Life Cycle Assessment of Deinked and Virgin Pulp FINAL

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1 Introduction

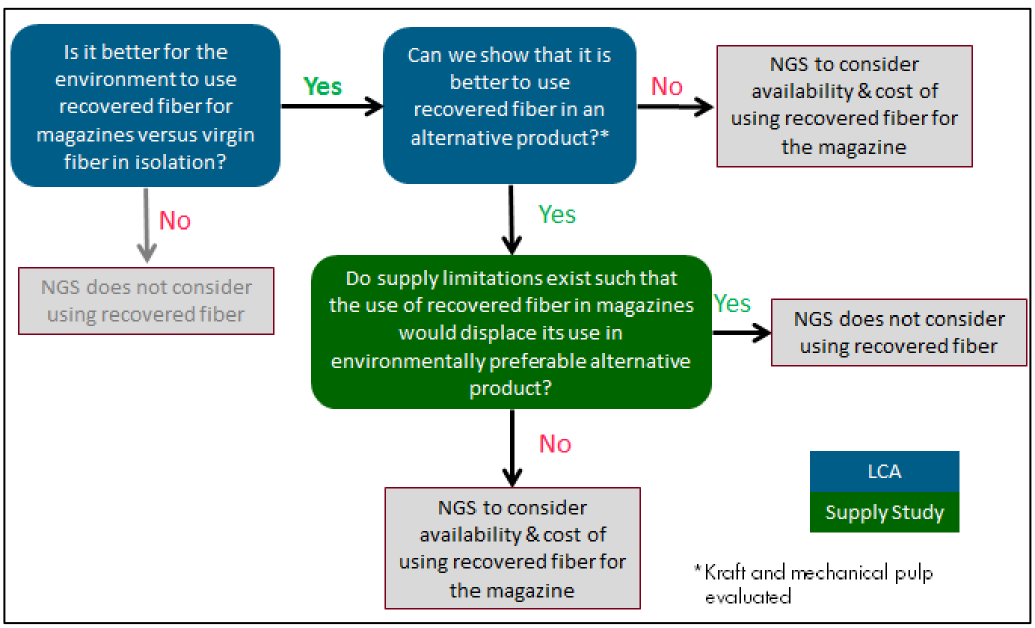
1.1 Goals and Objectives

The National Geographic Society (NGS) commissioned ENVIRON to conduct a life cycle assessment (LCA) to evaluate the relative impacts of deinked pulp derived from waste paper versus the impacts of virgin pulp produced from virgin wood sources that would be displaced by the use of the deinked pulp. The objectives of the study were to:

- Identify and quantify the key factors contributing to the relative environmental impacts of deinked and virgin pulp, and to
- Inform NGS actions and decision making.

As illustrated in Figure 1, the results of this study can be used to support whether or not NGS considers the availability and cost of using recovered fiber in its magazine. This study does not presume that a limited supply of fiber exists; an additional "supply" study is underway to investigate the availability of recycled high grade paper for Magazine use. Based on stakeholder group feedback, this study focused on evaluating the relative impact of recovered versus virgin fiber in a magazine in isolation. In addition, we examined the relative impact of displacing mechanical or kraft pulp to inform a comparison of alternate products.

Figure 1: Decision flowchart illustrating NGS potential actions



ENVIRON conducted the LCA study based on significant input from a stakeholders group and technical advisors. Stakeholders provided input on each phase of the project, as illustrated in Table 1. The stakeholders involved included NGS, Green America, Natural Resources Defense Council (NRDC) and Natural Resource Council of Maine (NRCM). We also obtained input from technical advisors from groups including the World Resource Institute (WRI), National Council for Air and Stream Improvement (NCASI) and pulp and paper producers to provide subject matter expertise. ENVIRON was responsible for facilitating the team meetings, preparing draft materials for review, incorporating feedback, and performing the Life Cycle Assessment calculations.

Table 1: Stakeholder Involvement

Task	Stakeholder Involvement
LCA Design	Design meeting Draft study design review and webinar
Process Map	Review and discuss process map components
Data Map	Identify potential data sources Review data sources, approaches, and gaps
Sensitivity Analysis	Discuss parameters to be included in sensitivity analysis
LCA Analysis & Report	Provide study activity data Review and comment on report

1.2 Methodology: Life Cycle Assessment

Life cycle assessment is a standardized method for examining the environmental and human health impacts associated with a product throughout its lifetime, including the general categories of raw material extraction, transportation, manufacturing, use and disposal. To provide consistency, comparability, and transparency to the analysis, ENVIRON followed the standards outlined in ISO 14040 – "Life cycle Assessment – Principles and framework"[1] and ISO 14044 – "Life cycle assessment – Requirements and guidelines" [2] to complete the LCA. As outlined in the ISO standards, an LCA consists of four phases:

1. Goal and scope definition: define the objectives and associated study framework and boundaries;
2. Life cycle inventory: create an inventory of the mass and energy inputs and outputs from processes associated with the product system processes (data collection phase);
3. Life cycle impact assessment: evaluation of the relative environmental significance (e.g., global warming potential) associated with the inputs and outputs; and,
4. Interpretation: summary of the conclusions in relation to the objectives of the study

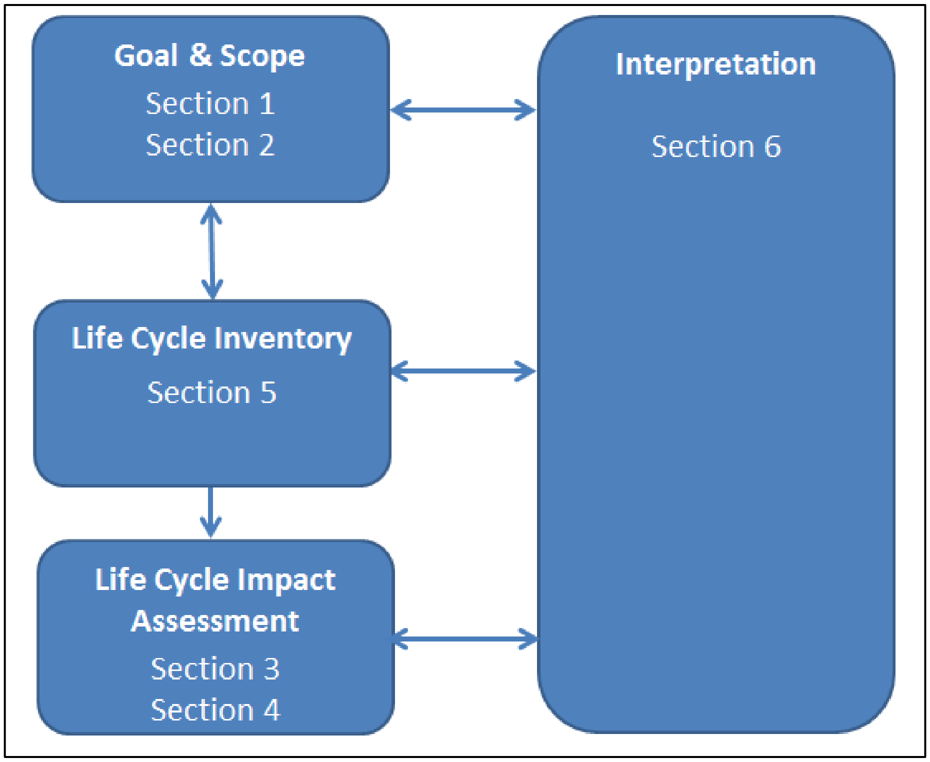
1.3 Report Organization

This report is organized into the following sections that address the four elements above, as illustrated in Figure 2.

