

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Terminology Used in this Report

Term	Definition
Background Unit Processes (or Background System)	Unit processes not specific to the product system under study, including those processes upstream and/or downstream where many suppliers are involved.
Biotic Resource	A resource derived 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, and is the second most important forcing agent after carbon dioxide.
Black Liquor	A by-product of wood pulping, which can be combusted to generate electricity in integrated virgin pulp and paper mills.
Category Indicator	Quantifiable representation of an impact category [Ref. ISO-14044] (Also referred to as "Impact Category Indicator," or simply, "Indicator.")
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.
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.
Data Quality	Characteristics of data that relate to their ability to satisfy stated requirements *[Ref: ISO 14044].*
Disturbance	Average deviation in overall ecological conditions in a terrestrial ecoregion biome, 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 biome ecoregion type.
Effect	See Impact
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 ISO 14044]*
Exceedance of Threshold	For a given impact category, represents the surpassing of a threshold (defined below).
Fiber Basket	Region supplying pulpwood to each dissolving pulp mill.
Foregone Growth	The forest growth avoided as a result of ongoing harvests. In terms of carbon or forest condition, this is the "opportunity cost" associated with ongoing harvests.
Forest Analysis Unit	An area of timberland used to represent forest ecosystem impacts resulting from forestry operations within a region.
Forest Inventory	An accounting of trees and their related characteristics of interest over a well-defined land area.
Forest Type	A classification of forest land based on the species that form a plurality of live-tree basal-area stocking. [1]
Forestland	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. [2]
Freshwater Ecosystem	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.
Functional Unit	Quantified performance of a product system for use as a reference unit. *[Ref. ISO 14044].*
Impact	An effect on human health or the environment.

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

Term	**Definition**
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.
Impact Profile	See LCIA Profile. *(Also referred to as "profile" or "eco-profile.")*
Indicator	See Category Indicator.
Input	Product, material or energy flow that enters a unit process. *[Ref. ISO 14044].*
Key Unit Process or Key Unit Operation	A unit process (or unit operation) contributing over 10% to any indicator result.
LCIA Profile	A discrete compilation of the LCIA category indicator results for different impact categories. *[Ref: ISO 14044, §4.4.2.5]*
Life Cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from providing environment to final disposal.
Life Cycle Assessment (LCA)	Compilation and evaluation of the inputs, outputs and the environmental and human health impacts of a product system throughout its life cycle. *[Based on ISO 14044]*
Life Cycle Impact Assessment (LCIA)	Phase of life cycle assessment aimed at determining the magnitude and significance of the environmental and human health impacts for a product system throughout the life cycle of the product. *[Based on ISO 14044]*
Life Cycle Interpretation	Phase of life cycle assessment in which findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations. *[Ref: ISO 14044]*
Life Cycle Inventory (LCI)	Phase of a life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle. *[Ref: ISO 14044]*
Midpoint Characterization Factor (M-CF)	A factor which characterizes the actual effect on the receiving environment of emissions, resource uses, or land uses. Multiplied with Potency Potential Characterization Factors (PP-CFs) to calculate results.
Midpoint	A distinct node in a stressor-effects network representing an observed chemical, physical, radiological or biological impact that is linked to the final category endpoint(s).
Node	The modeled representation of an observed chemical, physical, radiological, or biological impact within a distinct stressor-effects network.
Organic Carbon	The scattering component of carbonaceous aerosols, these emissions lead to a modest cooling effect globally due to their negative radiative forcing.
Output	Product, material or energy flow that leaves a unit process. *[Ref. ISO 14044].*
Potency Potential Characterization Factor (PP-CF)	A factor which characterizes the relative potency of emissions, resource uses, or land uses, in causing impacts. Multiplied with Midpoint Characterization Factors (M-CFs) to calculate results.
Product	Any good or service. *[Ref: ISO 14025]*.
Product System	Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product. *[Ref. ISO 14044]*
Woody Inputs	Includes roundwood, chips, and other mill residues used as inputs to produce pulp in pulping mills.
Radiative Forcing	Expresses the change in energy in the atmosphere due to GHG emissions. It is expressed in watts per square meter (W/m^2) or the rate of energy change per unit area of the globe measured at the top of the atmosphere.
Receiving Environment	The environment affected by stressor(s) including emissions, land use, or wastes.
Resource Depletion	The degree to which the net consumption of a resource results in a reduction in its reserve base, taking into account the extent of reserve base and projected consumption.
Roundwood	A length of cut tree generally having a round cross-section, such as a log or bolt.[3]

[3] 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. p.33

Term	Definition
Sensitivity Analysis	Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study. *[Ref. ISO-14044]*
Stressor	Any life cycle inventory input, output, or other activity associated with a unit process that can be linked to observable midpoints and endpoints in a defined environmental mechanism.
Stressor-Effects Network	A model used to represent an environmental mechanism, beginning with stressor(s) associated with a given unit process, which lead to midpoint(s) and eventually category endpoint(s) within an impact category. *(Also referred to as "Cause-Effect Chain")*
System	See product system.
Terrestrial Ecoregion/ Forest Ecoregion	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.
Threshold	A recognized environmental condition that, when exceeded, is linked to nonlinear changes in 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).[4]
Time Horizon	A specified timeframe.
Ton	Metric ton (1,000 kilograms or 2,200 pounds).
Ton-kilometer	Unit of transport, representing one metric ton transported one kilometer
Undisturbed Reference Area	Area of forest/other wooded land against which measurements of ecological conditions in a Forest Analysis Unit (FAU) are compared. The Undisturbed Reference Area is 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 should: • Include an area which has not been subject to significant human interventions (i.e., logging, intensive hunting, non-timber extraction, agriculture, mining, or other activities) for the longest time possible, which is not less than 80 years. • 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. • Be located as close as possible to the Forest Analysis Unit against which it is compared, and never farther away than 800 kilometers. • Include the largest possible contiguous area in the region satisfying these requirements, which is no less than 5,000 hectares.
Unit Process	Smallest element considered in the life cycle assessment for which input and output data are quantified *[Ref: ISO 14044].*
Watershed or Hydro-basin	The area of land where all of the water that falls in it and drains off of it goes into the same place.[5]
Wetland Ecosystem	A biotic community in a specific wetland, defined by: 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.

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

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

Acronyms

BOD	Biochemical Oxygen Demand
C	Carbon
CA	Canada
CF	Characterization Factor
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
Eq.	Equivalent
FAU	Forest Analysis Unit
ft^2	Square Feet
GHG	Greenhouse Gas
GLO	Ground Level Ozone
GWP	Global Warming Potential
H_2CO_3	Carbonic Acid
HAP	Hazardous Air Pollutant
HYSPLIT	Hybrid Single Particle Lagrangian Integrated Trajectory
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
kW	Kilowatt
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
m	Meters
m^2	Square Meter
m^3	Cubic Meter
M-CF	Midpoint Characterization Factor
MJ	Megajoule
MMBtu	Million British thermal units
MSW	Municipal Solid Waste
MWh	Megawatt-hours
N_2O	Nitrous Oxide
NOx	Nitrogen Oxides
NPRI	National Pollutant Release Inventory
O_3	Ozone
PCR	Product Category Rule
PM	Particulate Matter
PM2.5	Particulate Matter 2.5
ppb	Parts Per Billion

PP-CF	Potency Potential Characterization Factor
RF	Radiative Forcing
RoW	Rest of the World/Global
SO_2	Sulfur Dioxide
TRI	Toxic Release Inventory
TRS	Total Reduced Sulfur
TSS	Total Suspended Solids
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
URA	Undisturbed Reference Area
US	United States
VOC	Volatile Organic Compound
WHO	World Health Organization
yr	Year

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1 Introduction

The Paper Calculator, originally launched in 2005 by the Environmental Defense Fund (EDF), is an innovative web-based tool that is publicly available and allows users to compare the environmental impacts of different paper choices using a methodology based in life cycle assessment (LCA). LCA is a tool that can be used to assess the environmental impacts associated with the life cycle of paper, from raw material extraction and processing to end-of-life phase. LCA provides a unique, quantified approach for comparing the environmental performance of different sources of fiber.

The Environmental Defense Fund owned and operated the Paper Calculator from 2005 until 2011, at which time it was transferred to the ownership and management of the Environmental Paper Network. The Paper Calculator has been updated regularly over its lifetime, including significant modernizations completed in 2009 and 2011, and routine updates completed on an annual or biennial basis.

In 2017, SCS Global Services (SCS) was commissioned by the Environmental Paper Network (EPN) to undertake a major modernization to the Paper Calculator tool. This document outlines the methodology used for updating the Paper Calculator to Version 4.0. An LCA was conducted to evaluate the life cycle impact profile of 14 different paper grades, using a methodology conforming to ISO 14044,[6] the draft LEO-S-002 standard,[7] the Product Category Rule (PCR) for Pulp and Paper (hereafter referred to as Pulp/Paper PCR)[8], the Product Category Rule (PCR) Module for Roundwood (hereafter referred to as Roundwood PCR)[9] and the LCIA Methodology for Roundwood and Pulp/Paper PCR Modules (hereafter referred to as the LCIA Methodology for PCR Modules)[10]. The requirements of the draft LEO-S-002 standard ensure that LCA results are as complete, environmentally relevant, and accurate as possible.

2 Goal and Scope of the Study

The intended use of this LCA is to update the Paper Calculator tool, by quantitatively evaluating the environmental performance of fourteen different paper grades, based on the methodology published in the Pulp/Paper PCR, the Roundwood PCR and the LCIA Methodology for PCR Modules. The intended audience of this Paper Calculator are procurement officials at different institutions, retail distributors, consumers, sustainability managers at companies, LCA practitioners, and other stakeholders interested in the environmental performance of different paper grades.

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[6] ISO 14044:2006 Environmental management – Life Cycle Assessment – Requirements and guidelines
[7] LEO-SCS-002 Standard Draft Dated June 2014. Leonardo Academy.
http://www.leonardoacademy.org/programs/standards/life-cycle.html
[8] PCR Module for Pulp and Paper;
https://www.scsglobalservices.com/files/program_documents/pcr_final_pulp_paper_101816.pdf
[9] PCR Module for Roundwood Production:
https://www.scsglobalservices.com/files/resources/pcr_final_wood-products_101816.pdf
[10] Life Cycle Impact Assessment Methodology for PCR Modules for Roundwood and Pulp/Paper;
https://www.scsglobalservices.com/files/program_documents/pcr_final_lcia-methodology_101816.pdf

The scope of this LCA is cradle-to-grave, for each type of paper based on the user-specified recycled content, excluding the printing and use phase of papers (this is consistent with previous versions of the Paper Calculator). The technological scope includes 14 different paper grades listed in Table 1. The geographical scope includes production of 14 different paper grades in North America (USA and Canada). The life cycle impacts of 14 paper grades are assessed from the extraction and processing of all raw materials through the disposal of paper (end-of-life). The pulp and paper mills included for each paper grade were identified based on data from Resource Information System, Inc (RISI).These mills were selected based on location, capacity and grade of paper products produced, and factoring in the representativeness of the mills to present North American average results for all indicators in the Paper Calculator. The temporal scope includes production of paper in 2016. The latest available data were used in all cases (see Section 3.4 for summary of data sources).

Table 1. Types of paper grades included in the scope of the Paper Calculator v4.0 and the number of mills included in this assessment to present North American average results.

Type of Paper Grade	Number of mills included in the assessment
1. Coated Freesheet	9
2. Uncoated Freesheet	41
3. Coated Groundwood	10
4. Uncoated Groundwood	13
5. Supercalendered	10
6. Paperboard: Solid Bleached Sulfate	13
7. Paperboard: Coated Unbleached Kraft	3
8. Paperboard: Coated Recycled Board	16
9. Paperboard: Uncoated Bleached Kraft	1
10. Paperboard: Uncoated Unbleached Kraft	3
11. Paperboard: Uncoated Recycled Board	48
12. Linerboard	37
13. Corrugated product*	33
14. Tissue (included in the Paper Calculator: paper towels, napkins, bathroom tissue and facial tissue)	47

**Corrugated product is a mix of linerboard (70.1%) and corrugating medium (29.9%).*

The Paper Calculator v4.0 currently functions to present results for the following indicators (see table below).

Table 2. List of indicators presented as outputs in the Paper Calculator v4.0.

Paper Calculator v4.0 Outputs		
Impact Name	**Description**	**Unit of Measurement**
Wood Use	Wood use measures the amount of wood required to produce a given amount of paper.	Fresh/green tons
Total Energy	The total energy required over the paper's life cycle, including all renewable and nonrenewable resource use, including black liquor and all wood sources.	BTUs
Greenhouse Gases/Climate Change Impacts	Greenhouse gases (includes carbon dioxide or CO_2 from burning fossil fuels and methane from paper decomposing in landfills) and short-lived climate pollutants (includes black carbon and organic carbon) which contribute to climate change by trapping energy from the sun in the earth's atmosphere. This impact category also includes forest carbon storage loss from logged forests.	pounds CO_2 equiv.
Water Consumption	Water consumption measures the amount of process and cooling water that is consumed or degraded throughout the life cycle of the paper product.	gallons
Solid Waste	Solid waste includes sludge and other wastes generated during pulp and paper manufacturing, and used paper disposed of in landfills and incinerators.	pounds
Nitrogen Oxides (NOx) forming ground level ozone/Ground Level Ozone	Nitrogen oxides (NOx, which includes NO and NO2) are products of the combustion of fuels that contain nitrogen. NOx can react with volatile organic compounds and sunlight in the lower atmosphere to form ozone, a key component of urban smog. NOx forms ozone and can also, in parallel, lead to acid rain.	persons*hrs.*pounds O_3 eq/m^3
Purchased Energy	A subset of total energy, purchased energy measures how much energy comes from purchased electricity and other fuels.	million BTUs
Particulates/PM2.5 Impacts	Particulates are small particles generated during combustion, and pose a range of health risks, including asthma and other respiratory problems, when inhaled. This impact category considers the effect of particulate matter (PM) emissions from pulp/paper production, contributing to smog.	persons*hrs.*pounds PM2.5 eq/m^3
Sulfur Dioxide (SO2) and other acidifying emissions/Regional Acidification	Acidifying emissions are chemical compounds such as sulfur dioxide, nitrogen oxides, and other acids (e.g. ammonia) that are produced when boilers burn fuel containing sulfur and other acid-producing substances. Of the fuels used in the paper industry, oil and coal generally contain the highest quantities of sulfur. These acidifying emissions contribute to air pollution problems like acid rain and smog. This category includes SO2 emissions, but also other acids and emissions like NOx.	pounds SO_2 eq
Volatile Organic Compounds (VOCs)	Volatile organic compounds (VOCs) are a broad class of organic gases, such as vapors from solvent and gasoline. VOCs react with nitrogen oxides (NOx) in the atmosphere to form ground-level ozone, the major component of smog and a severe lung irritant.	pounds

Paper Calculator v4.0 Outputs		
Impact Name	**Description**	**Unit of Measurement**
Total Reduced Sulfur (TRS)	Total reduced sulfur (TRS) compounds cause the odor associated with kraft pulp mills. Exposure to TRS emissions has been linked to symptoms including headaches, watery eyes, nasal problems, and breathing difficulties.	pounds
Hazardous Air Pollutants (HAPs)	Hazardous air pollutants (HAPs) include any of a group of 188 substances identified in the 1990 U.S. Clean Air Act amendments because of their toxicity. Two of the most common occurring in air are formaldehyde and acrolein.	pounds
Chemical Oxygen Demand (COD)	Chemical oxygen demand (COD) measures the amount of oxidizable organic matter in the mill's effluent. Since wastewater treatment removes most of the organic material that would be degraded naturally in the receiving waters, the COD of the final effluent provides information about the quantity of more persistent substances discharged into the receiving water.	pounds
Biochemical Oxygen Demand (BOD)	Biochemical oxygen demand (BOD) measures the amount of oxygen that microorganisms consume to degrade the organic material in the wastewater. Discharging wastewater with high levels of BOD can result in oxygen depletion in the receiving waters, which can adversely affect fish and other organisms.	pounds
Total Suspended Solids (TSS) / Freshwater Eutrophication	Total suspended solids (TSS) measure solid material suspended in mill effluent, which can adversely affect bottom-living organisms upon settling in receiving waters and can carry toxic heavy metals and organic compounds into the environment.	pounds
Forest Disturbance	Forest disturbance measures the degree to which activities affect forest ecosystems and biodiversity. The indicator compares the ecosystem integrity of a harvested site to intact forests over 80 years old in the region, using on-the-ground measurements. It also considers the recovery potential which would be possible on the site if harvesting were halted, reflecting the long-term implication of forest management at suppressing ecosystem integrity.	acres of disturbed area
Freshwater Disturbance	Freshwater disturbance measures the number of freshwater systems possibly affected by logging. Logging can impact streams, rivers and creeks by increasing erosion, removing riverside vegetation and removing large woody debris that many fish species require for habitat. Although this impact is important and relevant, no data is currently available to calculate results. Reflecting the critical nature of this impact category, it is reported here as relevant to pulp/paper production, although results cannot be evaluated at this time.	Not Available
Threatened Species	Threatened species measures the possible number of species affected by logging for paper production in the North American region that are listed as Critically Endangered, Endangered, or Vulnerable in the IUCN Red	# of species

Paper Calculator v4.0 Outputs Impact Name	Description	Unit of Measurement
	List of Threatened Species, though the exact impact will vary by forest of origin. The number of species is based on correlation with logging threats assessed by IUCN and the fiber basket of pulp and paper mills in the region.	
Ocean Acidification	Ocean acidification measures increased ocean acidity caused by CO_2, which has detrimental consequences for many marine organisms. This indicator considers CO_2 emitted during the production of pulp and paper, but also evaluates the amount of CO_2 which could be sequestered in trees if forest harvests used for papermaking were halted.	pounds H_2CO_3
Mercury Emissions	Mercury is a very toxic substance which persists in the environment for very long periods of time. Emissions can therefore lead to contamination in the environment, including freshwater bodies and oceanic systems, subsequently exposing flora and fauna to elevated concentrations. This result considers the amount of mercury during the production of pulp and paper.	milligrams
Dioxin Emissions	Dioxin emissions measures the amount of toxic dioxin emissions that are released to air and water from pulp and paper mills. Dioxins are persistent and bioaccumulative, and even small amounts of emission can contaminate local waterways and bioaccumulate in fish.	micrograms
Herbicides	Herbicides measures the amount of toxic herbicides used in growing trees for paper production. Herbicides are applied to control the spread of non-desirable species. Although this impact is important and relevant, no data is currently available to calculate results. Reflecting the critical nature of this impact category, it is reported as relevant to pulp/paper production, although results cannot be evaluated at this time.	Not Available
Ocean Warming	Ocean warming measures increased ocean temperatures linked to emissions of greenhouse gases. Although this impact is important and relevant to emissions and foregone growth from logging, no algorithm is currently available to calculate results. Reflecting the critical nature of this impact category, it is reported as relevant to pulp/paper production, although results cannot be evaluated at this time.	Not Available
Wetland Disturbance	Wetland disturbance measures the acreage of wetlands possibly affected by logging. Logging can increase erosion, which will cause changes in the sediment, temperature and other characteristics of wetlands. Although this impact is important and relevant, no data is currently available to calculate results. Reflecting the critical nature of this impact category, it is reported as relevant to pulp/paper production, although results cannot be evaluated at this time.	Not Available

2.1 Key Limitations and Assumptions

2.1.1 Assumptions

Assumptions were made as a result of data limitations or for other reasons. These assumptions are important to understand, as some result in study limitations (discussed in Section 3.1.2). The assumptions with the most important effects on final results are as follows:

- The recycled content approach (also known as 100-0 cut off approach) is used to model impacts for recycled papers, whereby the impacts from the prior and subsequent life cycles are not included (see Section 3.3.2 for more detail).
- For 100% recycled paper, the recycling of waste paper into recycled pulp does not provide any credit associated with the avoidance of landfill impacts. However, the landfill avoidance credit is reported in a sensitivity analysis in Section 3.7 of this document.
- For the end-of-life phase, recycling rates for different paper grades are determined based on the 2014 US EPA Municipal Solid Waste (MSW) reports. Based on information from the MSW report, 80% of the materials not recycled are assumed to go to a municipal landfill and the remaining 20% are assumed to be incinerated.