[1] International Standards Organization (ISO) 14040:2006, (2006). Environmental management- Life Cycle Assessment – Principals and framework, Second edition.

[2] International Standards Organization ISO 14044 (2006). Environmental management- Life cycle assessment- requirements and guidelines.

Figure 2: Report Organization



Section 1 discusses the study goal. In Section 2, we review the scope of the study to establish system boundaries and discuss the assumptions of the life cycle assessment. Next we present the results of the study in Sections 3, which quantifies the relative environmental impact of deinked versus displaced pulp and Section 4, which illustrates the range of impacts that result from varying key model inputs, such as total energy used. Section 5 presents the underlying details on the mass and energy inputs and outputs that contribute to the environmental impacts, and discusses the data utilized to represent these flows. Section 6 summarizes the results and presents study conclusions.

2 Scope

In this section, we discuss the scope of the study. The scope of the study defines the system boundary and specific products to be studied, which then determines data collection and analysis needs. In addition, the scope establishes the impact categories evaluated, allocation procedures applied, and data requirements.

2.1 System Description & Study boundaries

The objective of this study is to evaluate the relative impacts of deinked pulp derived from waste paper versus the impacts of virgin pulp produced from virgin wood sources. Specifically we are to consider the virgin pulp that would be displaced by the use of deinked pulp in magazines. Figure 3 illustrates the life cycle processes included in virgin and deinked pulp production for magazines.

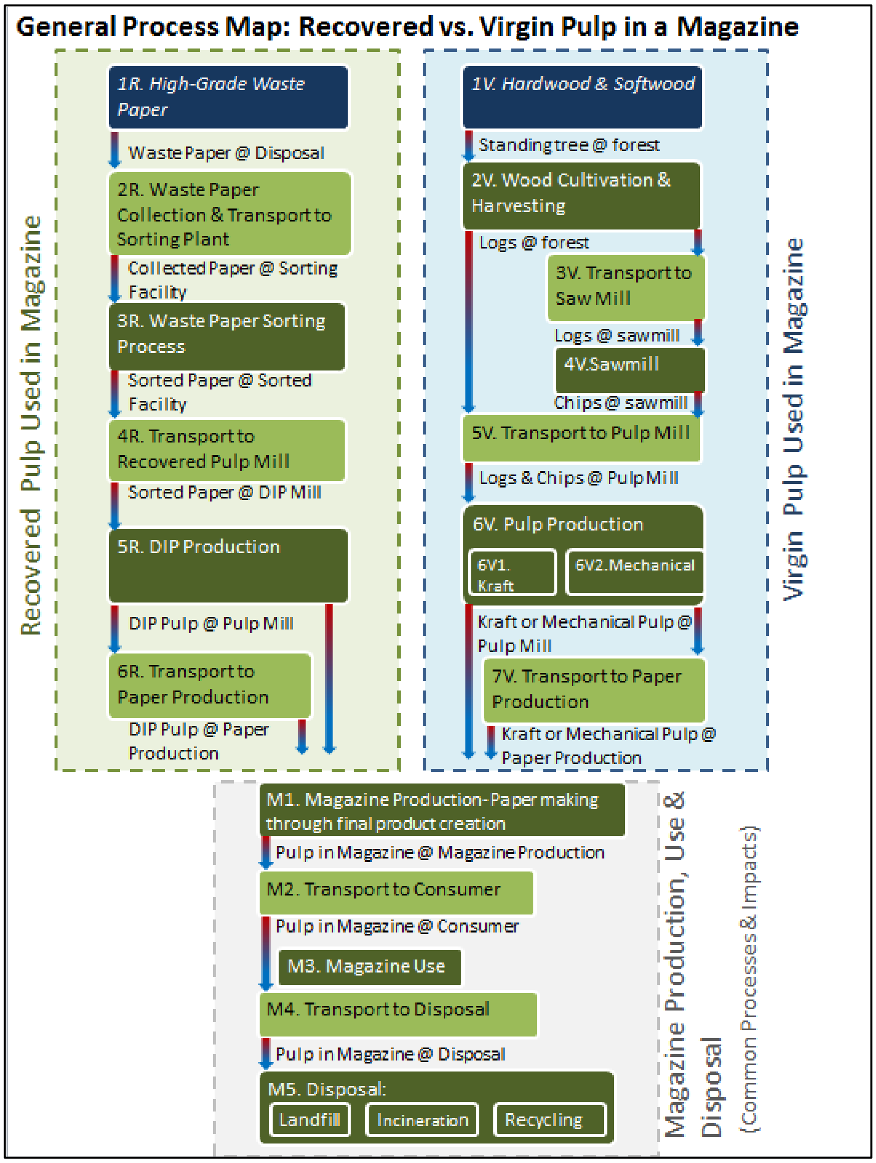
These life cycle processes include:

- Raw materials extraction and processing (waste paper collection and sorting, wood acquisition)
- Pulp production
- Use (paper making and magazine production)
- Disposal
- Transportation (multiple transport steps represented by the arrows)

In the raw materials extraction and processing for deinked pulp, the waste paper is collected, sorted, and transported to the deinked pulp mill. For virgin pulp, the hardwood and softwood are cultivated and harvested, then processed as logs and chips at the sawmill and transported to the pulp mill. Both deinked and virgin pulps are produced at pulp mills. After pulp production, both virgin and deinked pulps are transported to the paper mill where the pulp is processed into paper used in magazine production. Pulp and paper can also be produced at integrated mills. Paper is then processed and printed into magazines, delivered to the customer, and ultimately disposed of.

Because we are evaluating the *relative difference* in displacing virgin pulp with deinked pulp in a product at the paper making stage, we exclude those common life cycle steps that have the same processes and impacts. Thus, we assess the “cradle-to-paper mill” impacts of virgin and deinked pulp, and do not include magazine production, use and disposal in this assessment. Interviews with technical advisors confirmed that the paper and magazine production processes, use and disposal practices are equivalent whether a magazine uses virgin pulp, or displaces some of that virgin pulp with deinked pulp.

Figure 3 : System Boundaries/Process Overview



2.2 Specific Products Analyzed (Functional Unit)

This study evaluates the relative environmental impacts of deinked pulp versus the equivalent amount of virgin pulp it would displace. Pulp can be produced using a variety of wood or waste paper inputs depending on the paper product strength and quality requirements. Magazines utilize both mechanical pulp and kraft (i.e. chemical) pulp. The "functional unit" describes the reference to which products are related to allow results to be compared on a common basis. This study assumes that 1 kg of deinked pulp made from recovered fiber may be used to displace 1 kg of virgin pulp. Thus, the functional units of the study are:

- 1 kg deinked pulp used for magazines: 100% post-consumer premium printing and writing grade pulp (i.e., "deinked pulp") produced from high-grade waste paper

- 1 kg displaced virgin pulp used for magazines, where 1 kg of deinked pulp would displace 0.5kg bleached kraft pulp and 0.5 kg bleached mechanical pulp[3]

For purposes of this study, the virgin pulps displaced and deinked pulp classifications are based on pulp input specifications for the National Geographic Magazine. Since the virgin pulp displaced may vary from producer to producer, we provide a breakout of results for kraft and mechanical pulp on a pulp specific basis in Section 4.

2.3 Assessment Criteria

In this section we discuss the criteria and assumptions we used for the LCA including impact categories, allocation procedures, and data requirements.

2.3.1 Impact Categories

Environmental impact categories are used in life cycle assessment to relate the resource consumption and air, water, and soil emission to an environmental impact. In this study, we use the environmental impact categories in Table 2 to assess the environmental impact of deinked and virgin pulp. Other impact categories, such as biodiversity and carbon sequestration were not included, because supporting data and/or impact characterization factors could not be obtained within the project scope and available resources.

Table 2: Impact categories included in the analysis

Impact Category	Description
Climate Change	Related to global warming, climate change is the change to the Earth's climate caused by a changed heat balance in the Earth's atmosphere. Global Warming Potential (GWP) is the extent to which greenhouse gases (GHG) can absorb infrared radiation and thereby heat the atmosphere. GHGs include CO2, CH4, PFCs, etc.
Acidification	Also known as acid rain occurs when emissions of sulfur dioxide and nitrogen oxides react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds.
Carcinogens	Substances capable of causing cancer.
Non-carcinogens	Substances contributing to human health impacts other than cancer, such as organ damage, reproductive difficulty, and nervous system impairment.
Respiratory effects	Damages to human health, related to respiratory problems, as a result of particulate emissions of organic and inorganic substances and emissions contributing to ground-level ozone.
Eutrophication	The reduction in water quality caused by nutrient loading, which leads to shifts in species composition and increased biological productivity such as algal blooms. Nitrogen and Phosphorous are two substances most implicated in eutrophication.

[3] Craig Liska, Vice President of Sustainability, Verso Paper

Impact Category	Description
Ozone Depletion	Refers to the thinning of the stratospheric ozone layer as a result of various chlorinated and bromates substances, such as CFCs and halons.
Ecotoxicity	The measure of the potential adverse effects on populations of aquatic or terrestrial organisms.
Smog	Also known as ground level ozone, is a form of air pollution produced by the photochemical reaction of sunlight with hydrocarbons and nitrogen oxides that have been released into the atmosphere .
Energy from Biomass	The consumption of biomass such as black liquor or wood in megajoules (MJ).
Fossil Energy Consumption	The consumption of fossil energy such as petroleum in MJ.
Wood Use	Volume of wood used in cubic meters (m^3).

Section 3.1 provides details on the methods applied to calculate these impacts.

2.3.2 Allocation Procedures

Allocation is the process by which environmental impacts are assigned to the studied products, co-products, waste products, recycled products, and other outputs. This study follows the ISO 14044 allocation procedure, where it is recommended to avoid allocation by:

- Dividing unit processes into sub-processes relating to the outputs, or
- Including additional functions related to the outputs to expand the system.

Multiple allocation methods exist for estimating the environmental impacts associated with recycled materials. We applied the "cut-off" method described in ISO 14044[4] to model allocation for the recycled waste paper input to the deinked pulp process in which we assign no burdens from the original paper production from virgin material and no credit for displacing waste paper from landfills. Because the waste paper input is 100% recycled, no unit processes from the input of waste paper are allocated to the deinked pulp process. (As opposed to the virgin pulp, in which all of the input material emissions and impacts from wood extraction are allocated to the pulp because these input materials are not from recycled sources). We evaluate alternative recycling allocation methodologies in the sensitivity analysis (Section 4.4) to examine the effect of this assumption on the results.

2.3.3 Data Requirements

Data requirements provide guidelines for data quality in the life cycle assessment and are important to ensure data quality is consistently tracked and measured throughout the analysis.

[4] International Organization for Standardization (2006). "ISO 14040: Life cycle assessment – principles and framework." [Available online] http://www.iso.org/iso/catalogue_detail.htm?csnumber=37456

Data quality metrics include precision, completeness, and representativeness. *Precision* describes the variability of the inventory data. Since this study uses only secondary data sources from academic studies and external databases, precision is difficult to assess. Therefore, we evaluated significant variables including total pulp energy and energy fuel mixture with a sensitivity analysis to demonstrate their relative impact to the results (Sections 4.1 and 4.2). *Completeness* describes the usage of the available data in existence to describe the scope of the LCA. We assessed the data completeness by conducting a contribution analysis that identified the substances that contributed significantly to one or more impact categories for one or more of the three types of pulps considered. We evaluated the contribution analysis for inconsistencies and data gaps as detailed in Section 5.4. *Representativeness* describes the ability of the data to reflect the system in question. We measure representativeness with the time, technology, and geographic coverage of the data.

Time coverage describes the age of the inventory data and the period of time over which data is collected. The time coverage of the LCA study excludes data from before the year 2000. The technological coverage of this study is current to the time period over which the data was collected, which is representative of the pulp industry on average. The geographic coverage is based on North American data when available from literature and industry sources, as described in Section 5.1. When North American data was unavailable, proxies from European or Swiss data are used from Ecoinvent datasets (described in more detail in Table 13: Summary of Secondary Data Sources and Appendix B: Life Cycle Inventory Unit Process Sources).

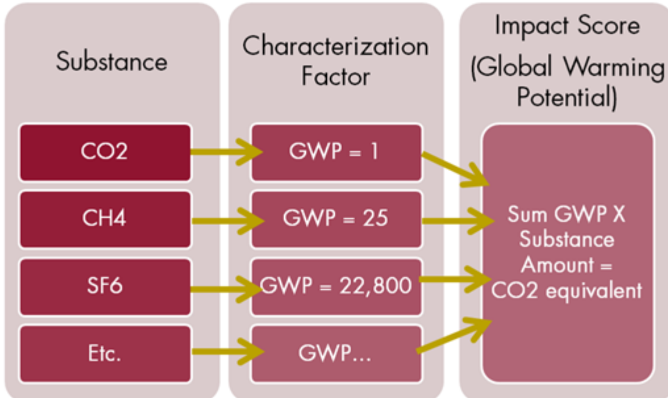
3 Quantifying Environmental Impacts: Life Cycle Impact Assessment

This section provides the results of the analysis by discussing the impact categories analyzed, presenting the impact results for deinked and virgin pulp, and illustrating the potential variability of the results through a series of sensitivity analyzes.

3.1 Translating Data (Life Cycle Inventory) into Life Cycle Environmental Impacts

The life cycle inventory (detailed in Section 5.3) includes hundreds of substances that represent the raw materials, energy and emissions to air, water and soil, and wastes associated within the pulping systems examined. This inventory data is central to the analysis but does not reflect relative environmental relevance. This data can be further analyzed and interpreted to provide insights into the potential environmental impacts. Inventory values can be grouped into impact categories based on characterization factors (i.e., the relative impact of each substance to each impact category) as illustrated in Figure 4 and then weighted based on their relative impact. For example, 1kg of sulfur hexafluoride (SF_6) emissions may seem insignificant compared to 10,000 kg of carbon dioxide (CO_2) emissions, but an impact assessment shows that the small amount of SF_6 has over twice the global warming potential than the CO_2 emissions.