2.1.2 Limitations

There are some key study limitations, resulting from limitations in the methodology used and data gaps, as well as assumptions made. The main limitations in the study are as follows:

- **Lack of data to calculate Ocean Warming and Herbicide indicator**. This indicator is relevant to the product system considered in this study. Impacts from herbicides associated with forest management are highly site variable. Consistent data on emissions and/or algorithms for assessment of impacts were not available to assess impacts from all mills. These impacts are all relevant to paper production and of major importance, but results could not be assessed.

- **Lack of data to calculate Freshwater and Wetland disturbance.** The freshwater and wetland disturbance conditions and trend could not be determined for all the paper grades due to lack of data. Nor could the specific affected watersheds and wetlands be determined, as there was no data of comparable quality across the paper grades which could be suitably used.

- **Lack of geographic representativeness for some paper grades for BOD, COD, TSS and solid waste indicators:** The Ecoinvent and USLCI databases are the main sources for secondary LCI data. USLCI data was used in most cases to estimate the amount of BOD, COD, TSS and solid waste emitted at the pulp and paper mills. However, USLCI data was only available for 5 virgin paper grades. Thus, Ecoinvent data was used to estimate these indicators for other paper grades. Although preference was given to ecoinvent datasets of Canadian origin to represent North American production data for these indicators, it should be noted that most, though not all, of the data within ecoinvent is of European origin and produced to represent European industrial conditions and processes. The datasets that were the most representative of the products and contexts being examined were selected.

- **Use of different mills for a given paper grade could influence results.** The pulp and paper mills producing 14 different paper grades were identified carefully, based on characteristics including location of the mill and production capacities provided in the RISI database. The results presented herein represent a national average for North America. It should be recognized that the use of mills located in different regions for a given paper grade could influence the Paper Calculator results.

- **Lack of geographic representativeness for modeling some background processes:** For some unit processes, Ecoinvent datasets may have limitations in terms of geographical representativeness. These datasets include: sulfuric acid production; soda ash production; hydrogen peroxide production, sodium sulfate production; starch production; coating and filler production; waste treatment processes at pulp and paper mills.

3 Methodology

The sections below describe the key points of the LCA methodology used to generate the Paper Calculator results. This LCA conforms to ISO 14044 and the draft LEO-S-002 standard,[11] the Pulp/Paper PCR[12], the Roundwood PCR[13] and the LCIA Methodology for PCR Modules[14].

3.1 Functional Unit

The functional unit is the quantitative reference point of an LCA, which serves the purpose of providing a common basis for calculating all the environmental impacts. All the environmental impacts occurring across the life cycle of a product are analyzed and quantified in relation to the function of the product. The paper grades defined in the Paper Calculator can be used in multiple applications (e.g. books, magazines, newspapers, posters, etc.). Due to its potential use in various applications, a specific functional unit cannot be clearly defined. Hence, a declared unit is used, in lieu of a functional unit in

[11] LEO-SCS-002 Standard Draft Dated June 2014. Leonardo Academy. http://www.leonardoacademy.org/programs/standards/life-cycle.html
[12] PCR Module for Pulp and Paper; https://www.scsglobalservices.com/files/program_documents/pcr_final_pulp_paper_101816.pdf
[13] PCR Module for Roundwood Production: https://www.scsglobalservices.com/files/resources/pcr_final_wood-products_101816.pdf
[14] Life Cycle Impact Assessment Methodology for PCR Modules for Roundwood and Pulp/Paper; https://www.scsglobalservices.com/files/program_documents/pcr_final_lcia-methodology_101816.pdf

this study. The declared unit clearly defines, quantitatively and qualitatively, the reference flow in the study.[15]

The declared unit of 1 metric ton of paper produced is used as the basis of evaluation of all the environmental indicators reported in the Paper Calculator. In case of tissue paper grade, there are four types of tissue products (paper towels, napkins, bathroom tissue and facial tissue) and these products are typically sold on an area basis (e.g. total square feet of bathroom tissue per roll). The results for tissue products are presented in the Paper Calculator v4.0 relative to the total area of product purchased. Average grammage values for tissue products[16] were applied to convert the indicator results from mass basis to an area basis (see Table 3 below). See Section 3.2.2 for more detail on user inputs for tissue paper products.

Table 3. Default grammage values by tissue paper grade.

Tissue Paper Grade	Average Grammage of tissue product	
	grams/ft^2	grams/inch^2
Paper towel	3.80	0.026
Paper napkins	2.85	0.020
Bathroom tissue	2.28	0.016
Facial tissue	2.47	0.017

3.2 System Boundary

A system boundary identifies the life cycle stages, processes and flows considered in the LCA. The system boundary modeled for the Paper Calculator is cradle-to-grave for each type of paper based on the user-specified recycled content, excluding the use phase of papers. The life cycle impacts of 14 North American paper grades are assessed from the extraction and processing of all raw materials through the disposal of paper (end-of-life). The 14 paper grades reported in the Paper Calculator are listed in Table 1.

Two versions were modeled for each paper grade, based on two types of fiber input:

(1) 100% Virgin Papers: Papers produced from 100% virgin fiber inputs including woody inputs such as hardwood/softwood chips and hardwood/softwood roundwood.

The system boundary diagram presented in Figure 1 illustrates the key inputs, outputs and processing steps which were included for 100% virgin paper grades. It includes all relevant impacts involved in

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[15] International Life Cycle Database Handbook: General Guide for Life Cycle Assessment – Detailed Guidance. Section 6.4.6. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC48157/ilcd_handbook-general_guide_for_lca-detailed_guidance_12march2010_isbn_fin.pdf
[16] Values in Table 3 are calculated based on Table 2.1.1 of the Green Seal Checklist. http://www.greenseal.org/Portals/0/Documents/Certification/Checklists%20(2013)/CCLGS1(2013).doc

wood extraction, production of chemical and energy inputs, pulp/paper production and paper disposal (end-of-life management) for 14 paper grades produced in North America (USA and Canada).

(2)100% Recycled Papers: Papers produced from 100% recycled fiber inputs including recovered paper or recovered paperboard inputs. The system boundary diagram presented in Figure 2 illustrates the key inputs, outputs and processing steps for 100% recycled paper grades. It includes all relevant impacts involved in waste paper collection and processing, production of chemical and energy inputs, pulp/paper production and paper disposal (end-of-life management) for 14 paper grades produced in North America (USA and Canada).

It is to be noted that the recycled content approach (also known as 100-0 cut off approach) is used to model impacts for recycled papers, whereby the impacts from the prior and subsequent life cycles are not included (see Section 3.3.2 for more detail). Due to the incorporation of only recovered paper inputs, impacts to terrestrial and freshwater ecosystems from land use and conversion are not relevant for these products. See Section 3.6.5 for more details.

3.2.1 Designating Recycled Content in Paper:

If the user designates a level of recovered fiber (recycled) content for a selected paper type, based on the amount designated, the Paper Calculator allocates the environmental burdens accordingly between virgin and recycled paper production. For example, if the recycled content of 1 metric ton of coated freesheet paper grade designated by a user is 30%, the Paper Calculator will allocate the environmental burden for this product in the following manner:

1 metric ton of coated freesheet paper (with 30% recycled content)= 700 kg of 100% virgin coated freesheet paper+300 kg of 100% recycled coated freesheet paper.

3.2.2 User Inputs for Tissue Paper Grade:

For the tissue paper grade, the user is presented with an option to select the type of tissue product among the following: (1) Paper towels; (2) Napkins; (3) Bathroom tissue; and (4) Facial tissue. Once the user selects the tissue product type, the user enters the following details:

-User enters the size of each sheet

-User enters the total number of sheets

-User is provided with an option of changing the default grammage values (see Table 3).

Based on the inputs entered, the Paper Calculator will compute the results for tissue products relative to the total area of the product purchased.

A description of the data requirements, LCI analysis, and LCIA, are provided in Sections 3.4, 3.5, and 3.6, including the most important data sources used to evaluate all the indicators presented in the Paper Calculator.

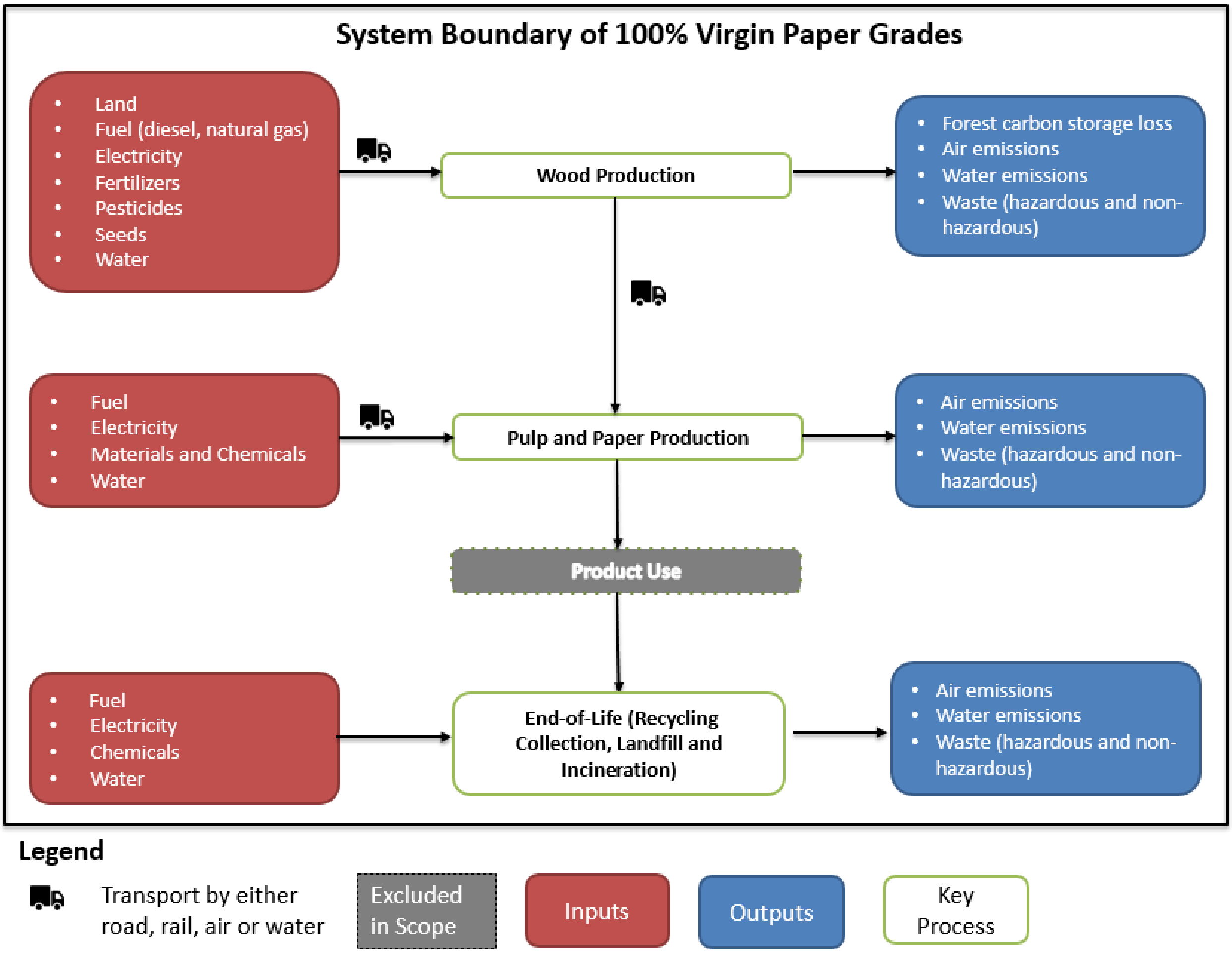

Figure 1. The system boundary depicts the key inputs, outputs and key processing steps associated with 100% virgin paper grades production from cradle-to-grave.

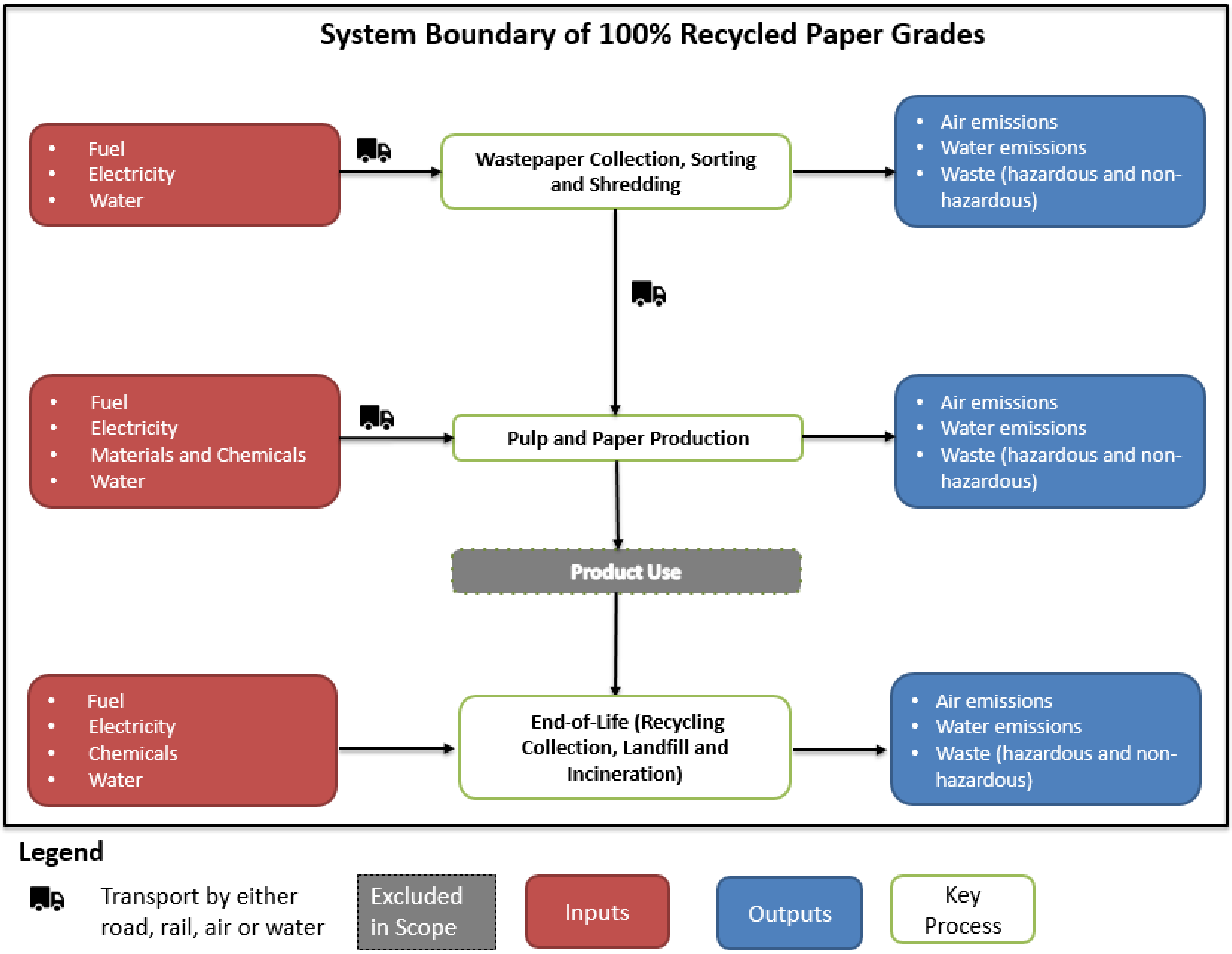

Figure 2. The system boundary depicts the key inputs, outputs and key processing steps associated with 100% recycled paper grades production from cradle-to-grave.

3.3 Allocation Procedures

Allocation is required when a single product system produces more than one good/product. In LCA, allocation addresses the problem of how to divide resource use, energy use and emissions between multiple products produced at the same production facility. Allocation guidelines in ISO 14044 state that wherever possible, the use of allocation should be minimized. However, if allocation is required, ISO 14044 states that mass-based allocation should be used preferentially over economic allocation, and for this reason, a mass-based allocation approach was used where necessary. Mass-based allocation takes a physical approach by partitioning inputs and outputs in the product system, based on relative mass of products and co-products generated.

3.3.1 Allocation Method to Determine Energy and Resource Inputs for All Papers

A mass-based allocation method was applied for each of the 14 paper grades to determine the amount of energy and resource inputs relative to 1 metric ton of paper produced. Energy and resource use (e.g.woody inputs, coatings, fillers, starch) at the pulp/paper mills were allocated to the product system based on the total mass of paper grades produced annually at the mill. The RISI Mill-Asset database was used to retrieve this information. Refer to Section 3.4.1 for more detail.

3.3.2 Allocation Method for Recycled Fiber Inputs in Recycled Papers

The most common approach for calculating the impacts of recycled paper is called the *100-0 cut-off approach*, which considers the environmental impacts of only one life cycle of the product (i.e., each product should only be assigned impacts directly caused by that product). In the 100-0 cut-off approach (also known as recycled content method), recovered fiber is not allocated any of the environmental impacts associated with the original fiber source or processing; instead, the impact associated with the paper recycling process (waste paper reprocessing into recycled pulp) is only accounted for on the input side, depending on the recycled content of the paper. At the disposal (end-of-life) phase, the transport to the recycling facility is the only process considered when materials are sent for recycling collection. There is no credit attributed to the recycling processes at the end-of life for displacing virgin fiber inputs in the next life cycle. The impacts of the recycling process will be allocated to the next life cycle using the recycled materials.

The recycling of waste paper into recycled pulp does not provide any credit associated with the avoidance of landfill impacts. However, the landfill avoidance credit is reported in a sensitivity analysis in Section 3.7 of this document.

3.4 Data Requirements

Representative pulp and paper mills were identified across North America (USA and Canada) for each of the 14 paper grades based on mill-level data purchased from Resource Information System, Inc (RISI). The RISI Mill Asset database consists of data on 300+ pulp/paper mills in USA and Canada and this data was used to characterize the paper grades produced at each mill. Data for each of the 14 paper grades represents the average of data across all paper mills producing a particular paper grade in North America.

To ensure the highest possible data quality for all the indicators reported in the Paper Calculator, data collection efforts were focused on the “key” unit processes and flows for the product system (1 metric ton of paper), as illustrated in Figure 3. In this figure, the “key” unit processes are represented by numbers 1 through 7 in boxes and letters A through E are used to represent the input flows (A through E) and output flows (F and G) relative to 1 metric ton of paper produced at the mill.