Figure 4 : Inventory Translated to Environmental Impacts



ISO standards do not recommend a specific characterization method, but require the selected method to be an internationally accepted method for comparative assertions. Table 3 lists the methods applied for each impact category evaluated in this analysis.

Table 3: Impact categories and impact characterization methods

Impact Category	Units	Characterization Method	Source
Climate Change-Total CO2eq (Fossil + Biogenic)	kg CO2 eq	Greenhouse Gas (GHG) Protocol	World Resources Institute (WRI) and the World Business Council for Sustainable Development(WBCSD)[5]
Climate Change-Fossil CO2eq	kg CO2 eq		
Climate Change-Biogenic CO2eq	kg CO2 eq		
Acidification	H+ moles eq	TRACI v.2.0 (Tool for the Reduction and Assessment of Chemical and other environmental Impacts)	U.S. Environmental Protection Agency and PRe Consultants[6]
Carcinogens	CTUh		
Non-carcinogens	CTUh		
Respiratory effects	kg PM10 eq		
Eutrophication	kg N eq		
Ozone Depletion	kg CFC-11 eq		
Ecotoxicity	CTUe		
Smog	kg O3 eq		
Energy from Biomass	MJ	Cumulative Energy Demand	PRe Consultants6
Nonrenewable (Fossil) Energy	MJ		
Wood Use	m3	Inventory of wood use	n/a

[5] WBCSD & WRI (2009) *Product Life Cycle Accounting and Reporting Standard. Review Draft for Stakeholder Advisory Group.* The Greenhouse Gas Protocol Initiative. November 2009.
[6] Goedkoop, M., Oele, M., Schryver, A., Vieira, M., & Hegger, S. (2010). SimaPro database manual methods library. *PRé Consultants, Netherlands*.

The GHG Protocol method corresponds to the WRI/WBSCD Product Lifecycle Accounting and Reporting Standard and is based on the IPCC 2007 method developed by the Intergovernmental Panel on Climate Change.[7] This method distinguishes between and individually includes each of carbon originating from fossil fuels (i.e., Climate Change- Fossil CO2eq) and biogenic carbon originating from plants and trees (i.e., Climate Change- Biogenic CO2eq). We also include an impact category that quantifies "Climate Change-Total CO2eq", and includes the carbon dioxide equivalence emissions from both fossil and biogenic sources.. We selected the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) for the environmental impact factors because the characterization factors were developed by the Environmental Protection Agency (EPA), are North America specific, and have been applied in other North America-specific paper product LCAs. For example, the AF&PA Printing and Writing Papers Life Cycle Assessment[8] and the Corrugated Packaging Alliance Life Cycle Assessment of U.S. Industry-Average Corrugated Product[9] both characterized potential environmental impacts using the TRACI impact assessment method. Energy use and wood use (i.e., wood harvested from the forest) are obtained directly from the inventory data.

3.2 Environmental Impact Results

In this section, we discuss the environmental impact results of displaced vs. deinked pulp for the impact categories discussed above. In addition, we break down the results by life cycle stages to evaluate the key impacts to identify specific process stages and substances that drive the results.

3.2.1 Relative Impact of Deinked vs. Virgin Pulp

Deinked pulp has a lower relative impact than the virgin pulp it would displace in all environmental categories analyzed. Figure 5 presents the relative impact of producing a kilogram of deinked pulp derived from waste paper compared to a kilogram of displaced pulp produced from virgin wood sources for a range of environmental impact categories and delivering. Displaced pulp represents the virgin pulp that would be replaced by incoming deinked pulp in National Geographic Magazine and consists of 50% kraft and 50% mechanical pulp. Results on the graph for each impact category are normalized to "1" for the pulp with the maximum impact for each category. Table 4 provides the impact per kilogram pulp from the cradle-to-paper mill for each category.

[7] Intergovernmental Panel on Climate Change (IPCC), (2007). *Climate Change 2007: Synthesis Report, Fourth Assessment Report of the Intergovernmental Panel on Climate Change.*

[8] National Council for Air and Stream Improvement (NCASI). 2010. Life cycle assessment of North American printing and writing paper products. Final report prepared for American Forest and Paper Association (AF&PA), Forest Products Association of Canada (FPAC). June 18, 2010.

[9] PE-Americas and Five Winds International. 2010. Corrugated Packaging Life Cycle Assessment. Final report prepared for Corrugated Packaging Alliance (CPA).

Figure 5 : Relative impact of Deinked vs. Virgin (50% kraft/50% mechanical) pulp

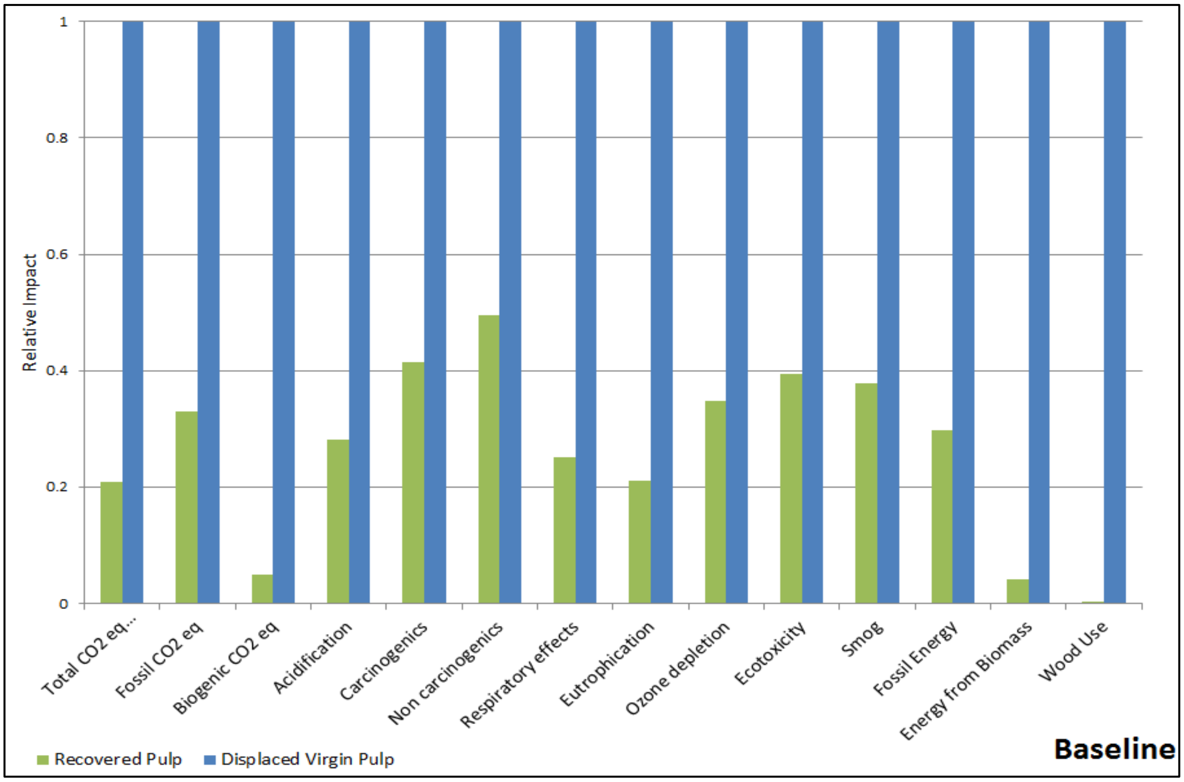


Table 4: Deinked and Displaced Virgin (50% kraft/50% mechanical) pulp impacts per kilogram (cradle to paper mill)

Impact Category	Units	Deinked Pulp	Displaced Virgin Pulp	Relative Impact (Deinked vs. Virgin)
Total CO2 eq (Fossil + Biogenic)	kg CO2 eq	0.60	2.87	0.21
Fossil CO2 eq	kg CO2 eq	0.54	1.63	0.33
Biogenic CO2 eq	kg CO2 eq	0.06	1.24	0.05
Acidification	Mol H+ eq	0.21	0.75	0.28
Carcinogenics	CTUh	1.53E-08	3.69E-08	0.42
Non carcinogenics	CTUh	7.78E-08	1.57E-07	0.49
Respiratory effects	kg PM10 eq	5.70E-04	2.27E-03	0.25
Eutrophication	kg N eq	6.80E-04	3.21E-03	0.21
Ozone depletion	kg CFC-11 eq	1.25E-08	3.57E-08	0.35
Ecotoxicity	CTUe	0.93	2.36	0.39
Smog	g O3eq	0.05	0.13	0.38
Non renewable (fossil) Energy	MJ	6.72	22.57	0.30
Energy from Biomass	MJ	0.53	12.92	0.04
Wood Use	m3	5.23E-06	3.40E-03	0.002

3.2.2 Key Life Cycle Stages: Contribution Analysis

LCA results have variability and uncertainty associated with a myriad of model assumptions and input data. The contribution analysis evaluates the relative impact of each life cycle process for each impact category. This analysis highlights key elements on which to focus by identifying specific process stages and substances that drive the results and variability. The contribution analysis and details can inform the following:

- Actions pulp producers can take to reduce impacts
- Identification of high variability impact factors (such as transportation distances, energy use and fuel mix) that can be examined via a sensitivity analysis or on a mill-specific basis)
- Target opportunities for data enhancements

Figure 6, 7, and 8 illustrate the relative contribution of significant inputs and processes to the environmental impacts by life cycle stage for deinked pulp, kraft pulp and mechanical pulp, respectively. The life cycle stages and inputs specific to the pulp process are shown across the top of the table. Impact categories are listed in the first column. Looking across a row allows the reader to see the relative effect of each life cycle process to the impact category shown in that row. Looking down a column allows the reader to see which impact categories are effected by the lifecycle stage shown in that column. We evaluated the results for deinked pulp from deinked waste paper, bleached kraft and bleached mechanical pulp separately; these tables are specific to the relative impacts of the life cycle processes **within** the individual pulp processes only and should not be used for direct comparisons between pulp products. For example, hydrogen peroxide contributes 19% of deinked pulp carcinogens relative to the other deinked pulp product-specific processes. But hydrogen peroxide contributes 27% of mechanical pulp carcinogens relative to other mechanical pulp product-specific processes. These results do not indicate that hydrogen peroxide contributes less to the impact of deinked pulp compared to mechanical pulp.

Tables 5, 6 and 7 provide details on the factors that influence the significant impacts for deinked pulp, kraft pulp and mechanical pulp. For example, diesel fuel used in transportation results in the majority of the potential environmental impacts associated with waste paper collection, sorting & transport to mill in the deinked pulping process.

Figure 6 : Impact by Lifecycle stage- Deinked Pulp

	Waste Paper Collection, Sorting & Transport to Pulp mill	Pulping Input Chemicals					Purchased Energy acquisition & combustion				Pulp Mill process emissions	Disposal from Pulping		Pulp Transport to Paper Mill
		Hydrogen peroxide	Sodium hydroxide	Sodium chloride	Sodium dithionite	Fatty acids	Electricity	RFO	Natural Gas	Coal		MSW	Deinking Sludge Ash to Landfill	
Fossil CO2 eq	19%	2%	2%	1%	2%	2%	40%	2%	4%	4%	0%	0%	5%	17%
Acidification	14%	1%	2%	0%	10%	3%	45%	1%	4%	4%	0%	0%	1%	14%
Carcinogenics	20%	19%	1%	0%	4%	2%	10%	1%	1%	1%	0%	0%	32%	8%
Non carcinogenics	13%	1%	3%	0%	35%	1%	11%	2%	1%	6%	0%	0%	11%	15%
Respiratory effects	9%	1%	2%	1%	12%	10%	45%	0%	5.0%	7%	0%	0%	2%	6%
Eutrophication	11%	3%	1%	0%	8%	20%	16%	0%	0%	1%	24%	2%	6%	5%
Ozone depletion	12%	10%	12%	1%	8%	7%	16%	1%	7%	6%	0%	0%	8%	12%
Ecotoxicity	30%	4%	1%	0%	4%	4%	11%	3%	3%	0%	9%	0%	7%	24%
Smog	26%	1%	1%	0%	1%	3%	30%	1%	1%	3%	0%	0%	2%	30%
Biogenic CO2 eq	51%	1%	0%	0%	0%	25%	17%	0%	0%	1%	0%	3%	1%	1%
Energy from Biomass	0%	0%	0%	0%	0%	98%	1%	0%	0%	0%	0%	0%	0%	0%
Fossil Energy	14%	3%	2%	1%	2%	2%	45%	2%	5%	4%	0%	0%	2%	18%
Wood Use	1%	1%	0%	0%	2%	76%	16%	0%	0%	2%	0%	0%	1%	0%

Table 5: Deinked Pulp Significant Life Cycle Stage Contributing Factors

Life Cycle Stage	Most Impactful Unit Processes	Significant Impact Categories	Contributors
Raw Material Extraction and Processing	Waste paper collection, sorting, and transport to pulp mill	Fossil CO2 eq, acidification, non-carcinogens, non-renewable fossil energy	*Diesel fuel used in transportation*
		Eutrophication, ecotoxicity	Disposal of waste from sorting
		Respiratory effects, ozone depletion	Electricity use from coal and natural gas
		Biogenic CO_2 eq	Waste paper incineration
Pulping Input Chemicals	Hydrogen peroxide	Carcinogens	Antraquinone process emission
		Ozone depletion	Electricity use from natural gas
	Sodium hydroxide	Ozone depletion	CFC-10 process emission.
	Sodium dithionite	Acidification, respiratory effects	SO_2 process emissions
		Non-carcinogens, Eutrophication	Zinc process emissions
		Ozone depletion	Crude oil production
	Fatty acids[10]	Respiratory effects, eutrophication, Energy from biomass	*Palm oil production*
		Wood Use	*Palm fruit cultivation*
		Ozone depletion	Crude oil production, natural gas use
Purchased Energy acquisition and combustion	Electricity	Fossil CO_2 eq, acidification, carcinogens, non-carcinogens, respiratory effects, non-renewable fossil energy	Coal
		Ozone depletion, ecotoxicity	Natural gas
		Biogenic CO2 eq	Municipal Solid Waste Disposal
	Natural Gas	Ozone Depletion	Halon 1211 process emission
		Non-renewable fossil energy	Natural Gas in ground
	Coal	Respiratory effects	SO_2 process emission
		Ozone Depletion	R-40 process emission
		Non-carcinogens	Mercury process emission
Pulp mill process emissions	Pulp mill process emissions	Eutrophication	*COD from organic matter, phosphorous and nitrogen emissions to water*
		Ecotoxicity	*Chlorophenols*
Disposal from pulping	Deinking Sludge Ash to Landfill	Carcinogens, non-carcinogens, eutrophication, ozone depletion, ecotoxicity	*Processes to make cement for solidification.*
Transportation	Pulp Transport to Paper Mill	Fossil CO_2 eq, acidification, carcinogens, non-carcinogens, respiratory effects, ozone depletion, ecotoxicity, smog, non-renewable, fossil	*Diesel fuel for transportation.*

**Data enhancement opportunity (See Table 16)*

[10] Fatty acids are used to produce fatty acid salts or soaps, which is one of the substances used in the deinking of pulp [Hannuksela and Rosencrance. Deinking Chemistry. Kemira Chemicals Inc. Available: http://www.cost-e46.eu.org/files/Deinking%20primer/Deinking%20Chemistry-FINAL.pdf], Listed as a data enhancement opportunity in Table 16.