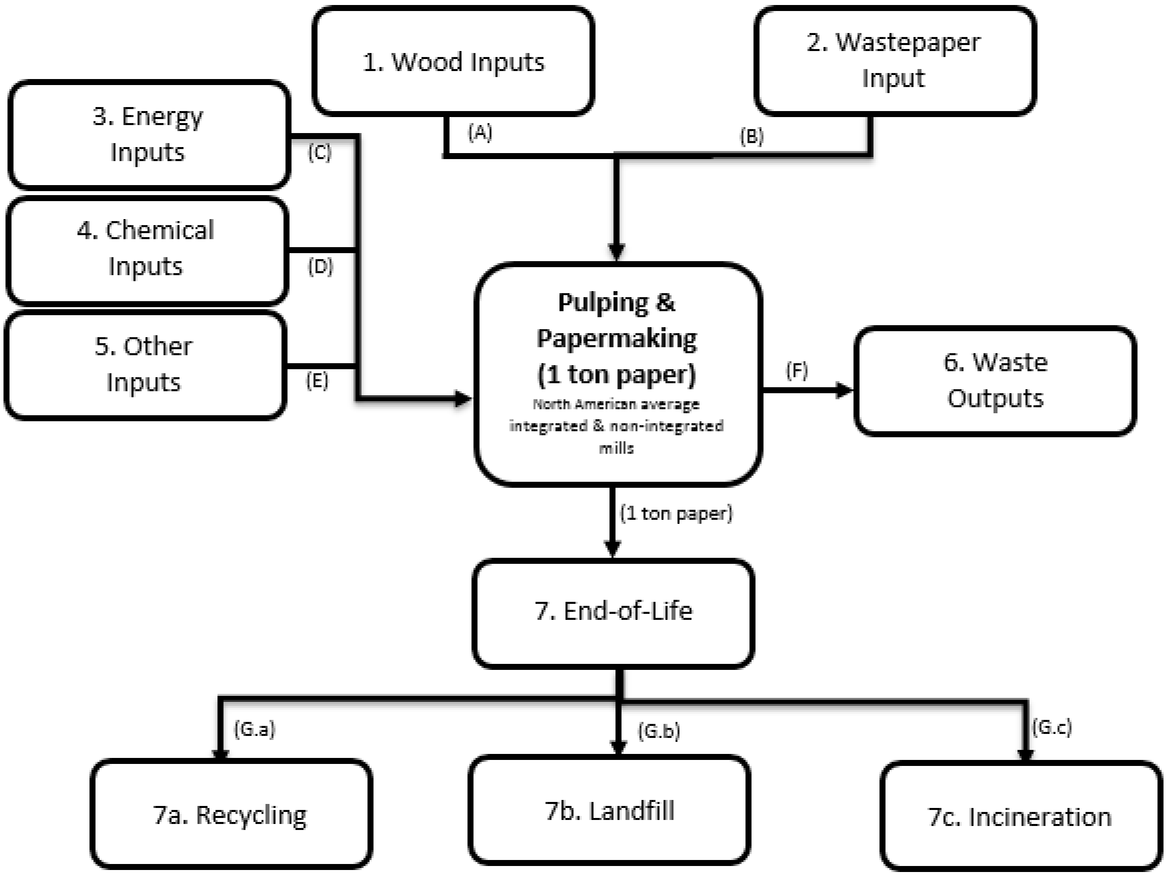

Figure 3. Data collection for key processes (1 through 7) and flows (A through G) relative to the production of 1 metric ton of paper.

Table 4 below presents the list of specific data points collected for pulp and paper mills producing all the paper grades and the corresponding data source used to model all the paper grades. Life cycle inventory data was used to model two sets of product systems (100% virgin papers and 100% recycled papers) for each of the 14 paper grades in the LCA software used (openLCA v1.5). Datasets from the Ecoinvent v3.3 database were used for background processes along with data from RISI Mill Asset database and the USLCI database.

An important dataset is related to the assessment of category indicator results for Terrestrial Ecosystem Impacts (includes four indicators: forest disturbance, freshwater disturbance, wetland disturbance and threatened species habitat disturbance) and forest carbon storage loss. The US Forest Service database, Canadian National Forest Inventory database and the IUCN Red List database were used to assess these category indicators. Data related to HAPs and dioxin emissions indicators were retrieved for all North

American pulp and paper mills from US EPA's Toxic Release Inventory (TRI)[17] database and Canada's National Pollutant Release Inventory (NPRI)[18] database.

Table 4. Data points and data sources used for modeling 100% virgin papers and 100% recycled papers based on Figure 3.

Parameters/ Flows	Data Points Collected	Data Source Used For the Assessed Paper Grades	
		100% Virgin Papers	**100% Recycled Papers**
General Information			
Paper mills in North America	• Number of pulp and paper mills, by grade in North America • Types of paper grade produced, by mill in North America	RISI database	
Production Outputs	• Annual production of all pulp and paper grades, by mill in North America	RISI database	
1. Wood Inputs Specific to the Pulp and Paper Mills			
(A) Wood Inputs	• Pulpwood harvest locations for pulp/paper mills	To calculate national average results for all paper grades, it is assumed that pulpwood is sourced from within 150 miles[19] of the location of pulp/paper mill	Not Applicable
	• Terrestrial ecosystem impacts and forest carbon storage loss, based on location of roundwood harvest	-US Forest Service[20] and Canadian National Forest Inventory[21] -IUCN Red List database[22] for assessing species impacted by wood harvest	Not Applicable
	• Amount of wood input consumed per metric ton paper	RISI database for all paper grades	Not Applicable
2. Waste Paper Input			
(B) Recovered fiber input (The user will enter a value from 0-100 to represent the desired recycled content)	• Amount of recovered fiber input consumed per metric ton paper	Not Applicable	RISI database
3. Energy Inputs			
(C) Energy Inputs	• Amount of fuel consumed, by type per metric ton paper	RISI database	
	• Amount of electricity consumed per metric ton paper	RISI database	
	• Amount of steam purchased per metric ton paper	RISI database	
	• Black liquor generated and consumed	RISI database	Not Applicable

[17] US EPA Toxic Release Inventory program; https://www.epa.gov/toxics-release-inventory-tri-program/tri-data-and-tools
[18] National Pollutant Release Inventory(NPRI); Environment Canada; www.ec.gc.ca/npri
[19] The Kimberly Clark LCA indicated that the Canadian Bioenergy Association evaluated 150 km as the average transport distance of Northern softwood.
[20] US Forest Service FIA database; https://www.fia.fs.fed.us/tools-data/
[21] https://nfi.nfis.org/en/data_and_tools
[22] IUCN Red List; http://www.iucnredlist.org/

Parameters/ Flows	Data Points Collected	Data Source Used For the Assessed Paper Grades	
		100% Virgin Papers	100% Recycled Papers
4. Chemical Inputs			
(D) Chemical Inputs	• Amount of chemical inputs by type per metric ton paper	-USLCI data is used for the following paper grades: coated freesheet, uncoated freesheet, coated groundwood, uncoated groundwood -Ecoinvent v3.3 is used for the remaining paper grades	-Table 39 and Table 43 of a comparative LCA study on recycled coated freesheet paper and virgin coated freesheet paper [23] is used for modeling chemical inputs in a recycled pulp/paper mill -Ecoinvent v3.3 is used for the remaining paper grades
5. Other Inputs			
(E) Other Inputs	• Amount of other material inputs by type per metric ton paper	-RISI database for coatings, fillers and starch for all paper grades	
	• Water consumption per metric ton paper	Ecoinvent v3.3 data used for all paper grades	
6. Waste Outputs			
(F) Waste Products	• Air emissions, by substance per metric ton paper	-US EPA Toxic Release Inventory (TRI) database for all paper grades -Canada's National Pollutant Release Inventory (NPRI) for all paper grades	
	• Amount of BOD, COD and TSS emissions per metric ton paper	-USLCI data was used for the following paper grades: coated freesheet, uncoated freesheet, coated groundwood, uncoated groundwood, corrugating medium and linerboard -Ecoinvent v3.3 was used for the remaining paper grades	-Table 40 of a comparative LCA study on recycled coated freesheet paper and virgin coated freesheet paper [24] was used to model BOD, COD, and TSS in the recycled pulp mill -Ecoinvent v3.3 is used for all paper grades
	• Amount of hazardous waste per metric ton paper	-US EPA Toxic Release Inventory (TRI) database for all paper grades -Canada's National Pollutant Release Inventory (NPRI) for all paper grades	
	• Amount of solid waste per metric ton paper	-USLCI data was used for the following paper grades: coated freesheet, uncoated freesheet, coated groundwood, uncoated groundwood, corrugating medium and linerboard. -Ecoinvent v3.3 was used for the remaining paper grades	Ecoinvent v3.3
7. End-of-Life			
(G.a) Recycling	• Amount of paper recycled per metric ton paper	For the end-of-life phase, recycling rates are assumed based on the 2014 US EPA Municipal Solid Waste (MSW) reports[25]. Based on information from the MSW reports, 80% of the materials not recycled are assumed to go to a municipal landfill and the remaining 20% are assumed to be incinerated. The following recycling rates were used for different paper grades: Coated freesheet, Uncoated freesheet, Coated groundwood, Supercalendered=44.4% Uncoated Groundwood= 68.2% All paperboards, linerboard and corrugating medium= 89%	
(G.b) Landfilling	• Amount of paper landfilled per metric ton paper		
(G.c) Incineration	• Amount of paper incinerated per metric ton paper		

[23] SCS Global Services, October 2015. Life Cycle Assessment of Reincarnation 100 Coated Freesheet Compared to Virgin Paper Products.
[24] SCS Global Services, October 2015. Life Cycle Assessment of Reincarnation 100 Coated Freesheet Compared to Virgin Paper Products.
[25] US EPA MSW (2014); https://www.epa.gov/sites/production/files/2016-11/documents/2014_smmfactsheet_508.pdf

3.4.1 Approach for retrieving data from the RISI Mill Asset Database

RISI data is commonly used in U.S. and global market modeling for the pulp and paper sector. RISI, the data provider for pulp and paper mills, works with industry and trade associations to collect information for their databases and is considered to be the leading information provider for pulp/paper industrial sector. The RISI data included information on mill location, production capacities by product type, energy inputs by fuel type and chemical inputs such as coatings, fillers and starch consumed in paper production. The pulp and paper mill data is publicly available for purchase on the RISI website, but is not shared in this document due to purchase restrictions. However, details on key specific aspects of the approach used to retrieve data from the RISI database are summarized in the sections below.

3.4.1.1 Step 1: Classifying paper products/paper grades produced at each mill

The first step was to classify the paper grades produced at each mill. RISI data in the "*assetData*" sheet was used to identify the products/paper grades produced at each mill. The mills were grouped by paper grade. RISI data in the *assetData* sheet was used to sort out pulp-only mills.

3.4.1.2 Step 2: Classifying mills as Integrated or Non-integrated

The second step was to determine whether the mills are *Integrated mills*[26] or *Non-Integrated mills*[27] from the "*pulpandpaperfurnishAnnualData"* sheet. An integrated mill consists of a pulp mill and a paper mill on the same site, whereas a non-integrated mill purchases pre-processed pulp ("market pulp") in either a slurry form or an air-dried and baled form from a market pulp mill, which most often is a standalone pulp mill. Data in the "*pulpandpaperfurnishAnnualData"* sheet was used to identify mills that purchase 100% of the pulp for paper production (i.e., mills that do not manufacture any pulp at the facility), as per the screenshot below (see the highlighted rows in yellow). All remaining mills were classified as integrated mills.

Mill Name	Region	Total Pulp Manufactured	Total Pulp Purchased
Mill A	USA - South	1,030,757	0
Mill B	USA - South	0	390,062
Mill C	Canada - Quebec	0	5,982
Mill F	USA - South	0	127,888
Mill A	USA - Northeast	283,290	0

Figure 4. Screenshot of format of data used to classify the mills as Integrated and Non-Integrated. The rows highlighted in yellow are examples of Non-integrated mills as they purchase 100% of the pulp. Note that the mill names and the table header names have been modified due to RISI's purchase restrictions. Data here is strictly for demonstrative purpose only.

[26] A facility producing pulp and making paper with paper as the primary product is considered an integrated mill.
[27] A facility that does not produce any pulp and purchases pre-processed pulp ("market pulp") to make paper is considered as a non-integrated mill.

3.4.1.3 Step 3: Classifying mills based on fiber inputs: 100% Virgin, 100% Recycled and Mixed (Virgin + Recycled)

RISI data in the "*naturalWoodData"* and "*recoveredPaperData"* worksheets were used to classify mills based on type of fiber inputs. As indicated in the snapshot below, mills which consume only recycled pulp or recovered paper inputs and which do not consume any wood inputs (such as hardwood chips, softwood roundwood and softwood chips) or pulp inputs (includes chemical pulp and mechanical pulp) are classified as mills using "100% recycled" fiber inputs.

Mill Name	Hardwood chips (ton/ton)	Softwood chips (ton/ton)	Roundwood (ton/ton)	Wastepaper (ton/ton)
Mill A	0	0	0	1.7
Mill B	0	0	0	2.4
Mill C	0	1	1	0
Mill D	0	0	2	0
Mill E		1	2	0

Figure 5. Screenshot of format of data used to classify mills with 100% recycled fiber inputs. The rows highlighted in yellow are examples of mills using only recovered fiber inputs (values indicated in red). Note that the mill names and the table header names have been modified due to RISI's purchase restrictions. Data here is strictly for demonstrative purpose only.

Similarly, mills which do not consume any recycled pulp or recovered paper inputs are classified as mills using "100% virgin" fiber inputs. These inputs include hardwood chips, softwood chips, roundwood, chemical pulp and mechanical pulp.

Mill Name	Hardwood chips (ton/ton)	Softwood chips (ton/ton)	Roundwood (ton/ton)	Wastepaper (ton/ton)
Mill A	0	0	0	1.7
Mill B	0	0	0	2.4
Mill C	0	1.0	1.0	1.0
Mill D	0	0.0	2.0	0
Mill E		1.0	1.0	0

Figure 6. Screenshot of format of data used to classify mills with 100% virgin fiber inputs. The rows highlighted in yellow are examples of mills using only virgin fiber inputs (values indicated in red). Note that the mill names and the table header names have been modified due to RISI's purchase restrictions. Data here is strictly for demonstrative purpose only.

Mills consuming both virgin and recycled fiber inputs are classified as mills using "mixed" fiber inputs.

Mill Name	Hardwood chips (ton/ton)	Softwood chips (ton/ton)	Roundwood (ton/ton)	Wastepaper (ton/ton)
Mill A	0	0	0	1.7
Mill B	0	0	0	2.4
Mill C	0	1.0	1.0	1.0
Mill D	0	0.0	2.0	0
Mill E		1.0	1.0	0

Figure 7. Screenshot of format of data used to classify mills with mixed fiber inputs. The rows highlighted in yellow are examples of mills using mixed fiber inputs (values indicated in red). Note that the mill names and the table header names have been modified due to RISI's purchase restrictions. Data here is strictly for demonstrative purpose only.

Figure 8 illustrates the approach described above to classify mills based on type of fiber input (100% virgin, 100% recycled and mixed). Table 5 presents the number of mills identified by mill type for each paper grade.

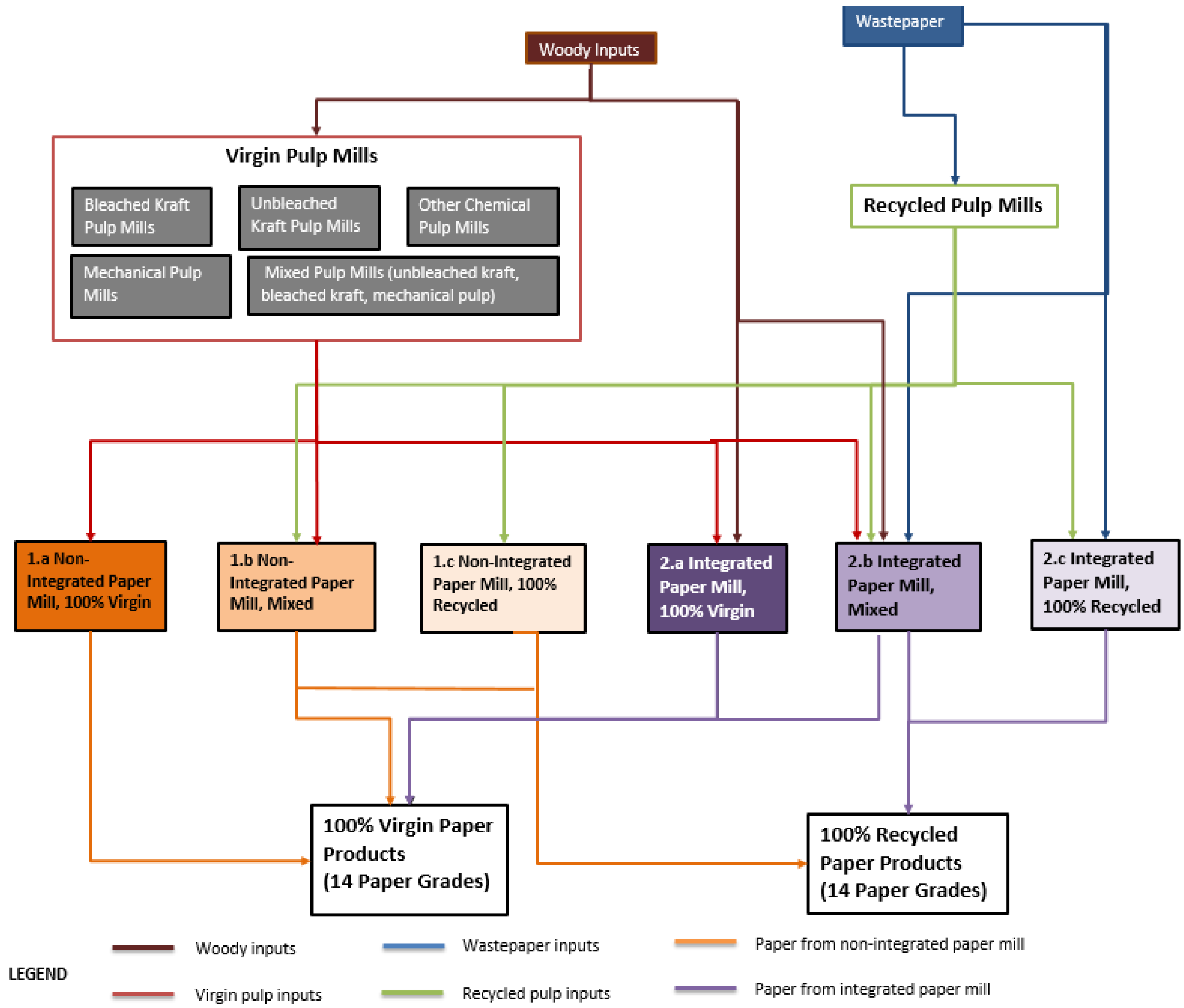

Figure 8. The above figure illustrates the classification of pulp and paper mills in the RISI Mill Asset Database. 100% virgin and 100% recycled paper grades are produced in non-integrated paper mills (indicated in orange color) and integrated paper mills (indicated in purple color). Virgin pulp mills (indicated in red color) supply virgin pulp to non-integrated and integrated paper mills producing 100% virgin paper products. Similarly, recycled pulp mills (indicated in green color) supply recycled pulp to non-integrated and integrated paper mills producing 100% recycled paper products. Woody inputs are required during virgin pulp production as well as in integrated paper mills producing virgin paper products. Wastepaper inputs are required for recycled pulp production as well as in integrated mills producing recycled paper products.

Table 5. Classification of mills by paper grade in the RISI Mill Asset Database based on Figure 8.

Type of Paper Grade	Number of mills by Mill Type as shown in Figure 8					
	1.a	1.b	1.c	2.a	2.b	2.c
1. Coated Freesheet				7	2	
2. Uncoated Freesheet	1	4		13	23	
3. Coated Groundwood				9	1	
4. Uncoated Groundwood				12	13	1
5. Supercalendered				9	1	
6. Paperboard: Solid Bleached Sulfate				13		
7. Paperboard: Coated Unbleached Kraft					3	
8. Paperboard: Coated Recycled Board						16
9. Paperboard: Uncoated Bleached Kraft					1	
10. Paperboard: Uncoated Unbleached Kraft				2	1	
11. Paperboard: Uncoated Recycled Board						48
12. Linerboard				8	29	29
13. Corrugating Medium				2	18	31
14. Tissue	30	4		6	10	11

Corrugated product grade was calculated based on mix of linerboard and corrugating medium mills.

To calculate the North American average results for 100% virgin paper grades, the data was averaged across the number of mills listed in 1.a and 2.a in Table 5. Similarly, to calculate the North American average results for 100% recycled paper grades, the data was averaged across the number of mills listed in 1.c and 2.c. For some paper grades (paper grades 1, 2, 3 and 5 in Table 5), mill data for 2.c was unavailable. Thus, the results for these four paper grades were calculated based on data averaged across the number of mills listed in 2.b.

3.4.1.4 Calculation of Emissions and Energy Input Data from RISI

RISI provides data on the total consumption of energy of all types at all pulp and paper mills in the USA and Canada. This was first converted to total emissions for each mill, calculated using standard emissions factors applied to each type of fuel.

The approaches to evaluate emissions and total energy use relative to the production of paper for integrated mills and non-integrated differ, and are each described below.