Figure 7 : Impact by Lifecycle stage- Kraft Pulp

		Pulping input chemicals					Purchased Energy acquisition & combustion						Waste from Pulping					
	Wood Acquisition	Hydrogen peroxide	Sodium hydroxide	Sodium chlorate	Sulphuric acid	Other Input Chemicals	Electricity	Coal	RFO	Natural Gas	Renewable Energy (Black Liquor)	Pulp Mill process emissions	Hazardous Waste Disposal	MSW	Wood ash to Landfill	Green Liquor Dregs to Landfill	Limestone residue to Landfill	Transport to Paper Mill
Fossil CO2 eq	7%	0%	2%	15%	0%	1%	25%	7%	26%	16%	0%	0%	0%	0%	0%	0%	0%	0%
Acidification	7%	0%	1%	11%	3%	1%	23%	0%	5%	13%	1%	35%	0%	0%	0%	0%	0%	0%
Carcinogenics	2%	0%	0%	57%	0%	0%	5%	1%	11%	2%	2%	2%	0%	0%	0%	15%	0%	0%
Non carcinogenics	6%	0%	3%	13%	0%	0%	7%	10%	25%	6%	25%	3%	0%	0%	0%	0%	0%	0%
Respiratory effects	3%	0%	1%	10%	3%	1%	19%	3%	3%	14%	21%	22%	0%	0%	0%	0%	0%	0%
Eutrophication	2%	0%	0%	27%	0%	0%	6%	1%	2%	1%	0%	56%	0%	2%	0%	4%	0%	0%
Ozone depletion	3%	0%	8%	27%	1%	1%	9%	9%	16%	26%	0%	0%	0%	0%	0%	0%	0%	0%
Ecotoxicity	6%	0%	0%	11%	0%	0%	5%	0%	28%	9%	1%	35%	0%	0%	0%	2%	0%	0%
Smog	17%	0%	1%	8%	0%	0%	20%	1%	6%	1%	1%	43%	0%	0%	0%	0%	0%	1%
Biogenic CO2 eq	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	98%	0%	0%	0%	0%	0%	0%	0%
Energy from Biomass	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Fossil Energy	7%	0%	2%	13%	0%	1%	26%	6%	26%	20%	0%	0%	0%	0%	0%	0%	0%	0%
Wood Use	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 6: Kraft Pulp Significant Life Cycle Stage Contributors

Life Cycle Stage	Most Impactful Unit Processes	Significant Impact Categories	Contributors
Raw Material Extraction and Processing	Wood Acquisition	Fossil CO_2 eq, acidification, smog	Diesel fuel used in transportation
		Non-carinogens, ecotoxicity, smog	Crude oil used in harvesting
Pulping Input Chemicals	Sodium hydroxide	Ozone Depletion	CFC-10 process emission
	Sodium chlorate	Fossil CO_2 eq, acidification, respiratory effects, smog, non-renewable fossil energy	Coal from intensive electricity use
		Non-carcinogens, eutrophication	Arsenic and phosphate from coal electricity production
		Carcinogens, ecotoxicity	Chromium VI process emission
Purchased Energy acquisition and combustion	Electricity	Fossil CO2 eq, acidification, non-carcinogens, respiratory effects, eutrophication, ecotoxicity, smog, non-renewable fossil energy	Coal electricity production
		Ozone depletion	Natural gas use
		Carcinogens	Disposal of basic oxygen furnace wastes
	Coal	Fossil CO_2 eq	CO2 process emission
		Non-carcinogens	Mercury process emission
		Ozone depletion	R-40 process emission
		Non-renewable fossil energy	Coal in ground
	Residual Fuel Oil (RFO)	Fossil CO_2 eq, carcinogens, non-carcinogens, ecotoxicity, smog, non-renewable fossil energy	Crude oil production
		Acidification	SOx process emission
		Ozone depletion	Halon 1211 process emission
	Natural Gas	Fossil CO_2 eq	CO_2 process emission
		Acidification	SO_2 process emission.
		Non-carcinogen, ecotoxicity	Barium process emission
		Ozone depletion	Halon 1211 process emission
		Non-renewable fossil energy	Natural gas in ground
Energy from Biomass	Black Liquor	Non-carcinogens	Acrolein combustion emission
		Respiratory effects	Particulates
		Biogenic CO2eq	CO_2 emissions from combustion
Pulp mill process emissions	Pulp mill process emissions	Acidification, Respiratory effects, smog	SO_2 and NOx process emissions
		Eutrophication	*COD process releases of organic matter to water**
		Ecotoxicity	*Chlorophenols process emission**
Waste from pulping	Green Liquor Dregs	Carcinogens	Chromium VI process emission

**Data enhancement opportunity (See Table 16)*

Figure 8 : Impact by Lifecycle stage- Mechanical Pulp

	Wood Acquisition	Pulping input chemicals			Purchased Energy			Biomass Energy	Pulp Mill process emissions	Disposal from Pulping			Transport to Paper Mill
		Hydrogen peroxide	EDTA	Sodium silicate	Electricity	Coal	RFO			Other Disposal	MSW	Wood ash to Landfill	
Fossil CO2 eq	3%	1%	1%	2%	90%	2%	1%	0%	0%	0%	0%	0%	1%
Acidification	3%	1%	0%	1%	91%	2%	1%	0%	1%	0%	0%	0%	0%
Carcinogenics	4%	27%	3%	5%	58%	1%	1%	0%	0%	0%	0%	0%	1%
Non carcinogenics	7%	1%	2%	8%	68%	8%	3%	1%	0%	0%	0%	1%	1%
Respiratory effects	1%	1%	0%	1%	89%	3%	0%	4%	0%	0%	0%	0%	0%
Eutrophication	1%	1%	2%	2%	26%	0%	0%	1%	66%	0%	0%	0%	0%
Ozone depletion	3%	7%	5%	13%	48%	4%	1%	18%	0%	0%	0%	0%	0%
Ecotoxicity	11%	6%	2%	2%	72%	0%	4%	0%	0%	0%	0%	0%	2%
Smog	9%	0%	0%	1%	81%	2%	1%	1%	3%	0%	0%	0%	1%
Biogenic CO2 eq	0%	1%	0%	0%	68%	0%	0%	29%	0%	0%	0%	0%	0%
Energy from Biomass	0%	0%	0%	1%	12%	0%	0%	87%	0%	0%	0%	0%	0%
Fossil Energy	3%	1%	1%	2%	90%	2%	1%	0%	0%	0%	0%	0%	1%
Wood Use	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 7: Mechanical Pulp Significant Life Cycle Stage Contributors