For integrated mills, the total emissions of GHG i (where GHG i includes greenhouse gases such as carbon dioxide, methane, nitrous oxide, etc.), per metric ton of product, are calculated by summing the emissions from all fuels consumed by the mill, as per the equation below.

$$\frac{\text{Total mill emissions}_{\text{i}}}{\text{metric ton paper}} = \sum^{\text{all fuels } j} \frac{\text{Emissions/Energy Use}_{\text{i,j}}}{\text{metric ton pulp and paper capacities}}$$

Where *Total mill emissions*$_i$ is the total mill emissions of GHG *i*, given in metric tons of GHG per metric ton of product produced.

For non-integrated paper mills, a national average figure for emissions from non-integrated pulp mills was used to model emissions associated with pulp inputs to the paper mill. Emissions for non-integrated paper mills were calculated using the equation below.

$$\frac{\text{Total emissions (non integrated mills)}_\text{i}}{\text{metric ton paper}} = \sum^{\text{all fuels j}} \left[\left(\frac{\text{Pulp Mill Emissions}_\text{i,j}}{\text{pulp capacity}} \times \frac{\text{pulp inputs}}{\text{metric ton paper}} \right) + \frac{\text{Paper Mill Emissions}_\text{i,j}}{\text{paper mill capacity}} \right]$$

Where $\frac{\text{Pulp Mill Emissions}_\text{i,j}}{\text{pulp capacity}}$ is a national average figure and $\frac{\text{pulp inputs}}{\text{metric ton paper}}$ and $\frac{\text{Paper Mill Emissions}_\text{i,j}}{\text{paper mill capacity}}$ are calculated for specific non-integrated paper mills.

For mills that produce multiple paper grades, the total mill energy consumption and total mill capacity were used to calculate emissions for all products (i.e., emissions per metric ton of paper will be the same across all products produced at the mill). RISI does not provide energy use broken down by paper grade, so it was not possible to calculate energy consumption on a product-by-product basis for each mill. The approach selected is the most transparent approach to calculating energy consumption and associated emissions for each product at each mill.

3.4.1.5 Calculation of Pulp Inputs Data from RISI

RISI provides data on the total pulp manufactured and purchased by each mill, broken down by pulp type. This data was used to calculate the pulp inputs, by pulp type, per metric ton of paper produced, for each mill, distinguishing between integrated and non-integrated mills. The following equation was applied:

$$\frac{\text{Pulp Inputs}_\text{k}}{\text{metric ton paper}} = \frac{\text{Total Pulp Inputs}_\text{k}}{\text{total mill paper capacity}}$$

Where *k* represents the different pulp types consumed.

3.4.1.6 Calculation of Wood Inputs Data from RISI

RISI provides data on the total wood inputs at each mill, broken down by type of wood. This data was used to calculate wood inputs, by wood type, per metric ton of paper produced for each mill. The following equation was applied:

$$\frac{\text{Wood Inputs}_\text{k}}{\text{metric ton paper}} = \frac{\text{Total Wood Inputs}_\text{k}}{\text{total mill capacity}}$$

Where *k* represents the different wood types consumed.

3.4.1.7 Calculation of Other Inputs Data from RISI

RISI provides data on the total other inputs (coatings, fillers, starch) at each mill. This data was used to calculate other inputs, by input type, per metric ton of paper produced for each mill. The following equation was applied:

$$\frac{\text{Other Inputs}_k}{\text{metric ton paper}} = \frac{\text{Total Other Inputs}_k}{\text{total mill paper capacity}}$$

Where *k* represents the other input type (coating, filler, starch, etc.).

3.4.2 Calculation of toxic air emissions data

Pulp and paper mills report toxic releases to government bodies on an annual basis. Toxic air emissions data was retrieved for all pulp and paper mills operating in North America in year 2015 from US EPA's Toxic Release Inventory (TRI) database and Canada's National Pollutant Release Inventory (NPRI) database. This data was cross-referenced with data in the RISI Mill Asset database to generate national average toxic air emissions data for each of the 14 paper grades. The annual air emissions data was normalized relative to 1 metric ton of paper, based on the production capacities of the paper grades at the pulp and paper mills. This data was used to calculate results for HAPs, VOC, TRS, mercury emissions and dioxin emission indicators.

3.4.3 Use of Ecoinvent and USLCI Datasets

The background processes associated with pulp and papermaking processes were modeled using LCA database such as Ecoinventv3.3 and USLCI database. The Ecoinvent and USLCI datasets were used to model the upstream impacts of all inputs (chemical inputs, material inputs and energy inputs) into the pulp and papermaking processes. To the extent possible, datasets representing North American production were selected to build the LCA model. European or global average datasets were used to fill the remaining data gaps. A detailed list of datasets used for modeling all the paper grades is presented in Table 7.

3.4.4 Waste output data per metric ton of paper- BOD, COD, TSS and Solid Waste

The EPA TRI database does not contain BOD, COD and TSS data for pulp/paper mills. A mix of USLCI and Ecoinvent datasets was used to estimate the BOD, COD and TSS emissions (see Table 4 for more detail) during papermaking. The Ecoinvent v3.3 data behind these processes for certain paper grades were based on global average production data and thus not necessarily representative of the North American context (see table below). These data were the only ones available that made the distinction between virgin and recycled paper production for different paper grades and thus these data was used to report the BOD, COD and TSS indicators.

Solid waste data on pulp and paper production is based on a mix of USLCI and Ecoinvent datasets (see Table 6. for more detail). The amount of solid waste generated from discarding 1 metric ton of paper is assumed to be the amount of paper that is disposed to a landfill and a municipal incinerator. The amount of paper being recycled, landfilled and incinerated is based on MSW reports for 2014 (see Table 4).

Table 6. Datasets used to determine the amount of BOD, COD, TSS and solid waste outputs during papermaking. (Note: "cut-off, U" refers to the classification of datasets used to model the paper grades in the Ecoinvent v3.3 LCA database. Letters US, CA and QC denote the region represented by the dataset. "US" refers to United States", "CA" refers to Canada" and "QC" refers to Quebec province in Canada).

Data Source	Dataset Name for Paper Grade by Type of Fiber Input	Region, Year
US LCI Ecoinvent v3.3	Coated Freesheet: *100% virgin*: Paper, freesheet, coated, average production, at mill *100% recycled*: graphic paper[28] production, 100% recycled | graphic paper, 100% recycled | cut-off, U	US, 2006 Global, 2016
US LCI Ecoinvent v3.3	Uncoated Freesheet: *100% virgin*: Paper, freesheet, uncoated, average production, at mill, 2006 *100% recycled*: paper production, woodfree, uncoated, 100% recycled content, at non-integrated mill | paper, woodfree[29], uncoated | cut-off, U -paper production, woodfree, uncoated, 100% recycled content, at integrated mill | paper, woodfree, uncoated | cut-off, U	US, 2006 CA, 2016 CA, 2016
US LCI Ecoinvent v3.3	Coated Groundwood: *100% virgin*: Paper, mechanical, coated, average production, at mill *100% recycled*: graphic paper production, 100% recycled | graphic paper, 100% recycled | cut-off, U	US, 2006 Global, 2016
US LCI Ecoinvent v3.3	Uncoated Groundwood: *100% virgin*: Paper, mechanical, uncoated, average production, at mill *100% recycled:* paper production, newsprint, recycled | paper, newsprint | cut-off, U	US, 2006 CA, 2016
US LCI Ecoinvent v3.3	Supercalendered: *100% virgin*: paper production, woodcontaining, supercalendered | paper, woodcontaining, supercalendered | cut-off, U-CA *100% recycled*: graphic paper production, 100% recycled | graphic paper, 100% recycled | cut-off, U	CA, 2016 Global, 2016
Ecoinvent v3.3 Ecoinvent v3.3	Paperboard: Solid Bleached Sulfate/Coated Bleached Kraft, Uncoated Bleached Kraft *100% virgin*: solid bleached board production | solid bleached board | cut-off, U CA-QC *100% recycled*[30]: chipboard production, white lined | folding boxboard/chipboard | cut-off, U	CA, 2016 Global, 2016
Ecoinvent v3.3 Ecoinvent v3.3	Paperboard: Coated Unbleached Kraft, Uncoated Unbleached Kraft *100% virgin*: solid unbleached board production | solid unbleached board | cut-off, U *100% recycled*[30]: chipboard production, white lined | folding boxboard/chipboard | cut-off, U	Global, 2016 Global, 2016

[28] Note that graphical paper includes coated freesheet, uncoated freesheet, coated groundwood, uncoated groundwood and supercalendered paper grades.
[29] Note that in the Ecoinvent databse, woodfree refers to paper that contains atleast 90% of the fibers in the form of chemical pulp.
[30] Note that the recycled version of Paperboard: Coated Unbleached Kraft paper grade corresponds to Paperboard: Coated Recycled Board paper grade in the Paper Calculator. Similarly, recycled version of Paperboard: Uncoated Bleached Kraft/Uncoated Unbleached Kraft paper grades corresponds to Paperboard: Uncoated Recycled Board paper grades.

Data Source	Dataset Name for Paper Grade by Type of Fiber Input	Region, Year
Ecoinvent v3.3	Paperboard: Coated Recycled Board, Uncoated Recycled Board Chipboard production, white lined | folding boxboard/chipboard | cut-off, U	Global, 2016
Ecoinvent v3.3 Ecoinvent v3.3	Linerboard *100% virgin*: linerboard production, kraftliner | linerboard | cut-off, U CA-QC *100% recycled*: treatment of recovered paper to linerboard, testliner| cut-off, U CA-QC	CA, 2016 CA, 2016
USLCI Ecoinvent v3.3	Corrugating Medium *100% virgin*: Corrugated product, containerboard, average production, at mill, 2010 *100% recycled*: treatment of recovered paper to fluting medium, wellenstoff | fluting medium | cut-off, U	US, 2010 Global, 2016
Ecoinvent v3.3 Ecoinvent v3.3	Tissue *100% virgin*: tissue paper production, virgin | tissue paper | cut-off, U *100% recycled*: tissue paper production | tissue paper | cut-off, U	Global, 2016 Global, 2016

3.5 LCI Analysis Summary

A life cycle inventory (LCI) analysis was conducted in conformance with ISO 14044 and LEO-S-002. The openLCA software[31] was used to model and analyze the complete set of inputs and outputs associated with all production stages in each product system, by unit process. As indicated in Table 7, the LCI of 14 paper grades is based on data from RISI Mill Asset database, and representative data from the Ecoinvent v3.3 database[32] and USLCI database[33].

The data sources used for the LCI analysis are summarized by paper grade in Table 4. See Table 7 below for more details on the background datasets used for modeling key inputs and outputs illustrated in Figure 3. The table also provides the associated level of data quality including representativeness and materiality of the data used for modeling. The data quality of the inventory, environmental characterization, and parameter data used is required to be sufficient to differentiate results between the environmental impacts of 14 paper grades. Indication on quality of data includes evaluation of the reliability and completeness of the data itself, combined with the evaluation of the representativeness (temporal, geographical and technological) of processes used to model it (indicated as high, medium or low).

The table below also provides the materiality associated with the processes used to model the paper grades. A process with a high materiality means that its relative contribution to the total Paper Calculator indicator results are high, indicating that the data is likely to have a relatively big influence on the indicator result. On the other hand, a process with low materiality means that it has lower

[31] openLCA modeling software, version 1.5.beta1 By GreenDelta.
[32] Ecoinvent v3.3 Swiss Center for Life Cycle Inventories, 2016. The system model used is based on the recycled content cut-off method. http://www.ecoinvent.org
[33] USLCI database; https://uslci.lcacommons.gov/uslci/search

importance compared to other data points and the relative contribution to the Paper Calculator indicator results is low and is likely to have a very small influence on the indicator result.

Table 7. List of background datasets used to model major inputs (see Figure 3) required for production of 14 paper grades.The representativeness and materiality of the data has been addressed qualitatively using the acronyms H=High, M=Medium and L=Low.

Material/ Process	Data Source	Dataset Name	Region, Year	Representativeness	Materiality
1. Wood Inputs					
Roundwood production	US LCI	-Roundwood, hardwood, green, at mill, E/m3/RNA -Roundwood, hardwood, green, at mill, NE-NC/m3/RNA -Roundwood, hardwood, green, at mill, SE/m3/RNA -Roundwood, softwood, green, at mill, INW/kg/RNA -Roundwood, softwood, green, at mill, NE-NC/m3/RNA	US, 2005	H	L
Wood chips production	USLCI	-Wood chips, hardwood, green, at sawmill, NE-NC/kg/RNA -Wood chips, softwood, green, at sawmill NE-NC/kg/RNA -Wood chips, softwood, green, at sawmill, INW/kg/RNA -Pulp chips, at sawmill, US SE/kg/US	US, 2005	H	L
Forest conditions	USFS & Canadian NFI	USFS / CNFI data on forest conditions used to model impacts on forests.	US, CA, last 5-10 years	H	H
2. Wastepaper Inputs					
Waste paper collection and sorting	SCS/Government	-*Wastepaper collection:* Estimated that wastepaper is transported 300 miles from shredder to recycled paper mill. Estimated based on data from a comparative LCA study on recycled coated freesheet paper and virgin coated freesheet paper[34]. -*Wastepaper shredding and sorting process:* Oregon Department of Environmental Quality provides data that 0.25 MMBTU of energy is required to shred 1,000 pounds of office paper (580 MJ per ton). This is data used in a comparative LCA study on recycled coated freesheet paper and virgin coated freesheet paper.[35] [36] [37]	Wisconsin, 2014 Oregon, 2004	M M	L L
3. Energy Inputs					
Natural gas	Ecoinvent	heat production, natural gas, at boiler modulating >100kW | heat, district or industrial, natural gas | cut-off, U – US,CA-QC	US,CA, 2016	H	H
Electricity	Ecoinvent	-market group for electricity, medium voltage | electricity, medium voltage | cut-off, U – US -market group for electricity, medium voltage | electricity, medium voltage | cut-off, U – CA	US, CA 2016	H	H
Hog fuel	USLCI	Hog fuel, self-gen., combusted in and boiler, at pulp and paper mill	US, 2001	H	L
Steam	Ecoinvent	steam production, in chemical industry | steam, in chemical industry | cut-off, U - RoW	Global, 2016	L	M
Coal	Ecoinvent	hard coal | cut-off, U-RNA	North America, 2016	H	L

[34] SCS Global Services, October 2015. Life Cycle Assessment of Reincarnation 100 Coated Freesheet Compared to Paper Products.

[35] SCS Global Services, October 2015. Life Cycle Assessment of Reincarnation 100 Coated Freesheet Compared to Virgin Paper Products.

[36] Oregon DEQ. LIFE CYCLE INVENTORY OF PACKAGING OPTIONS FOR SHIPMENT OF RETAIL MAIL-ORDER SOFT GOODS. April 2004.

[37] According to previous LCA completed by Kimberly Clark which treated this topic, other estimates for collection, sorting, and delivery, of mixed offer paper to de-inking pulp mill varies between 510-1500 MJ per ton.

Material/ Process	Data Source	Dataset Name	Region, Year	Representativeness	Materiality
Oil	Ecoinvent	heavy fuel oil, burned in refinery furnace | heavy fuel oil, burned in refinery furnace | cut-off, U - RoW	Global, 2016	L	L
4. Chemical Inputs					
Lime[38]	Ecoinvent	quicklime production, milled, loose | quicklime, milled, loose | cut-off, U - CA-QC	CA, 2016	M	M
Bleaching chemicals	Ecoinvent	- air separation, cryogenic | oxygen, liquid | cut-off, U - CA-QC -chlor-alkali electrolysis, membrane cell | chlorine, gaseous | cut-off, U - CA-QC -hydrogen peroxide production, product in 50% solution state | hydrogen peroxide, without water, in 50% solution state | cut-off, U - RoW	CA, 2016 CA, 2016 Global, 2016	M M L	M M M
Sodium hydroxide	Ecoinvent	chlor-alkali electrolysis, membrane cell | sodium hydroxide, without water, in 50% solution state | cut-off, U - CA-QC	CA, 2016	M	M
Hydrochloric acid	Ecoinvent	hydrochloric acid production, from the reaction of hydrogen with chlorine | hydrochloric acid, without water, in 30% solution state | cut-off, U - CA-QC	CA, 2016	M	L
Soda ash	Ecoinvent	modified Solvay process, Hou's process | soda ash, dense | cut-off, U - GLO	Global, 2016	L	L
Sulfuric acid	Ecoinvent	sulfuric acid production | sulfuric acid | cut-off, U – RoW	Global, 2016	L	L
Sodium chlorate	Ecoinvent	sodium chlorate production, powder | sodium chlorate, powder | cut-off, U - CA-QC	CA, 2016	M	L
Sodium sulfate	Ecoinvent	sodium sulfate production, from natural sources | sodium sulfate, anhydrite | cut-off, U - RoW[38]	Global, 2016	L	L
Sizing agent	Ecoinvent	rosin size production, for paper production | rosin size, for paper production | cut-off, U - RoW[38]	Global, 2016	L	L
Aluminum sulfate	Ecoinvent	aluminium sulfate production, without water, in 4.33% aluminium solution state | aluminium sulfate, without water, in 4.33% aluminium solution state | cut-off, U - CA-QC	CA, 2016	M	L
5. Other Inputs					
Coating[38]	Ecoinvent	kaolin production | kaolin | cut-off, U - RoW	Global, 2016	L	M
Filler[38]	Ecoinvent	-malusil production | malusil | cut-off, U – RoW -activated bentonite production | activated bentonite | cut-off, U - RoW	Global, 2016 Global, 2016	L	M
Starch[38]	Ecoinvent	maize starch production | maize starch | cut-off, U - RoW	Global, 2016	L	M
Water consumption	Ecoinvent	Water input data for each paper grade is based on datasets listed below: Coated Freesheet: *100% virgin*: paper production, woodfree[39], coated, at integrated mill | paper, woodfree, coated | cut-off, U			

[38] US LCI does not have any data. Ecoinvent has thorough data for European production of these chemicals. This data is also more recent and applicable.
[39] Note that in the Ecoinvent databse, woodfree refers to paper that contains atleast 90% of the fibers in the form of chemical pulp.

Material/ Process	Data Source	Dataset Name	Region, Year	Representativeness	Materiality
		100% recycled: graphic paper[40] production, 100% recycled | graphic paper, 100% recycled | cut-off, U Uncoated Freesheet: *100% virgin*: paper production, woodfree, uncoated, at integrated mill | paper, woodfree, uncoated | cut-off, U *100% recycled*: paper production, woodfree, uncoated, 100% recycled content, at non-integrated mill | paper, woodfree[41], uncoated | cut-off, U -paper production, woodfree, uncoated, 100% recycled content, at integrated mill | paper, woodfree, uncoated | cut-off, U Coated Groundwood: *100% virgin*: paper production, newsprint, virgin | paper, newsprint | cut-off, U *100% recycled*: paper production, newsprint, recycled | paper, newsprint | cut-off, U Uncoated Groundwood: *100% virgin*: paper, mechanical, uncoated, average production, at mill *100% recycled:* paper production, newsprint, recycled | paper, newsprint | cut-off, U Supercalendered: *100% virgin*: paper production, woodcontaining, supercalendered | paper, woodcontaining, supercalendered | cut-off, U-CA *100% recycled*: graphic paper production, 100% recycled | graphic paper, 100% recycled | cut-off, U Paperboard: Solid Bleached Sulfate/Coated Bleached Kraft, Uncoated Bleached Kraft *100% virgin*: solid bleached board production | solid bleached board | cut-off, U CA-QC *100% recycled*[42]: chipboard production, white lined | folding boxboard/chipboard | cut-off, U Paperboard: Coated Unbleached Kraft, Uncoated Unbleached Kraft *100% virgin*: solid unbleached board production | solid unbleached board | cut-off, U *100% recycled*[42]: chipboard production, white lined | folding boxboard/chipboard | cut-off, U	CA, Global, 2016	H	L

[40] Note that graphical paper includes coated freesheet, uncoated freesheet, coated groundwood, uncoated groundwood and supercalendered paper grades.
[41] Note that in the Ecoinvent databse, woodfree refers to paper that contains atleast 90% of the fibers in the form of chemical pulp.
[42] Note that the recycled version of Paperboard: Coated Unbleached Kraft paper grade corresponds to Paperboard: Coated Recycled Board paper grade in the Paper Calculator. Similarly, recycled version of Paperboard: Uncoated Bleached Kraft/Uncoated Unbleached Kraft paper grades corresponds to Paperboard: Uncoated Recycled Board paper grades.

Material/ Process	Data Source	Dataset Name	Region, Year	Representativeness	Materiality
		Paperboard: Coated Recycled Board, Uncoated Recycled Board Chipboard production, white lined | folding boxboard/chipboard | cut-off, U Linerboard *100% virgin*: linerboard production, kraftliner | linerboard | cut-off, U CA-QC *100% recycled*: treatment of recovered paper to linerboard, testliner| cut-off, U CA-QC Corrugating Medium *100% virgin*: Corrugated product, containerboard, average production, at mill, 2010 *100% recycled*: treatment of recovered paper to fluting medium, wellenstoff | fluting medium | cut-off, U Tissue *100% virgin*: tissue paper production, virgin | tissue paper | cut-off, U *100% recycled*: tissue paper production | tissue paper | cut-off, U			
6. Waste Outputs					
Waste Treatment Processes from Pulping and Papermaking	Ecoinvent	-Treatment of sludge from pulp and paper production, sanitary landfill | sludge from pulp and paper production | cut-off, U – RoW treatment of wood ash mixture, pure, sanitary landfill | wood ash mixture, pure | cut-off, U – RoW -Treatment of ash from paper production sludge, residual material landfill | ash from paper production sludge | cut-off, U – RoW -Treatment of hazardous waste, underground deposit | hazardous waste, for underground deposit | cut-off, U – RoW -Treatment of municipal solid waste, incineration | municipal solid waste | cut-off, U - CA-QC - Treatment of municipal solid waste, sanitary landfill | municipal solid waste | cut-off, U - CA-QC	Global, CA, 2016	L	L
7. End-of-Life					
Recycling, Landfill and Incineration	Ecoinvent	<u>Recycling:</u> transport, freight, lorry 16-32 metric ton, EURO4 | transport, freight, lorry 16-32 metric ton, EURO4 | cut-off, U - RoW *Only the transportation impacts associated with transporting paper to the recycling facility are included in this assessment.* <u>Landfilling:</u> -For coated freesheet, uncoated freesheet, coated groundwood and supercalendered paper grades: treatment of waste graphical paper, sanitary landfill | waste graphical paper | cut-off, U - Europe without Switzerland -For uncoated groundwood: treatment of waste graphical paper, sanitary landfill | waste graphical paper | cut-off, U - Europe without Switzerland	Global, 2016 Europe, 2016 Europe, 2016	L L L	L L L

Material/ Process	Data Source	Dataset Name	Region, Year	Representativeness	Materiality
		-For all paperboards, corrugating medium and linerboard: treatment of waste paperboard, sanitary landfill | waste paperboard | cut-off, U - RoW	Global, 2016	L	L
		Incineration: -For coated freesheet, uncoated freesheet, coated groundwood and supercalendered paper grades: treatment of waste graphical paper, municipal incineration | waste graphical paper | cut-off, U - Europe without Switzerland	Europe, 2016	L	L
		-For uncoated groundwood: treatment of waste graphical paper, municipal incineration | waste graphical paper | cut-off, U - Europe without Switzerland	Europe, 2016	L	L
		- For all paperboards, corrugating medium and linerboard: treatment of waste paperboard, municipal incineration | waste paperboard | cut-off, U - RoW	Global, 2016	L	L

This analysis shows that data quality for most relevant inputs is considered to be highly reliable and complete. For most indicators, they are also representative of the temporal, geographical and technological contexts. Processes with high and medium materiality in terms of environmental impacts are all modeled using consistent data sources such as RISI data and LCA databases (Ecoinvent v3.3 and USLCI), which make data uncertainties less significant. As the modelling was done with processes from ecoinvent v3.3 database, the data behind some processes were global averages and thus not necessarily representative of the North American context.

3.5.1 Accounting for Biogenic Carbon Flows

An important component of results related to changes in biogenic carbon is impacts from foregone growth, which affect results for GHG emissions/ Climate Change and Ocean Acidification indicators. The approach used to evaluate results is described conceptually in sections 3.6.2.1 and 3.6.2.2, while the LCIA Methodology for PCR Modules[43] contains more detail on the algorithms used.

Another important climatic effect is the emissions and absorption of climate pollutants at the time of harvests, including:

- Net forest regrowth, which is assumed to sequester atmospheric CO_2 in the year that it occurs.
- During logging, decay and/or combustion of aboveground logging residues (i.e., “slash”) and carbon stored in tree roots were assumed to occur immediately, with all of the carbon assumed to be converted into emissions of CO_2. It is assumed that slash left on the site is 25% of the

[43] Life Cycle Impact Assessment Methodology for PCR Modules for Roundwood and Pulp/Paper; https://www.scsglobalservices.com/files/program_documents/pcr_final_lcia-methodology_101816.pdf

harvest volume. Belowground roots are assumed to have a carbon mass same as in slash. These fractions are considered typical of most forestry practices, and have been used in past LCAs.[44]

3.6 LCIA Methodology Summary

The LCA conforms to ISO 14044, the draft LEO-S-002 standard, the Roundwood PCR, the Pulp/Paper PCR and the LCIA Methodology for PCR Modules. The LCIA methodology in the draft LEO-S-002 standard requires that all impacts relevant to production of paper grades be accounted for, and that the metrics used be environmentally relevant and based in a scientific and technically valid approach.

The final Paper Calculator results are based upon the compilation of category indicator results for all core impact categories (see Section 1.3 for a list of core impact categories, and LCA results, for 14 paper grades). Category indicators numerically represent the contribution of specific unit processes to midpoints in the environmental mechanism for each core impact category.

Each category indicator result is calculated using characterization factors (CF) which are applied to LCI data per flow. For some impact categories, two CF are used: potency potential characterization factors (PP-CFs) and midpoint characterization factors (M-CFs). PP-CFs characterize the relative potency of emissions, resource uses, or land uses in causing impacts. M-CFs characterize the actual effect on the receiving environment of these emissions, resource uses, or land uses, which can vary on a site-specific basis.

The significance of the indicators presented in the Paper Calculator, along with an overview of the calculation approach, is summarized in the sections below. The in depth equations, and CFs, used to calculate results, are given in the LCIA Methodology for PCR Modules.

3.6.1 Biotic/Abiotic Resource Depletion Indicators

3.6.1.1 Wood Use

Wood use measures the amount of wood required to produce a given amount of paper. Results are reported in fresh/green tons of wood. The methodology used to estimate wood use only considers the quantity of wood consumed during pulp and paper production and does not include the forest residues left behind during pulpwood harvest in the forests (i.e., slash, roots). If forest residues are included it is likely to be twice the value, as roughly 50% of biomass is left after harvest.

It should be noted that effects of loss of wood resources on forest ecosystems are treated in the impact category group of Terrestrial and Freshwater Ecosystem Impacts (i.e., forest disturbance, freshwater disturbance and threatened species indicators) and forest carbon loss is treated in the Greenhouse

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[44] SCS Global Services, October 2015. Life Cycle Assessment of Reincarnation 100 Coated Freesheet Compared to Virgin Paper Products.

Gas/Climate Change and Ocean Acidification indicators. These impact indicators are all linked to losses of wood resources but nevertheless are distinct categories of impact.

Calculation Approach: This indicator was calculated based on the amount of wood chips and roundwood consumed during paper production. This data was retrieved from the RISI database as indicated in Table 4 in units of dry tons of wood. A conversion factor of 2 was applied to convert the units from dry tons of wood to fresh/green tons of wood (1 fresh/green ton = 1 dry ton*2). This indicator is not applicable to 100% recycled paper.

3.6.1.2 Total Energy and Purchased Energy

Total energy measures the total energy required over the paper's life cycle, including all renewable and non-renewable energy resources. It includes purchased electricity, hog fuel, steam, natural gas, black liquor, coal, oil, etc. consumed during paper production. It also accounts for energy consumed in the upstream sources such as production of pulping chemicals, coatings, fillers, etc.

Purchased energy is a subset of total energy, accounting for the amount of purchased electricity and other fuels.

Calculation Approach: This indicator was calculated based on the energy content of the resources (using lower heating value) and the energy consumption was aggregated across the paper's life cycle from cradle-to-grave. Purchased energy was calculated based on the amount of electricity and fuel purchased by the pulp and paper mills. Data sources used for calculation of this indicator are presented in Table 4 and Table 7.

3.6.1.3 Water Consumption

Water consumption measures the amount of process and cooling water that is consumed throughout the life cycle of the paper product. In general, water consumption indicator includes the water withdrawn from surface water or groundwater source and not directly returned.[45] Consumption of saltwater is not included.

Calculation Approach: This indicator provides an aggregate of water consumed across the paper's life cycle from cradle-to-grave. The results also include the water consumed in upstream sources (e.g. pulping chemicals, coatings, fillers) as well as water consumed in the end-of-life phase.

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

3.6.2 Climate System Impacts

3.6.2.1 Greenhouse Gas (GHG)/ Climate Change Impacts

Greenhouse gases (includes carbon dioxide or CO_2, methane or CH_4, nitrous oxides or N_2O, etc.) and short-lived climate pollutants (includes black carbon and organic carbon) are emitted across the life cycle of paper products (e.g. during energy generation, burning of biomass and fossil fuels in pulp/paper mills, transportation, etc.). These pollutants contribute to climate change by trapping energy from the sun in the earth's atmosphere. This impact category also includes forest carbon storage loss from logged forests, which is the carbon that would have been sequestered in the forest had it not been harvested.

The results for this indicator were evaluated based on the "Global Climate Change" impact category. All results for this impact category are calculated in terms of pounds carbon dioxide equivalent (pounds CO_2e) per mass of paper grade produced for 20 years, based on radiative forcing metrics (see calculation approach below for more detail).

The production of virgin paper grades requires the harvesting of wood across large areas of forests (fiber baskets). These harvests disturb the forest compositional structure, amount of biomass present, and dominant species type. These disturbances results in forests with very different characteristics than what can be found in undisturbed forestlands. In the fiber baskets of the mills,[46] forestry activities have, over many decades, led not only to ecosystem disturbances and key species impacts, but also reductions in stored forest carbon, when compared to undisturbed forestlands. According to the IPCC,[47] historic CO_2 emissions from land use changes are responsible for roughly 33% of the additional CO_2 burden in the atmosphere from anthropogenic activities. Most of the terrestrial ecoregions considered, if left unharvested, would re-absorb a large portion of this CO_2. IPCC estimates, for example, that afforestation and reforestation could sequester 40-70 billion tons of carbon,[48] indicating the large potential of allowing disturbed ecosystems to re-sequester carbon which has been lost to the atmosphere. The effect on ongoing harvest therefore *suppresses the rate of forest carbon storage recovery in most scenarios.* [49]

Calculation Approach: All results are calculated based on integrated radiative forcing (IRF) metrics in terms of pounds of carbon dioxide equivalent (pounds CO_2 e) for 20 years, based on radiative forcing calculations specified in Section 5.2.1 of the LCIA Methodology for PCR Modules. Two effects on radiative forcing (RF) are included:

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[46] The forests which supply wood to the pulp and paper mills are the fiber baskets of each mill.
[47] Intergovernmental Panel on Climate Change. Working Group I Contribution to the IPCC Fifth Assessment Report. *Climate Change 2013: The Physical Science Basis. Summary for Policymakers.*
[48] IPCC Fifth Assessment Report. Table 6.1.5. 2013.
[49] Across the scenarios, the socio-economic implications of avoiding harvests will be different. For example, the socio-economic implications of regenerating forests in Europe are very different from forgoing harvesting in forests in Indonesia or Canada's Boreal. These socio-economic considerations are outside the scope of this LCA.

(1) *Emissions*: This indicator considers climate pollutants causing warming and cooling, using radiative forcing, which expresses the average heat increase per square meter of the Earth's surface. 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, and burning biomass in pulp mills) and forest carbon fluxes (e.g., net forest regrowth, decomposition of belowground biomass) are included in this indicator. To calculate IRF effects from emissions, Global Warming Potential values evaluated over 20 years (GWP-20) are used (see table below).

Table 8. GWP-20 values used for evaluating GHG/Climate Change Impacts indicator.

Pollutant	GWP-20 value
Carbon Dioxide (CO_2)	1
Methane (CH_4)[50]	102
Nitrous Oxide (N_2O)[51]	264
Sulfur Hexafluoride (SF_6)[52]	17,500
HFC-134a[53]	3,710
Nitrogen Trifluoride (NF_3)[54]	12,800
Black Carbon[55] [56]	3,385
Organic Carbon[57]	-128
Sulfur Dioxide (SO_2) [58]	-274
Nitrogen Oxide (NOx)[59]	122

(2) *Forest carbon storage loss calculations*: carbon storage losses resulting from foregone growth resulting from land use management activities lead to changes in atmospheric CO_2 concentrations over the next 20 years.

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[50] Shindell, D.T., Faluvegi, G., Koch, D.M. et al. (2009). Improved Attribution of Climate Forcing to Emissions. Science. 326:716-718. Note that this paper states a GWP-20 value of 105 for methane based on IPCC AR4 report. The GWP-20 value was adjusted to 102 based on AGWP CO2 values provided in IPCC AR5 report in 2013.
[51] IPCC Fifth Assessment Report. Table 8.A.1. 2013.
[52] Ibid.
[53] Ibid.
[54] Ibid.
[55] 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.
[56] 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.
[57] Ibid. Value is based on the highest SPF value for organic carbon (i.e., lowest in magnitude).
[58] W.J. Collins, et al. *Temperature-change potentials for near-term climate forcers.* Atmos. Chem. Phys., 13, 2471,2485, 2013. These are adjusted with a multiplier of 1.75 to include the aerosol indirect effect, using the approach in Shindell, et al., 2009, *Improved Attribution of Climate Forcing to Emissions.* 30 October 2009, Vol. 326, Science magazine.
[59] Collins, W.J., et al (2010): How vegetation impacts affect climate metrics for ozone precursors. Journal of Geophysical Research, Vol. 115, 2010.

This forest carbon storage loss was calculated in conformance with the Roundwood PCR, the Pulp/Paper PCR and Section 5.2.1.2 of the LCIA methodology for PCR Modules. Assessing impacts from foregone growth is based on consideration of the forest growth trajectory under two scenarios:

1. Harvest scenario, where the forests in the forest analysis unit (FAU)[60] are maintained according to the forecasted growth in FAU under planned logging activities.

2. No-harvest scenario: The lands in the forest analysis unit are not subjected to timber harvests, but recover to the same conditions present in undisturbed forest areas (Undisturbed Reference Areas, URA)[61].

Data on forest biomass/carbon stored per hectare was retrieved from the US FIA database[62] and the Canadian National Forest Inventory database for the fiber baskets of mills considered in this assessment. The forest carbon storage loss per hectare was computed based on guidelines provided in Section 5.2.1.2 of the LCIA Methodology for PCR Modules and translated into carbon dioxide equivalents (CO_2e) using Equation 4 and Equation 9 of the document. This is converted to IRF (in units which can be compared to the GWP-20 values) by dividing by 0.0249 $mWm^{-2}Tg^{-1}$ yrs., the Absolute Global Warming Potential over 20 years for CO_2.

3.6.3 Ocean Ecosystem Impacts

This impact group generally deals with effects on ocean ecosystems. The only relevant impact category is Ocean Acidification.

3.6.3.1 Ocean Acidification

Ocean acidification measures increased ocean acidity caused by CO_2, which has detrimental consequences for many marine organisms. This impact indicator 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. This indicator considers CO_2 emitted during the production of pulp and paper, but also evaluates the amount of CO_2 which could be sequestered in trees if forest harvests used for papermaking were halted.

[60] An area of timberland used to represent forest ecosystem impacts resulting from forestry operations within a region.
[61] Area of forest/other wooded land against which measurements of ecological conditions in a Forest Analysis Unit (FAU) are compared. The Undisturbed Reference Area is 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.
[62] US Forest Service FIA database; https://www.fia.fs.fed.us/tools-data/

This impact category is treated separately from Global Climate Change, as the impact categories are linked but represent parallel environmental mechanisms; while CO_2 retained in the atmosphere affects the climate, the portion (roughly 25% of emissions) which is absorbed by the oceans increases ocean acidity. Furthermore, the non-CO_2 climate forcers (e.g. N_2O, NOx, SO_2, etc.) do not affect ocean acidification. This approach is similar to other published LCA papers which have provided characterization models for ocean acidification.[63]

Calculation Approach: The only considered emissions are carbon dioxide (CO_2) and methane (CH_4) from cradle-to-grave. 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 cradle-to-grave emissions of CO_2 and CH_4 occurring from paper production (e.g., net forest regrowth, decomposition of belowground biomass), and (2) carbon storage losses resulting from foregone growth resulting from logging. The PP-CF and M-CFs used to calculate results for this indicator are available in Table 8 of Section 5.3.1 of the LCIA Methodology for PCR Modules.

3.6.3.2 Ocean Warming

Ocean warming measures increased ocean temperatures linked to emissions of greenhouse gases. Although this impact is important and relevant to emissions and foregone growth from logging, no algorithm is currently available to calculate results. Reflecting the critical nature of this impact category, it is reported as relevant to pulp/paper production, although results cannot be evaluated at this time.

3.6.4 Terrestrial and Freshwater Ecosystem Impacts (from Emissions)

3.6.4.1 Sulfur Dioxide (SO_2) and Other Acidifying Emissions/Regional Acidification

Acidifying emissions are chemical compounds such as sulfur dioxide, nitrogen oxides, and other acids (e.g. ammonia) that are produced when boilers burn fuel containing sulfur and other acid-producing substances. Of the fuels used in the paper industry, oil and coal generally contain the highest quantities of sulfur. These acidifying emissions contribute to air pollution problems like acid rain and smog. This category includes SO_2 emissions, but also other acids and emissions like NOx. NOx forms ozone and can also, in parallel, lead to acid rain. The impacts from acid rain are considered in the regional acidification indicator; the health impacts from ozone are considered separately in the "Nitrogen Oxides (NOx) forming Ground Level Ozone/Ground Level Ozone" indicator.

Calculation Approach: This impact category addresses cradle-to-grave 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. The results were calculated based on the potential release of hydrogen ions per kg of acidifying emissions (PP-CF) and the fraction of acidifying emissions which deposit into sensitive soils

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[63] Bach, V., Möller, F., Finogenova, N. et al. Int J Life Cycle Assess (2016) 21: 1463. doi:10.1007/s11367-016-1121-x.

(M-CF). The fraction of emission which deposits into sensitive regions is determined from dispersion plumes of acidifying emissions and differs by location of pulp and paper mill (see Appendix for details on dispersion model used). The PP-CFs used to calculate results for this indicator are available in Table 9 of Section 5.4.1 of the LCIA Methodology for PCR Modules[64]. The M-CFs applied for each paper grade differ by location of the paper mill. To calculate the North American average results of paper grades for this indicator, M-CFs were averaged across a representative sample of paper mills located in North America for each of the 14 paper grades. Table 9 presents the average M-CFs applied for 100% virgin and 100% recycled paper grades.

Table 9. M-CFs for 100% virgin and 100% recycled paper grades used to model North American average results for acidifying emissions/regional acidification indicator.

Type of Paper Grade	M-CF for 100% Virgin (fraction as a percent)	M-CF for 100% Recycled (fraction as a percent)
1. Coated Freesheet	49%	47%
2. Uncoated Freesheet	47%	46%
3. Coated Groundwood	63%	63%
4. Uncoated Groundwood	74%	47%
5. Supercalendered	66%	66%
6. Paperboard: Solid Bleached Sulfate	81%	40%
7. Paperboard: Coated Unbleached Kraft	95%	40%
8. Paperboard: Coated Recycled Board	Not Applicable	40%
9. Paperboard: Uncoated Bleached Kraft	38%	48%
10. Paperboard: Uncoated Unbleached Kraft	54%	48%
11. Paperboard: Uncoated Recycled Board	Not Applicable	48%
12. Linerboard	62%	36%
13. Corrugated	51%	51%
14. Tissue	58%	72%

3.6.4.2 BOD, COD and TSS Emissions

Biochemical oxygen demand (BOD) measures the amount of oxygen that microorganisms consume to degrade the organic material in the wastewater. Discharging wastewater with high levels of BOD can result in oxygen depletion in the receiving waters, which can adversely affect fish and other organisms.