Life Cycle Stage	Most Impactful Unit Processes	Significant Impact Categories	Contributors
Raw Material Extraction and Processing	Wood acquisition	Non-carcinogens, ecotoxicity, smog, wood use	Diesel fuel used in transportation and crude oil used in harvesting.
Pulping Input Chemicals	Hydrogen peroxide	Carcinogens, ecotoxicity	Antraquinone organic compound process emission
		Ozone depletion	Natural gas from intensive electricity use.
	EDTA	Ozone depletion	Gaseous chlorine process emission.
	Sodium silicate	Carcinogens	Spoil from coal mining[11]
		Non-carcinogens	Sodium hydroxide input to process
		Ozone depletion	Natural gas from intensive electricity use.
Purchased Energy acquisition and combustion	Electricity	Fossil CO_2 eq, acidification, carcinogens, non-carcinogens, respiratory effects, eutrophication, ozone depletion, ecotoxicity, smog, biogenic CO_2 eq, energy from biomass, non-renewable fossil energy	Coal electricity production.
	Coal	Non-carcinogen	Mercury process emission
Energy from Biomass	Biomass Energy	Ozone depletion	CFC-10 process emission.
		Biogenic CO2eq	CO_2 emissions from combustion
Pulp mill process emissions	Pulp mill process emissions	Eutrophication	*COD and BOD from releases of organic matter to water.**

**Data enhancement opportunity (See Table 16)*

4 Quantifying the Impact of Variability and Assumptions: Sensitivity Analysis

Sensitivity analysis is a systematic procedure for estimating the effects of the choices made regarding methods and data on the outcome of a study[12]. Sensitivity analysis can be used to:

[11] Spoil from mining includes waste-specific emissions from lignite spoil leachate and short and long term emissions to ground water from rainwater infiltration leaching. It does not include leaching by lateral groundwater flow.
[12] ISO 14040:2006, p. 5, Definitions

- Target data quality improvements and determine data precision;
- direct behavior by identifying what actions matter; and
- allow for product comparison recognizing variability.

Sensitivity analysis is a key component of life cycle assessment data quality analysis and can be applied to quantify the impact of changes in assumptions or input data on study results. For example, if the study assumes certain average values for production values, the sensitivity analysis can evaluate the impact if minimum or maximum values are applied instead. Similarly, if the study assumes a certain fuel mix used for energy, the sensitivity analysis can determine whether a change to that fuel mix assumption will significantly affect study results. It can be used to determine key factors that may have a material impact when changes are made, and can be used to describe the relative variability of study results. This section presents the results for sensitivity analyses based on varying the following parameters:

Scenario 1: Total pulping production energy used

Scenario 2: Fuel mix of pulping production energy

Scenario 3: Impact characterization method

Scenario 4: Recycling allocation methodology

We selected the scenarios based on stakeholder group feedback from a list of key parameters identified during the scope, data collection and analysis phases of the project. For scenarios 1, 2 and 3 we evaluated mechanical and kraft pulp separately to enable a comparison of the virgin alternate pulp products, as energy use and fuel mix can vary significantly within and between the two systems

4.1 Scenario 1: Variations in Total Pulp Production Energy

As illustrated in Figures 6 through 8, energy used in pulp production is the most significant contributor to deinked, kraft and mechanical pulp environmental impacts for the majority of impact categories evaluated. Energy use can vary significantly based on factors such as type of mill, type of technology and equipment efficiency. For example, integrated mills avoid intermediate drying of the pulp, which is on the order of 25% of the total heat requirement for a non-integrated kraft mill[13]. The secondary data evaluated (shown in Table 8) reported a wide range of pulping energy requirements.

Figure 9 illustrates the relative impact of deinked, kraft and mechanical pulp based on the pulping production energy use ranges shown in Table 8. Kraft and mechanical pulp are shown separately to illustrate the differences between the alternative pulp products. Results for each impact category are normalized to “1” for the maximum impact among the pulp products compared. For example, the mechanical pulp (orange bar) has the highest relative impact for Fossil CO2e and is set at 1; the kraft and deinked pulp values are shown relative to this normalized value. The light blue error bars in Figure 9 demonstrate the range in impacts that

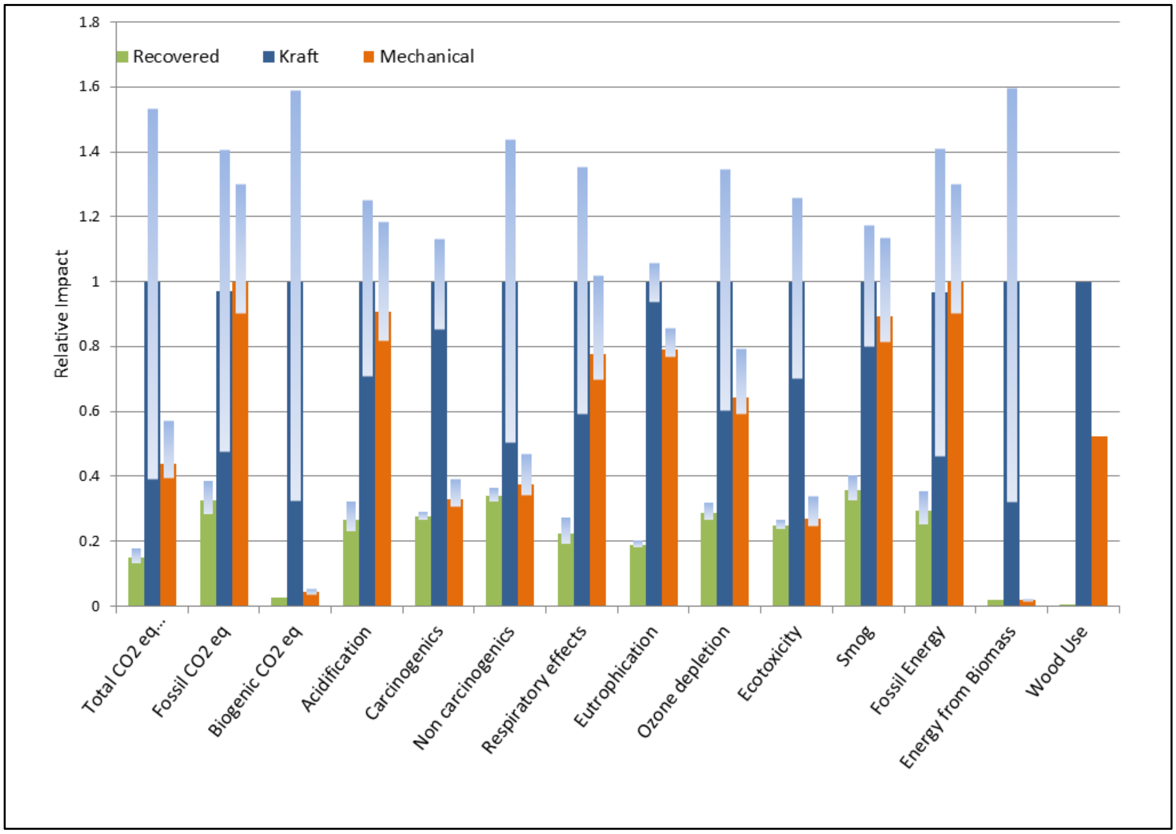
[13] Ecofys, Methodology for the free allocation of emission allowances in the EU ETS post 2012, Sector report for the pulp and paper industry, November 2009.

result from applying the low value and high value range of total pulping process energy for each pulp type, relative to the normalized maximum impact. We obtained the low and high energy production values from the secondary data sources as noted in Table 8 to represent a range of feasible scenarios. Specific mills may have higher or lower total energy values than those included in the analysis.