Chemical oxygen demand (COD) measures the amount of oxidizable organic matter in the mill's effluent. Since wastewater treatment removes most of the organic material that would be degraded naturally in the receiving waters, the COD of the final effluent provides information about the quantity of more persistent substances discharged into the receiving water.

Total suspended solids (TSS) measure solid material suspended in mill effluent, which can adversely affect bottom-living organisms upon settling in receiving waters and can carry toxic heavy metals and organic compounds into the environment.

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[64] Life Cycle Impact Assessment Methodology for PCR Modules for Roundwood and Pulp/Paper; https://www.scsglobalservices.com/files/program_documents/pcr_final_lcia-methodology_101816.pdf

Calculation Approach: Results consider cradle-to-gate estimates of BOD, COD and TSS, accounting for BOD, COD and TSS generated in the production of pulping chemicals, coatings, fillers and other waste treatment processes occurring in the upstream. They are reported as aggregated inventory results in terms of pounds per mass of paper grade selected.

Note: The deinking and pulping processes for recycled paper can sometimes generate higher volumes of wastewater discharges. Treatment of wastewater results in the formation of sludge waste. Sludge generated from the deinking process contains minerals, coatings, fillers, ink particles and deinking additives, resulting in BOD, COD and TSS generations. Therefore, the BOD and COD results for some recycled paper grades are higher compared to virgin paper grades.

3.6.5 Impacts on Terrestrial and Freshwater Ecosystems (from Land Use and Conversion)

Four indicators (forest disturbance, freshwater disturbance, wetland disturbance and threatened species disturbance) reported in the Paper Calculator belong to the group of impacts titled “Terrestrial and Freshwater Ecosystem Impacts from Land Use” (see Section 7.2 of the Roundwood PCR[65] and Section 5.5 of the LCIA Methodology for PCR Modules[66]). These indicators account for land-use related activities that can lead to physical disturbance which eventually leads to impacts to local or regional ecosystems in terrestrial and freshwater settings. These impacts are inherently local, though the scale of effects, both direct and indirect, can vary broadly.

Impacts to terrestrial and freshwater ecosystems from land-use activities around the world have consequences on many scales. Impacts of concern to many stakeholders include loss of biodiversity, changes in biosphere integrity, loss of endangered species, and more. In the production of paper, the main contributing activity is logging. These activities directly alter ecological conditions in terrestrial and freshwater ecosystems (i.e., lead to disturbances), which are measurable within ecosystems at many different scales. It is critical to understand these impacts at the landscape scale, understanding not only the impacts from direct harvest, but effects from fragmentation on adjacent forests.

3.6.5.1 Forest Disturbance

The forest disturbance indicator measures the degree to which activities affect forest ecosystems and biodiversity. The indicator compares the ecosystem integrity of a harvested site to intact forests over 80 years old in the region, using on-the-ground measurements. It also considers the recovery potential which would be possible on the site if harvesting were halted, reflecting the long-term implication of forest management at suppressing ecosystem integrity. This is important to understand in terms of the

[65] PCR Module for Roundwood Production:
https://www.scsglobalservices.com/files/resources/pcr_final_wood-products_101816.pdf
[66] Life Cycle Impact Assessment Methodology for PCR Modules for Roundwood and Pulp/Paper;
https://www.scsglobalservices.com/files/program_documents/pcr_final_lcia-methodology_101816.pdf

"opportunity cost" of forest recovery suppression, which is salient both in understanding the effect of current forest management on future disturbance levels, but also the possible carbon storage which could be accrued in the forest.

Results of this indicator provide data on the *current* conditions of these impacts, within the fiber basket for each paper grade. However, a critical component to understand ecosystem impacts is also the duration and trend in conditions. Terrestrial and freshwater ecosystems, after significant and persistent disturbance, can take decades to fully recover; and conversely, intact ecosystems can take long periods of time to be converted into a highly disturbed state. For these reasons, it is critical to understand whether the forest is improving or being further degraded in addition to the current state. Each affected forest, if no longer subject to harvest, would recover over time.

Calculation Approach

Terrestrial systems are defined using the WWF Wildfinder database[67] for ecoregions (see Figure 10); within each terrestrial system, average ecological conditions such as average tree diameter, tree species composition, and biomass are measured in specific Forest Analysis Units (FAUs) and compared to undisturbed conditions. The deviation in ecological conditions is averaged to evaluate current terrestrial disturbance, which provides a holistic and quantitative measure of understanding the severity of effects on local terrestrial ecosystems. The site productivity is another parameter, which has a very important effect on the embedded impact of fiber. For additional context, potential recovery, which could be realized in forest ecosystems, is also provided. There was a high quality of data to evaluate terrestrial disturbance for all paper grades. Figure 9 presents an example of the publicly available forest carbon data on the US Forest Services website that was used for assessing this indicator.

[67] WWF Wildfinder database; https://www.worldwildlife.org/science/wildfinder/

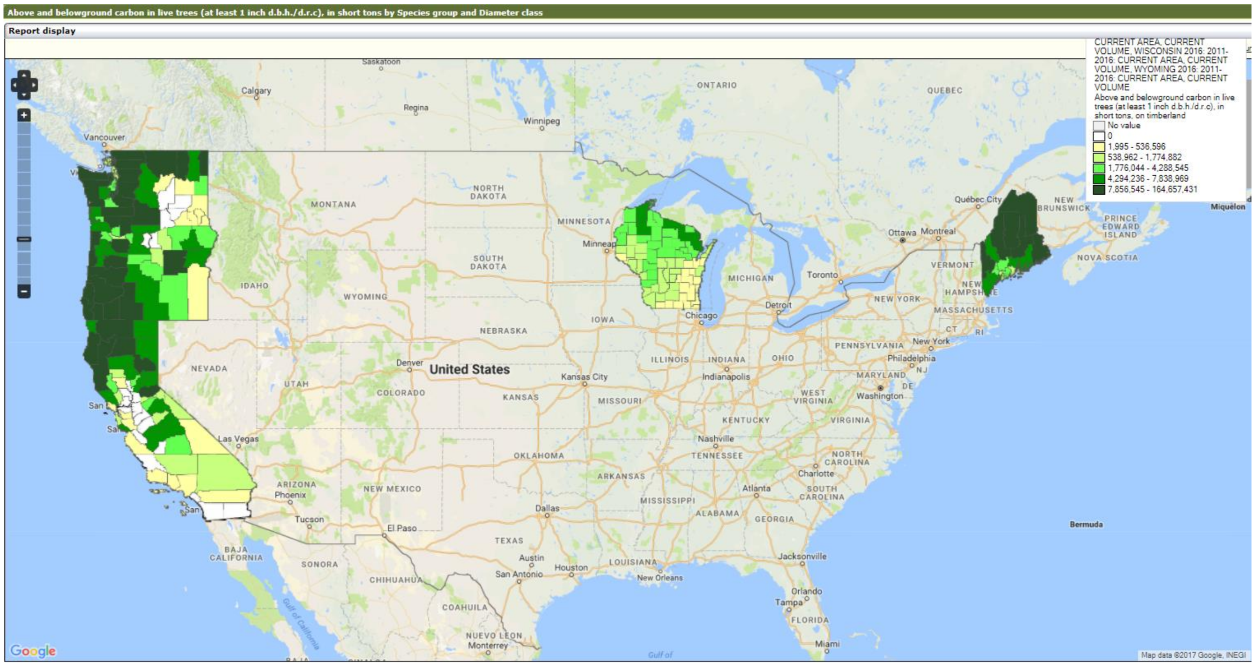

Figure 9. Snapshot of "Above and below ground carbon in live trees" dataset representing the forest carbon density for the states of California, Oregon, Washington, Wisconsin and Maine from the US Forest Services website[68].

The foregone recovery of forest ecosystems was calculated in conformance with the Roundwood PCR, the Pulp/Paper PCR and the guidelines specified in Section 5.5.1 of the LCIA Methodology for PCR Modules. Based on the trend of disturbance (increasing, decreasing or recovering trend) determined from historic data, the current level of terrestrial disturbance in the forest analysis unit was assumed to continue with the same trend over the next 20 years, and then compared after 20 years to a conservatively high estimate of rate of recovery (assuming that the forest system would recover by 2% every year if the forests had not been harvested). Refer to Section 5.5.1.1 and 5.5.1.2 in LCIA Methodology for PCR Modules[69] for more details on equations and methodology. This indicator is not applicable to 100% recycled paper.

3.6.5.2 Freshwater Disturbance

Logging can impact streams, rivers, and creeks, by increasing erosion, removing riverside vegetation, and removing large woody debris which many fish species require for habitat. This indicator evaluates the number of freshwater systems possibly affected by logging. This indicator is relevant to the product system considered in this study and is highly variable across different regions. However, there was insufficient data of comparable quality to identify affected freshwater systems across the scope of mills

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[68] https://apps.fs.usda.gov/fia/fido/

[69] Life Cycle Impact Assessment Methodology for PCR Modules for Roundwood and Pulp/Paper; https://www.scsglobalservices.com/files/program_documents/pcr_final_lcia-methodology_101816.pdf

considered in this assessment. Results could not be evaluated. This indicator is not applicable to 100% recycled paper.

3.6.5.3 Wetland Disturbance

Logging can impact wetlands by increasing erosion, which will cause changes in sediment, temperature and other characteristics of wetlands. Although this impact is important, no data is currently available to calculate results. Reflecting the critical nature of this impact category, it is reported as relevant to pulp/paper production, although results cannot be evaluated at this time. This indicator is not applicable to 100% recycled paper.

3.6.5.4 Threatened Species Habitat Disturbance

Threatened species refers to effect on habitats of threatened species; the indicator evaluates the possible species affected by harvesting of wood for paper production. Number of species sensitive to logging operations in the fiber basket of the mill are included for all the paper grades. Guidelines provided in Section 5.5.4 of the LCIA Methodology for PCR Modules[70] document were used to assess this indicator. Terrestrial systems are defined using the WWF Wildfinder database[71] for ecoregions (see Figure 10) in North America. The number of threatened species in fiber basket of the mills located in these terrestrial ecoregions is estimated from the IUCN Red List database[72].

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[70] Life Cycle Impact Assessment Methodology for PCR Modules for Roundwood and Pulp/Paper; https://www.scsglobalservices.com/files/program_documents/pcr_final_lcia-methodology_101816.pdf
[71] WWF Wildfiner database; https://www.worldwildlife.org/science/wildfinder/
[72] IUCN Red List; http://www.iucnredlist.org/

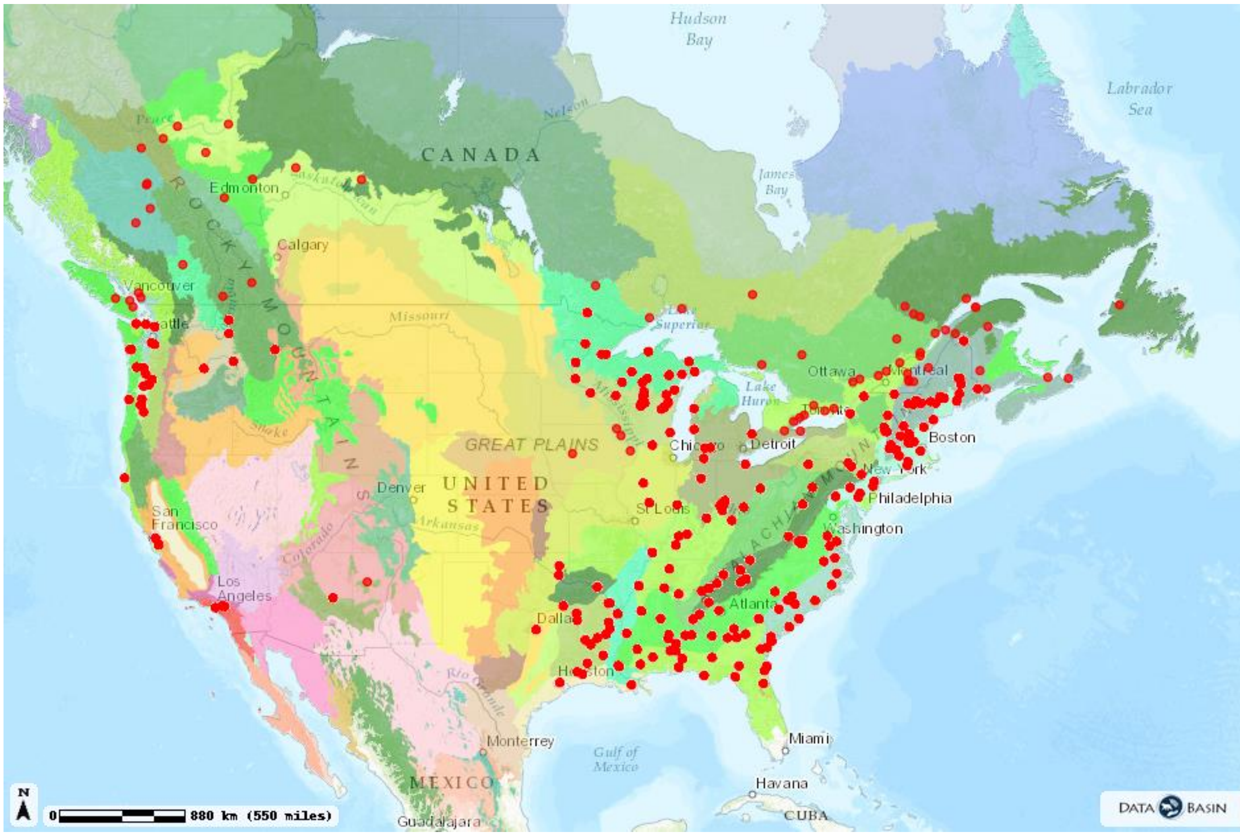

Figure 10. The figure represents the terrestrial ecoregions across North America, as defined by WWF Wildfinder database. The red spots represent the location of the pulp and paper mills.

Calculation Approach: Included are all threatened categories of species affected by wood harvested for pulp and paper production, based upon the definition of the "threatened categories" according to the IUCN Red List Categories and Criteria Version 3.1 Second Edition[73]. This includes species (mammals, amphibians, reptiles and birds) meeting the categories of Critically Endangered, Endangered, or Vulnerable in the IUCN Red List database[74]. Only those species with habitats and/or populations negatively affected by logging in the North American region were included. The number of species included is based on correlation of logging threats assessed by IUCN and the fiber basket of pulp and paper mills. This indicator is not applicable to 100% recycled paper.

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[73] IUCN Red List; http://www.iucnredlist.org/
[74] IUCN Red List; http://www.iucnredlist.org/

3.6.6 Human Health Impacts (from Chronic Exposure to Hazardous Chemicals)

3.6.6.1 Nitrogen Oxides (NOx) Forming Ground Level Ozone/ Ground Level Ozone

Nitrogen oxides (NOx, which includes NO and NO_2) are products of the combustion of fuels that contain nitrogen. NOx emissions occur in pulp and paper mills due to the use of boilers and recovery furnaces to produce the steam and electricity for pulp/paper production. NOx can react with volatile organic compounds and sunlight in the lower atmosphere to form ozone, a key component of urban smog. NOx can also, in parallel, lead to acid rain. The health impacts from ozone are considered here; the acid rain impacts on the environment are considered separately in the "Sulfur Dioxide (SO_2) and Other Acidifying Emissions/Regional Acidification" category. Human health impacts are widely recognized to occur when ozone near the Earth's surface (ground level ozone, or "GLO") is found at concentrations above critical threshold concentrations, especially for prolonged periods of time.

Calculation Approach: This indicator addresses the cradle-to-grave 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). Based on guidelines provided in Section 5.6.1 of the LCIA Methodology for PCR Modules, a PP-CF of 1 ton of ozone per ton of NOx emission was used as default. The M-CF characterizes the exposure of human population to ground level ozone at concentrations exceeding safe threshold defined by the WHO (see Appendix for details on dispersion model used). The M-CFs applied for each paper grade differs by location of the paper mill. The M-CFs were generated using air dispersion models of ground level ozone across a sample of locations of pulp and paper mills. To calculate the North American average results of paper grades for this indicator, M-CFs were averaged across a sample of representative paper mills located in North America for each of the 14 paper grades. Table 10 presents the average M-CFs applied for 100% virgin and 100% recycled paper grades.

Table 10. M-CFs for 100% virgin and 100% recycled paper grades used to model North American average results for ground level ozone indicator.

Type of Paper Grade	M-CF for 100% Virgin (persons * hrs. * ppb O_3 / metric ton O_3)	M-CF for 100% Recycled (persons * hrs.* ppb O_3 / metric ton O_3)
1. Coated Freesheet	107	106
2. Uncoated Freesheet	189	185
3. Coated Groundwood	29.5	29
4. Uncoated Groundwood	68	69
5. Supercalendered	45	44
6. Paperboard: Solid Bleached Sulfate	60	324
7. Paperboard: Coated Unbleached Kraft	55	324
8. Paperboard: Coated Recycled Board	Not Applicable	324
9. Paperboard: Uncoated Bleached Kraft	167	79
10. Paperboard: Uncoated Unbleached Kraft	558	79
11. Paperboard: Uncoated Recycled Board	Not Applicable	79
12. Linerboard	60	387
13. Corrugated	102	103
14. Tissue	122	34

3.6.6.2 Particulates/PM 2.5 Impacts

Particulates are small airborne particles generated during combustion of fossil fuels and biomass in boilers in pulp and paper mills. PM2.5 pose a range of health risks, including asthma and other respiratory problems, when inhaled. This impact category considers the effect of particulate matter (PM) emissions from pulp/paper production, contributing to smog. It addresses the health risks from inhalation of particles less than 2.5 microns in diameter ($PM_{2.5}$).

Calculation Approach: This indicator refers to human exposure to particulates smaller than 2.5 microns at levels above human health thresholds. 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. This impact category characterizes the mass of $PM_{2.5}$ transported into the atmosphere as the result of an emission (PP-CF) and characterizes the exposure of humans to fine particulate matter, considering the local severity of health impacts linked to elevated levels of $PM_{2.5.}$(M-CF; see Appendix for details on dispersion model used). The M-CFs applied for each paper grade differs by location of the paper mill. The PP-CFs used to calculate results for this indicator are available in Table 16 of Section 5.6.2 of the LCIA Methodology for PCR Modules. The M-CFs were generated using air dispersion models of particulate emissions across a sample of locations of pulp and paper mills. To calculate the North American average results of paper grades for this indicator, M-CFs were averaged across a sample of paper mills located in North America for each of the 14 paper grades. Table 11 presents the average M-CFs applied for 100% virgin and 100% recycled paper grades.

Table 11. M-CFs for 100% virgin and 100% recycled paper grades used to model North American average results for PM2.5 Impacts.

Type of Paper Grade	M-CF for 100% Virgin (persons * hrs. * microgram PM2.5 m^{-3} / metric ton PM2.5)	M-CF for 100% Recycled (persons * hrs. * microgram PM2.5 m^{-3}/ metric ton PM2.5)
1. Coated Freesheet	22	21
2. Uncoated Freesheet	60	58
3. Coated Groundwood	15	14
4. Uncoated Groundwood	39	501
5. Supercalendered	14	14
6. Paperboard: Solid Bleached Sulfate	19	560
7. Paperboard: Coated Unbleached Kraft	26	560
8. Paperboard: Coated Recycled Board	Not Applicable	560
9. Paperboard: Uncoated Bleached Kraft	997	23
10. Paperboard: Uncoated Unbleached Kraft	77	23
11. Paperboard: Uncoated Recycled Board	Not Applicable	23
12. Linerboard	25	117
13. Corrugated	20	20
14. Tissue	858	35

Note: In some instances, the M-CF for recycled mills are higher than M-CF of virgin mills, resulting in higher ground level ozone and PM2.5 impacts for recycled papers compared to virgin papers. The M-CFs are subject to the location of the paper mill and depends on the population exposure risk from inhalation of ozone/particulates at the particular location. Generally, recycled paper mills emit lower amount of particulates and nitrogen oxide emissions compared to virgin papers. However, the population exposure to these emissions at levels above human health thresholds could be higher for recycled paper mills compared to virgin paper mills depending on the population density surrounding the location of the mill. Thus, use of mills located in different regions for a given paper grade could influence results for PM2.5 and ground level ozone level impacts.

3.6.6.1 Hazardous Air Pollutants (HAPs), Total Reduced Sulfur (TRS) and Volatile Organic Compounds (VOCs) Indicators

Hazardous air pollutants (HAPs) include any of a group of 188 substances identified in the 1990 U.S. Clean Air Act amendments because of their toxicity.

Total reduced sulfur (TRS) compounds cause the odor associated with kraft pulp mills. Exposure to TRS emissions has been linked to symptoms including headaches, watery eyes, nasal problems, and breathing difficulties.

Volatile organic compounds (VOCs) are a broad class of organic gases, such as vapors from solvent and gasoline. VOCs react with nitrogen oxides (NOx) in the atmosphere to form ground-level ozone, the major component of smog and a severe lung irritant.

HAPs, TRS and VOCs are mainly emitted from pulping process equipment such as recovery furnaces, smelt dissolving tanks and industrial boilers.

Calculation Approach: Data for HAPs, TRS and VOC indicators were retrieved for all pulp and paper mills operating in North America in year 2015 from US EPA's Toxic Release Inventory (TRI) database[75] and Canada's National Pollutant Release Inventory (NPRI) database[76]. Results for these indicators represent cradle-to-grave aggregated inventory emissions of HAPs, TRS and VOC compounds.

3.6.7 Additional Environmental Information

In addition to the indicators reported above, the Paper Calculator provides aggregated inventory results for the following key indicators.

[75] US EPA Toxic Release Inventory program; https://www.epa.gov/toxics-release-inventory-tri-program/tri-data-and-tools
[76] National Pollutant Release Inventory(NPRI); Environment Canada; www.ec.gc.ca/npri

3.6.7.1 Mercury Emissions and Dioxins Emissions

Mercury is a very toxic substance which persists in the environment for very long periods of time. Mercury emissions usually results from combustion of fuels containing trace amounts of mercury, which subsequently transports in the atmosphere. Emissions can therefore lead to contamination in the environment, including freshwater bodies and oceanic systems, subsequently exposing flora and fauna to elevated concentrations. This result considers the amount of mercury emissions released across the paper's life cycle from cradle-to-grave.

Emissions of dioxins occur at pulp mills as a by-product of the chlorine bleaching process. Dioxin emissions measures the amount of toxic dioxin emissions that are released to air and water from pulp and paper mills. Dioxins are persistent and bioaccumulative, and even small amounts of emission can contaminate local waterways and bioaccumulate in fish.

Calculation Approach: Data for mercury and dioxin indicators were retrieved for all pulp and paper mills operating in North America in year 2015 from US EPA's Toxic Release Inventory (TRI) database and Canada's National Pollutant Release Inventory (NPRI) database. Results for these indicators represent cradle-to-grave aggregated inventory emissions of mercury and dioxins.

3.6.7.2 Solid Waste

Solid waste results are from cradle-to-grave and only include the amount of solid waste generated during pulp and paper production, and amount of waste generated during the end-of-life phase. Solid waste generated in upstream sources (e.g. pulping chemical production, electricity production, coating/fillers, etc.) is excluded, consistent with the approach used in the previous version of the Paper Calculator (V3.2).

Calculation Approach: Solid waste data on pulp and paper production is based on mix of USLCI and Ecoinvent datasets (see Table 6 for more detail). During the end-of-life phase, a fraction of paper is either recycled, landfilled or incinerated. Calculation for end-of-life are based on 2014 statistics regarding municipal solid waste generation and disposal in the United States, from the US EPA[77]. These data provide recycling rates for paper and packaging products. Based on information from the MSW reports (see Table 4), 80% of the materials not recycled are assumed to go to a municipal landfill and the remaining 20% are assumed to be incinerated. For the end-of-life phase, the amount of solid waste generated from discarding 1 metric ton of paper is determined based on the fraction of paper that is disposed in a landfill and a municipal incinerator. For example, according to the MSW report, the recycling rate of newspaper is 68.2%, which means for 1 metric ton of paper disposed, 0.68 metric ton of paper is recycled, and of the remaining 0.32 metric ton of paper, 80% is landfilled (i.e. 0.25 metric ton of

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[77] US EPA. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Tables and Figures for 2014. https://www.epa.gov/sites/production/files/2016-11/documents/2014_smmfactsheet_508.pdf

paper is landfilled) and 20% is incinerated (i.e. 0.07 metric ton paper is incinerated). Thus, the amount of solid waste generated at the end-of-life of newspaper production would be 0.32 metric ton of paper.

3.6.7.3 Herbicides

Herbicides measures the amount of toxic herbicides used in growing trees for paper production. Herbicides are applied to control the spread of non-desirable species. This indicator is relevant to the product system considered in this study and is highly variable across different regions. However, there was no data available to evaluate this indicator.

3.6.8 Factors Applied to Determine Equivalencies for Impact Indicators

Table 12 provides the equivalency factors used to determine equivalencies for Paper Calculator v4.0 indicator results. For the most part, the equivalencies applied in v4.0 are the same as in v3.2. However, some equivalencies have been updated based on latest data made available by government agencies such as the US EPA, Department of Energy, etc. These new equivalencies are indicated with an asterisk (*) sign and heighted in blue text in the table below.

Table 12. Equivalency Factors applied for Paper Calculator v4.0 Indicators.

Paper Calculator v4.0 Outputs			
Impact Indicator Name	**Unit of Measurement**	**Equivalency Used**	**Reference for Equivalency**
Wood Use	Fresh/green tons	# of trees	Approximately 6 trees per fresh ton of wood. The number of typical trees assumes a mix of hardwoods and softwoods 6-8" in diameter and 40' tall. Calculated collaboratively by Conservatree, Environmental Defense Fund, and Environmental Paper Network.
Total Energy	BTUs	# homes/year # residential refrigerators operated/year*	The average U.S. household uses 91 million BTUs of energy in a year[78]. Annual energy consumption is 0.84 million BTU for operating 1 refrigerator. This is based on estimates from the US Federal Standard[79]. The US Federal Standard is the maximum energy consumption in kWh/year allowed by the DOE for a residential refrigerator with a total volume of 7-15 cubic feet.
Greenhouse Gases/Climate Change Impacts	pounds CO_2 equiv.	# of cars/year	The average car emits 11,013 pounds of CO_2e in a year[80].

[78] EIA (2016). 2016 Annual Energy Outlook, Table A4.
[79] https://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrig_finalrule_frnotice.pdf
[80] https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

Paper Calculator v4.0 Outputs			
Impact Indicator Name	Unit of Measurement	Equivalency Used	Reference for Equivalency
Water Consumption	gallons	# swimming pools # of clothes washers operated/year*	1 Olympic-sized swimming pool holds 660,430 gallons[81]. The estimated annual water use of the washer under typical conditions is 1386 gallons per clothes washer. It is based on an annual usage of around 295 loads per year or around 6 loads per week, as referenced by Department of Energy (DOE) test procedure, Code of Federal Regulations Title 10, Section 430, Appendix J2[82].
Solid Waste	pounds	# of garbage trucks # people generating solid waste/day*	1 fully-loaded garbage truck weighs an average of 28,000 pounds (based on a rear-loader residential garbage truck). US EPA's 2012 Municipal Solid Waste (MSW) report[83] estimates that an average of 4.38 pounds of solid waste is generated per person per day.
Nitrogen Oxides (NOx) Forming Ground Level Ozone/Ground Level Ozone	persons*hrs.*pounds O_3 eq/m^3	# of 18-wheelers/year # gasoline powered passenger cars/year*	The average 18-wheel truck emits 261 pounds of NOx per wheeler per year[84]. Based on GREET model's emissions factors[85], the average gasoline powered car emits 3 pounds of NOx per car per year.
Purchased Energy	million BTUs	# homes/year # residential refrigerators operated/year*	The average U.S. household uses 91 million BTUs of energy in a year[86]. Annual energy consumption is 0.84 million BTU for operating 1 refrigerator. This is based on estimates from the US Federal Standard[87]. The US Federal Standard is the maximum energy consumption in kWh/year allowed by the DOE for a residential refrigerator with a total volume of 7-15 cubic feet.
Particulates/PM2.5 Impacts	persons*hrs.*pounds PM2.5 eq/m^3	# of buses/year # gasoline powered passenger cars/year*	The average urban bus emits 11.2 pounds of particulate matter in a year.[88] Based on GREET model's emissions factors[89]. The average gasoline powered car emits 0.17 pounds per car per year.

[81] http://www.patagoniaalliance.org/wp-content/uploads/2014/08/How-much-water-does-an-Olympic-sized-swimming-pool-hold.pdf
[82] https://energy.gov/sites/prod/files/2015/07/f24/clothes_washers_tp_finalrule.pdf
[83] https://www.epa.gov/sites/production/files/2015-09/documents/2012_msw_fs.pdf
[84] It is equivalent to 52,461 persons*hrs.*pounds O_3 eq/m^3 per wheeler per year.
[85] Table A2 for passenger cars; https://greet.es.anl.gov/files/vehicles-13
[86] EIA (2016). 2016 Annual Energy Outlook, Table A4.
[87] Table A2 for passenger cars; https://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrig_finalrule_frnotice.pdf
[88] It is equivalent to 1,680 persons*hrs.*pounds PM2.5/m^3 per bus per year.
[89] Table A2 for passenger cars; https://greet.es.anl.gov/files/vehicles-13

Paper Calculator v4.0 Outputs			
Impact Indicator Name	Unit of Measurement	Equivalency Used	Reference for Equivalency
Sulfur Dioxide (SO_2) and Other Acidifying Emissions/Regional Acidification	pounds SO_2 eq	# of 18-wheelers/year	The average 18-wheel truck emits 3.1 pounds of SO_2 in a year.
Volatile Organic Compounds (VOCs)	pounds	# of passenger cars/year # number of miles driven in a car/year*	The average passenger car in the US emits 2.6 pounds of VOCs in a year. Based on GREET model's emissions factors[90]. The average gasoline powered car emits 0.0002 pounds of VOC per mile per year.
Hazardous Air Pollutants (HAPs)	pounds	# of passenger cars/year	The average passenger car in the US emits 5 pounds of HAPs in a year.
Chemical Oxygen Demand (COD)	pounds	# of homes/year	The average home discharges 465 pounds of COD in a year[91].
Biochemical Oxygen Demand (BOD)	pounds	# of homes/year	The average home discharges 186 pounds of BOD in a year[92].
Total Suspended Solids (TSS) / Freshwater Eutrophication	pounds	# of homes/year	The average home discharges 207 pounds of TSS in a year[93].
Forest Disturbance	acres of disturbed area	# of equivalent football fields*	The average American football field occupies 1.32 acres[94].
Ocean Acidification	pounds H_2CO_3	# of cars/year	The average car emits 11,013 pounds of CO_2e in a year, which correlates to 3,881 pounds of H_2CO_3 per car per year.
Mercury Emissions	milligrams of mercury	# of CFL lamps*	According to EPA[95], on average, CFLs contain about 4 milligrams of mercury sealed within the glass tubing.

**New equivalency introduced in Paper Calculator v4.0.*

[90] Table A2 for passenger cars; https://greet.es.anl.gov/files/vehicles-13
[91] U.S. EPA NPDES Permit Writers' Manual; https://www3.epa.gov/npdes/pubs/owm0243.pdf
[92] U.S. EPA NPDES Permit Writers' Manual; https://www3.epa.gov/npdes/pubs/owm0243.pdf
[93] U.S. EPA NPDES Permit Writers' Manual; https://www3.epa.gov/npdes/pubs/owm0243.pdf
[94] Area calculated based on the standard dimensions of an American football field: 120 yards long and 53.33 yards wide.
[95] https://www.epa.gov/cfl/what-are-connections-between-mercury-and-cfls

3.7 Sensitivity Analysis for Recycled Papers by Assigned Credit for Diversion of Wastepaper from Landfill

The current evaluation of results for the Paper Calculator (v4.0) uses a different allocation method for modeling impacts of recycled paper compared to the previous version of the Paper Calculator (v3.2).

Overview of allocation method used in Paper Calculator v3.2

Paper Calculator v3.2 used an *open loop recycling methodology*, in which burdens for material production, recovery and reprocessing and disposal were shared among the useful lives of the material, reducing the burdens allocated to each use of the material. In the Paper Calculator v3.2, recycling of a paper-based product was assumed to have an average of three useful lives: 1) pulp production and paper-making and product use; 2) collection, fiber recovery, re-pulping, paper-making, and product use; and 3) collection, fiber recovery, re-pulping, paper-making, product use, and disposal.

In the end-of-life phase, the impacts for recycling in Paper Calculator v3.2 included burdens for collection and sorting of recovered paper and credits for waste diversion due to recycling—applied twice, once after each of the first two useful lives—and final disposal impacts (from collection and landfilling/incineration) after the third useful life. This open loop recycling methodology makes assumptions about previous and subsequent life cycles, embedding a high degree of uncertainty. Hence this approach was not used in the Paper Calculator v4.0.

Allocation method used in Paper Calculator v4.0: Paper Calculator v4.0 uses the recycled content approach (also known as 100-0 cut off approach), whereby the impacts from the prior and subsequent life cycles are not included (see Section 3.3.2 for more detail). In the current assessment, the recycling of waste paper into recycled pulp does not provide any credit associated with the avoidance of landfill impacts.

A sensitivity analysis was conducted for select indicators (GHG impacts, ocean acidification and solid waste) by providing a credit for the amount of waste paper diverted from the landfill for making recycled paper. The section below summarizes the calculation method used to assign the landfill avoidance credit.

3.7.1.1 Calculation of the Landfill Avoidance Credit

The following landfill emissions are included**:** carbon dioxide (CO_2) and methane (CH_4), which would have been emitted during paper decomposition in the landfill (also included is the combustion of methane in some landfills). To calculate the credit, these emissions are considered to be “avoided” as a result of the diversion of recycled wastepaper; these “avoided emissions” are attributed as a positive environmental credit to recycled paper. The equation used to calculate the CO_2 and CH_4 emissions from landfill are based on Equation 1, all evaluated per metric ton of carbon included in the wastepaper diverted from landfill (itself roughly one third of the total mass of paper).

Equation 1. Calculation for avoided CO_2 and CH_4 from landfills. (A) Is the avoided CO_2, in metric tons and (B) is the avoided CH_4, in metric tons. In both equations, C is the total mass of carbon in the wastepaper diverted from landfill and used in the pulping process (in metric tons), while CH_4 Combustion Fraction is the fraction of methane combusted at the landfill site. 44/12 and 16.04/12 are respectively the molar mass ratios of CO_2 and methane CH_4 to elemental carbon.

$$(A)\ \ Avoided\ CO_2 = C \times 0.5 \times \frac{44}{12} \times (1 + CH_4\ Combustion\ Fraction)$$

$$(B)\ \ Avoided\ CH_4 = C \times 0.5 \times \frac{16.04}{12} \times (1 - CH_4\ Combustion\ Fraction)$$

Example Calculation

The landfill avoidance credit for 1 metric ton of 100% Recycled Coated Freesheet Paper Grade was calculated based on Equation 1 in the following manner:

C= Total mass of carbon in the wastepaper diverted from landfill = (34% carbon content[96]*1.1 metric ton of wastepaper) = 0.374

CH_4 combustion fraction = 100% (this is an assumption which results in a conservatively low positive credit amount for recycled paper)

(a) Avoided CO_2 = 0.374 x 0.5*x 44/12 x (1+ 100%) = 1.372 metric tons CO_2e

(b) Avoided CH_4= 0.374 x 0.5*x 16.04/12 x (1-100%) = 0 metric tons CO_2e

Landfill avoidance GHG impact for 1 metric ton of 100% recycled coated freesheet paper = (a) + (b) = 1.372 metric tons CO_2e per metric ton of paper = 3,019 pounds CO_2e per metric ton of paper

GHG impacts for 1 metric ton of 100% recycled coated freesheet with landfill avoidance impacts = 8,249 pounds CO_2e - 3019 pounds CO_2e per metric ton of paper= 5,230 pounds CO_2e per metric ton of paper.

Similarly, landfill avoidance credit was calculated for other paper grades. Figure 11 through Figure 13 presents results for select indicators (GHG Impacts, Ocean Acidification and Solid Waste) for 14 recycled paper grades. These results include the application of a landfill avoidance credit for recycled papers. The charts also illustrate the results for virgin paper grades and recycled paper grades (without credit) for a basis of comparison with the results for recycled papers with a landfill avoidance credit.

[96] Based on carbon content of materials tested in the following: (1) Barlaz, M.A. (1998). Carbon storage during biodegradation of municipal solid waste components in laboratory-scale landfills. Global Biogeochemical Cycles, 12 (2), 373–380 and (2) Wang, X., Padgett, J.M., De la Cruz, F.B., and Barlaz, M.A. (2011). Wood Biodegradation in LaboratoryScale Landfills. Environmental Science & Technology, 2011 (45), 6864-6871.

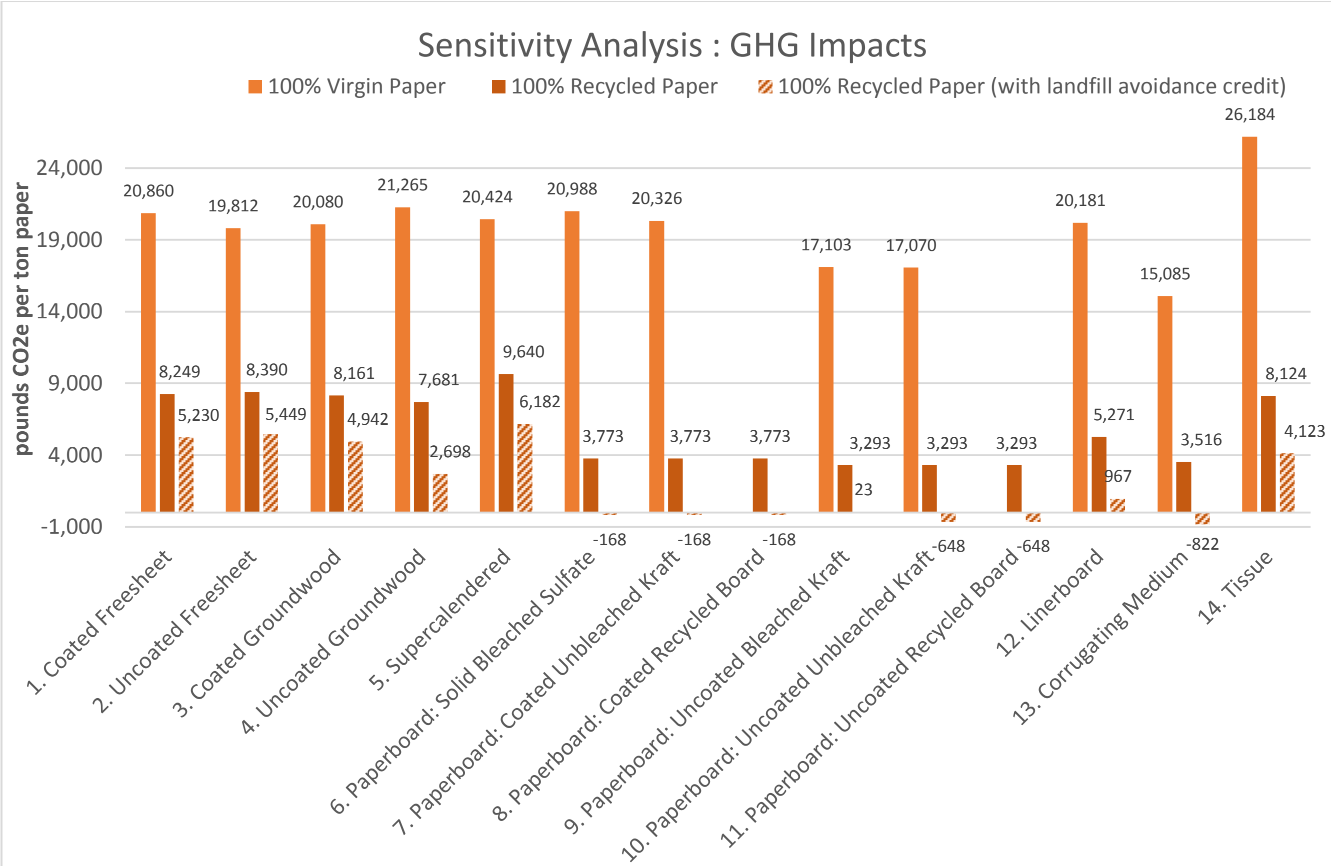

Figure 11. Sensitivity analysis is explored for the GHG Impact indicator for 100% Recycled Papers, by providing a credit for the amount of waste paper diverted from the landfill. For the purpose of comparison, results for 100% Virgin Paper and 100% Recycled Paper (without the credit) are illustrated in the chart.

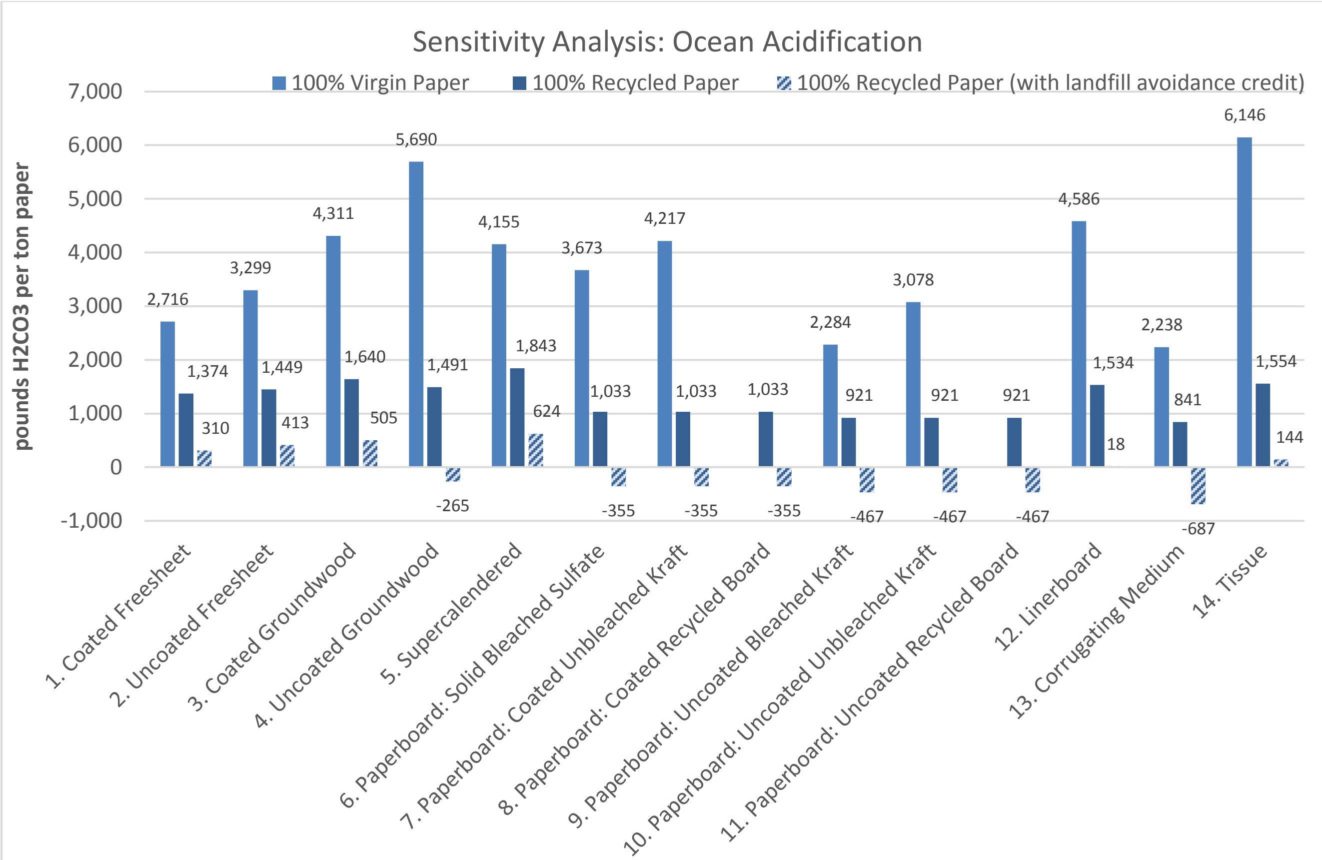

Figure 12. Sensitivity analysis is explored for the Ocean Acidification indicator for 100% Recycled Papers, by providing a credit for the amount of waste paper diverted from the landfill. For the purpose of comparison, results for 100% Virgin Paper and 100% Recycled Paper (without the credit) are illustrated in the chart.

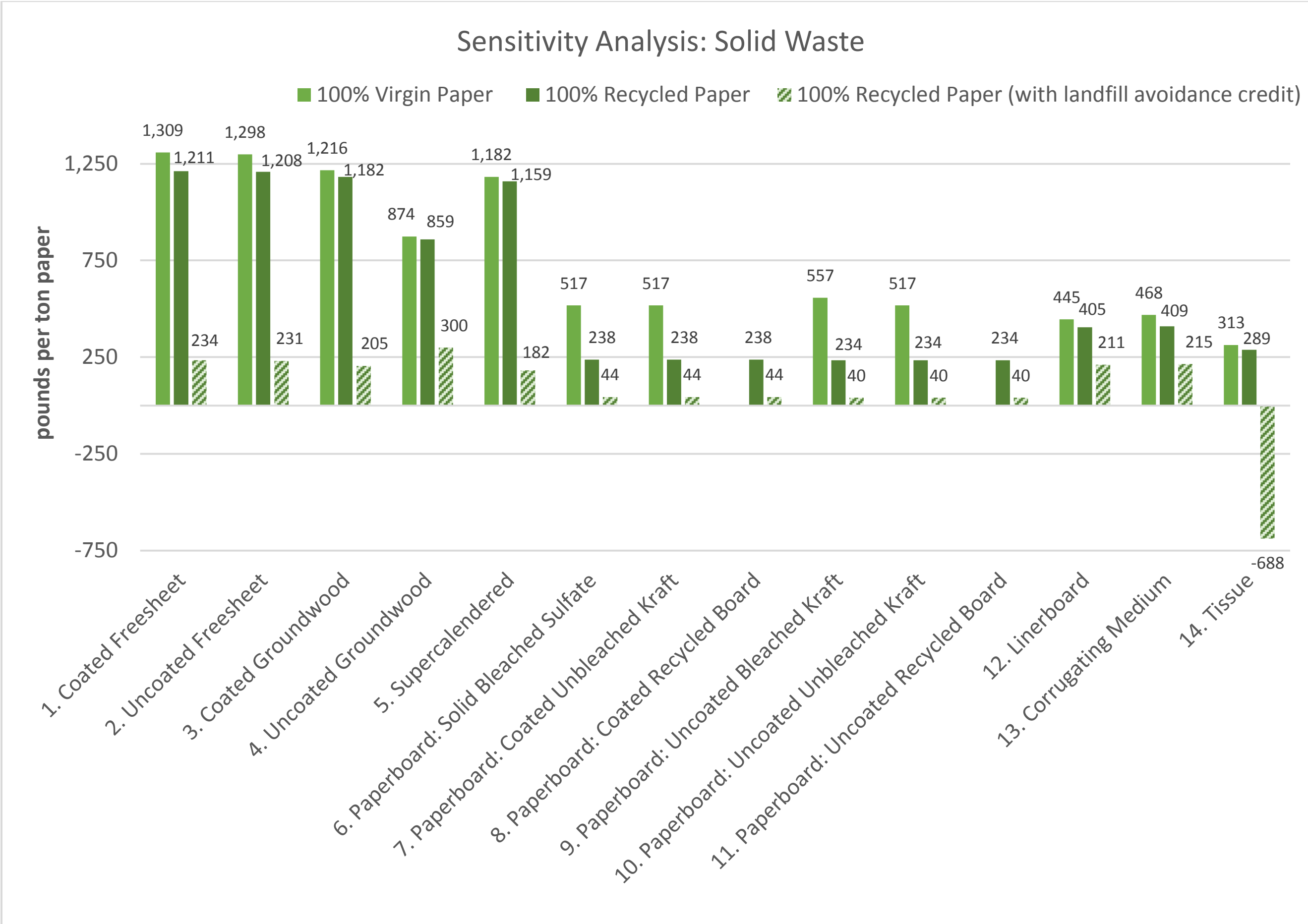

Figure 13. Sensitivity analysis is explored for the Solid Waste indicator for 100% Recycled Papers, by providing a credit for the amount of waste paper diverted from the landfill. For the purpose of comparison, results for 100% Virgin Paper and 100% Recycled Paper (without the credit) are illustrated in the chart.

The application of a credit for diversion of wastepaper from landfills increases the differential between results for 100% Virgin Papers and 100% Recycled Papers. The negative relative impact results are due to the significant impact of paper disposal in landfills that is credited to deinked pulp. For example, paper grades with high recycling rates such as paperboard (89% recycling rate according to US EPA) receive larger credits at the end-of-life, resulting in negative results for some paper grades. The sensitivity analysis results indicate that 100% Recycled Papers appear highly favorable compared to 100% Virgin Papers, even without the application of the landfill avoidance credit.

4 Conclusions

This methodology document describes the factors used to update the Paper Calculator. In order to update the Paper Calculator, the impact profile of 14 different paper grades manufactured in North America were assessed using LCA in conformance with ISO 14044[97], the draft LEO-S-002 standard[98], the Roundwood PCR[99], the Pulp/Paper PCR[100] and the LCIA Methodology for PCR Modules[101]. The data sources, background datasets, assumptions, limitations and methodology used to assess 24 indicators used in the Paper Calculator are included in this documentation.

97 ISO 14044:2006 Environmental management – Life Cycle Assessment – Requirements and guidelines
98 LEO-SCS-002 Standard Draft Dated June 2014. Leonardo Academy. http://www.leonardoacademy.org/programs/standards/life-cycle.html
99 PCR Module for Roundwood Production: https://www.scsglobalservices.com/files/resources/pcr_final_wood-products_101816.pdf
100 PCR Module for Pulp and Paper; https://www.scsglobalservices.com/files/program_documents/pcr_final_pulp_paper_101816.pdf
101 Life Cycle Impact Assessment Methodology for PCR Modules for Roundwood and Pulp/Paper; https://www.scsglobalservices.com/files/program_documents/pcr_final_lcia-methodology_101816.pdf

Appendix: Dispersion Models Used to Assess Regional Acidification, Ground Level Ozone and PM2.5 Impacts

Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information (location, emission rates, stack height, etc.), these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and, in some cases, secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere. The models are commonly used in regulatory applications by air quality management agencies and others for a variety of purposes. For example, air quality models can be used during the permitting process to verify that a new source will not exceed ambient air quality standards or, if necessary, determine appropriate additional control requirements. In addition, air quality models can also be used to predict future pollutant concentrations from multiple sources after the implementation of a new regulatory program in order to estimate the effectiveness of the program in reducing harmful exposures to humans and the environment.

Dispersion models use mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, a dispersion model can be used to predict concentrations at selected downwind receptor locations. Within an LCIA, typically simple dispersion models are used to estimate the geographic extent of pollutants dispersed through the atmosphere from specific emission sources. Model outputs include the spatial extent, concentration gradients, and pollutant depositions, of emitted chemical species based on locally-specific meteorological conditions and emission source characteristics (stack locations, heights, temperatures, flow-rates, etc.). In this LCA, these outputs are used to estimate human exposures to particulate matter (PM) as well as to estimate pollutant depositions for regional acidification.

In the US, these air quality models are used to determine compliance with National Ambient Air Quality Standards (NAAQS), and other regulatory requirements such as New Source Review (NSR) and Prevention of Significant Deterioration (PSD) regulations. The USEPA provides guidance and support (available at http://www.epa.gov/ttn/scram/guidanceindex.htm) for the use of numerous air quality models which are periodically updated and revised to ensure the new model developments or expanded regulatory requirements are incorporated. Access to, and descriptions, of air dispersion models and more comprehensive photochemical transport models routinely used in air quality management studies can be found at http://www.epa.gov/ttn/scram/. Included are primarily regulatory air quality models and modeling systems recommended for use by the USEPA.

In addition to EPA regulatory models, the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL) has developed a modeling system for trajectory, dispersion and deposition which can be used to estimate air pollution concentrations, including ozone and PM, based on archive meteorological data, regional emission inventories and a semi-empirical chemical mechanism for atmospheric ozone formation. The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model and related input databases can be obtained from: http://ready.arl.noaa.gov/. A brief description of the HYSPLIT air dispersion model is provided below.

The HYSPLIT model is a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. The initial development was the result of a joint effort between NOAA and Australia's Bureau of Meteorology. Recent upgrades include enhancements provided by a number of different contributors. New features include improved advection algorithms, updated stability and dispersion equations, continued improvements to the graphical user interface, and the option to include modules for chemical transformations. Without the additional dispersion modules, HYSPLIT computes the advection of a single pollutant particle, or simply its trajectory.

Gridded meteorological data, on a latitude-longitude grid or one of three conformal (Polar, Lambert, Mercator) map projections, are required at regular time intervals. The input data are interpolated to an internal sub-grid. Calculations may be performed sequentially or concurrently on multiple meteorological grids, usually specified from fine to coarse resolution.

The dispersion of a pollutant is calculated by assuming either puff or particle dispersion. In the puff model, puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with its share of the pollutant mass. In the particle model, a fixed number of particles are advected about the model domain by the mean wind field and spread by a turbulent component. The model's default configuration assumes a 3-dimensional particle distribution (horizontal and vertical). Figure 14, shown below, presents an example of a concentration plume resulting from the emission release from a single source calculated using the HYSPLIT model and archived meteorological data fields.

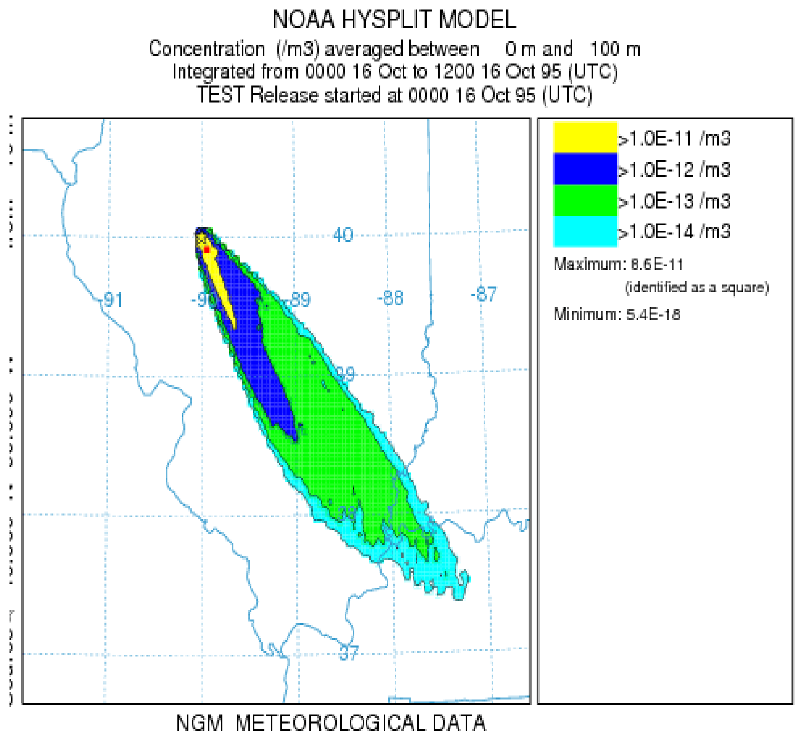

Figure 14. Example concentration plume from single emission source (Source: http://www.arl.noaa.gov/HYSPLIT_info.php.)

A.1 Regional Acidification

Evaluation of the regional acidification impact category for LCIA requires the specification of the soil sensitivity characteristics in order to determine the buffering capacity within the receiving environment (area of deposition). The soil characteristics database used in the analyses presented herein are described below. Inland water bodies are also included in the soils sensitivity mapping and indicator calculations, as it is assumed that inland freshwater bodies are not buffered and are acid sensitive.

The Harmonized World Soil Database (HWSD) is a 30 arc-second raster database with over 15,000 different soil mapping units that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1: 5,000,000 scale FAO-UNESCO Soil Map of the World.

The resulting raster database consists of 21,600 rows and 43,200 columns, which are linked to harmonized soil property data. The use of a standardized structure allows for the linkage of the attribute data with the raster map to display or query the composition in terms of soil units and the characterization of selected soil parameters. The global database includes the following relevant parameters: organic carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry. Links to access the GIS formatted digital databases can be found at http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html. Figure 15 displays the soil sensitivity class for North America based on the soil characterization methodology of Kuylenstierna,[102] derived from the Harmonized World Soil Database for the conterminous US.

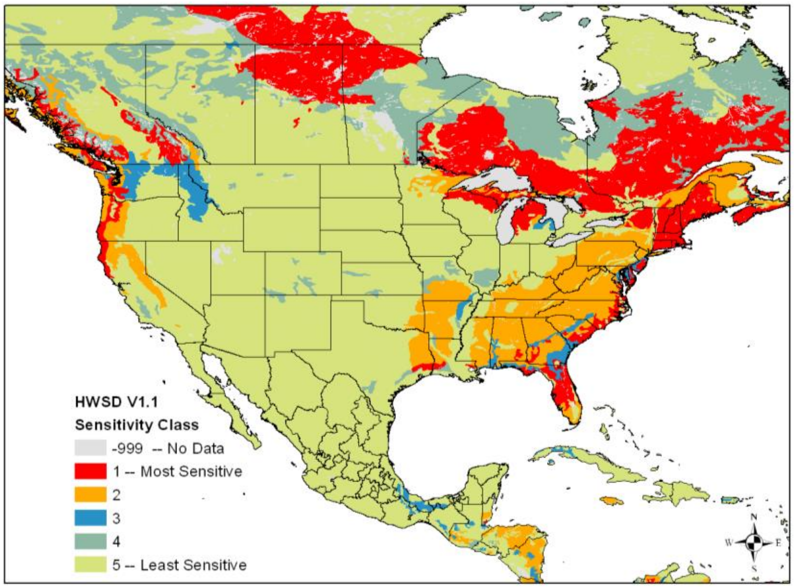

Figure 15. Soil sensitivity class based on the HWSD for North America. Soils of sensitivity class 1 (most sensitive) through sensitivity class 4 are classified, while soils of class 5 are not classified.

A.2 Ground Level Ozone Exposures

The accumulated AOT60 value expresses the hourly accumulated ozone concentration above 60 parts per billion (ppb) during daytime hours throughout the ozone season, typically May through October, and is expressed in ppb-hrs. Thus, the indicator represents the accumulated exposure risks, as the total number of people exposed to an emission, multiplied by the hours of cumulative ozone exposure using the AOT60 metric. Using this measurement, the category indicator result is scaled by the cumulative risk factor (CRF) to reflect the severity of exceedance of threshold and accumulated risks from continued multi-year exposures over this defined threshold.

However, in this study, which considered fiber production in regions around the world, a consistent dataset containing information on ground level ozone concentrations was unavailable, presenting a consistent assessment of all scenarios. This impact category could not be evaluated.

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[102] 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.

A.3 PM2.5

The calculation of $PM_{2.5}$ exposure risks requires the establishment of a Cumulative Risk Factor (CRF). In the case of PM emissions, the CRF represents the increase in the severity of human exposure risks linked to higher average ambient $PM_{2.5}$ concentrations compared to a minimum ambient concentration level of 1 $\mu g/m^3$. The category indicator result is scaled by the cumulative risk factor to reflect the severity of $PM_{2.5}$ exposure risks. Annual average ambient $PM_{2.5}$ concentrations and CRF values across the world were developed using monitored data from NASA.[103]

[103] Global Annual PM2.5 Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD), v1 (1998 – 2012). http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-avg-pm2-5-modis-misr-seawifs-aod-1998-2012