Table 8: Range of Pulp Production Energy values by Pulp Type (MJ per MT)

Pulp	Baseline	Low	High
Kraft	36.17	11.47[14]	57.73[15]
Mechanical	7.91	7.09[16]	10.48[17]
Deinked	1.60	1.24[18]	2.10[19]

Figure 9 : Variation in Relative Impact based on a range of Total energy per kg/pulp



[14] Hard wood kraft process emissions from Table 4.5 , American Institute of Chemical Engineers (AIChE) (2006) Pulp and Paper Industry Bandwidth Study.

[15] Tables 4-2 and 4-3 from Natural Resources Canada (2008) Benchmarking Energy Use in Canadian Pulp and Paper Mills Study. Average of 75th percentile integrated and non-integrated kraft pulp mill.

[16] Tables 3-3/3-5 (for mechanical) from Natural Resources Canada (2008) Benchmarking Energy Use in Canadian Pulp and Paper Mills Study. Average of 25th percentile integrated and non-integrated mechanical pulp mill.

[17] Stone groundwood pulp (SGW) process emissions from Table 4.5 , American Institute of Chemical Engineers (AIChE) (2006) Pulp and Paper Industry Bandwidth Study.

[18] Department of Energy: Energy Efficiency and Renewable Energy Industrial Technologies Profile (2005) Energy and Environmental Profile of the US Pulp and Paper Industry

[19] NRC Tables 3-3/3-5 (for recycled pulp) from Natural Resources Canada (2008) Benchmarking Energy Use in Canadian Pulp and Paper Mills Study.

Table 9 provides a summary of the range in relative values considering variations in the total pulp manufacturing energy.

Table 9: Range of relative impacts based on variations in total pulp production energy

Impact Category	Deinked Pulp	Kraft Pulp	Mechanical Pulp
Total CO2 eq (Fossil + Biogenic)	0.13-0.18	0.39-1.53	0.4-0.57
Fossil CO2 eq	0.28-0.39	0.48-1.41	0.9-1.3
Biogenic CO2 eq	0.02-0.03	0.33-1.59	0.04-0.06
Acidification	0.23-0.32	0.71-1.25	0.82-1.18
Carcinogens	0.27-0.29	0.85-1.13	0.31-0.39
Non Carcinogens	0.32-0.37	0.5-1.44	0.34-0.47
Respiratory effects	0.19-0.27	0.6-1.36	0.7-1.02
Eutrophication	0.18-0.2	0.94-1.05	0.77-0.86
Ozone depletion	0.264-0.319	0.6-1.35	0.59-0.79
Ecotoxicity	0.24-0.27	0.7-1.26	0.25-0.34
Smog	0.33-0.4	0.8-1.17	0.81-1.14
Fossil Energy	0.25-0.35	0.46-1.41	0.9-1.3
Energy from Biomass	0.0207-0.0209	0.32-1.6	0.016-0.024
Wood Use	0.0011-0.0012	1-1	0.521-0.522
Key			
Pulp that consistently has the lowest relative environmental impact for each of the total pulp process energy scenarios evaluated			
Pulps that can potentially have the lowest relative environmental impact depending on the total pulp process energy (i.e., the range of relative minimum impacts overlaps)			
Pulp that has the highest relative environmental impact for each of the three total pulp process energy scenarios evaluated			
Pulps that can potentially have the highest relative environmental impact depending on the total pulp process energy (i.e., the range of relative maximum impacts overlaps)			
Pulp whose impact is neither the relative minimum nor maximum of the three pulp types evaluated			

Scenario 1 Analysis: Variations in total pulp manufacturing energy can have a significant impact across a range of impact categories. Recovered fiber has a consistently lower environmental impact for the majority of environmental impacts. For non-carcinogens and ecotoxicity and Energy from Biomass, recovered fiber can potentially have higher impacts than mechanical pulp. These results can be used in conjunction with the process contribution analysis to identify potential actions. For example, as illustrated in Figure 6, over a third of the non-carcinogen effects of deinked pulp are due to the input chemical sodium dithionate; this chemical could be targeted for reduction or substitution. For seven out of 14 categories, kraft pulp consistently has the highest relative impact. Kraft pulp has the highest relative impact for biogenic carbon dioxide equivalence, due to the large amount of biomass fuel, primarily black liquor, used to produce energy during its production. For six categories (primarily related to air

emissions from energy consumption) the relative impact of kraft versus mechanical pulp depends on the total energy requirements for each process. For these categories, mechanical pulp can have a relatively higher impact than kraft pulp or vice versa, depending on the total pulp production energy used in both processes.

4.2 Scenario 2: Variations in Pulp Production Energy Fuel Mix

Pulp mills can utilize different sources of energy (e.g., purchased energy, coal, natural gas, hog fuel, black liquor etc.) Depending on the type of mill, specific processes and equipment are used. Different raw materials, input chemicals, waste and emissions are associated with different sources of energy and using different fuel mixes can result in different environmental impacts. For example, acquiring and combusting natural gas produces approximately 60% of the GHG emissions as coal per mega joule.

Figure 10 illustrates the relative impact of deinked, kraft and mechanical pulp based on the fuel mix scenarios shown in Table 10. These scenarios (Baseline, Mix A, and Mix B) are based on the proportion of purchased electricity (for deinked pulp and mechanical pulp) and black liquor (for kraft pulp) obtained from the secondary data sources listed in Table 13. The additional fuel types and percentages are estimated based on the These scenarios represent a set of feasible fuel mix scenarios for each pulp production type to illustrate the potential variability in results; individual pulp producers may use fuel mixes that have different relative proportions or additional fuels. Kraft and mechanical pulp are shown separately to illustrate the differences between possible alternative pulp products. Results for each impact category are normalized to "1" for the maximum impact among the pulp products compared. The light blue bars in Figure 10 demonstrate the range in impacts that result from using the range of fuel mixes.

Table 10: Deinked Pulp Impacts Based on Fuel Type

Impact Category	**Deinked Pulp**			**Kraft Pulp**			**Mechanical Pulp**		
Scenario →	Base	Mix A	Mix B	Base	Mix A	Mix B	Base	Mix A	Mix B
Purchased Electricity	60%	38%	92%	5%	4%	10%	83%	70%	95%
Coal	14%	21%	3%	3%	2%	4%	4%	7%	1%
Fuel Oil	6%	10%	1%	11%	7%	13%	2%	3%	1%
Natural Gas	20%	31%	4%	11%	7%	13%	6%	11%	2%
Black Liquor (kraft) /Hog Fuel (mechanical)	0%	0%	0%	70%	80%	60%	5%	9%	1%

Figure 10 : Variation of Relative Impact based on a Range of Input Fuels

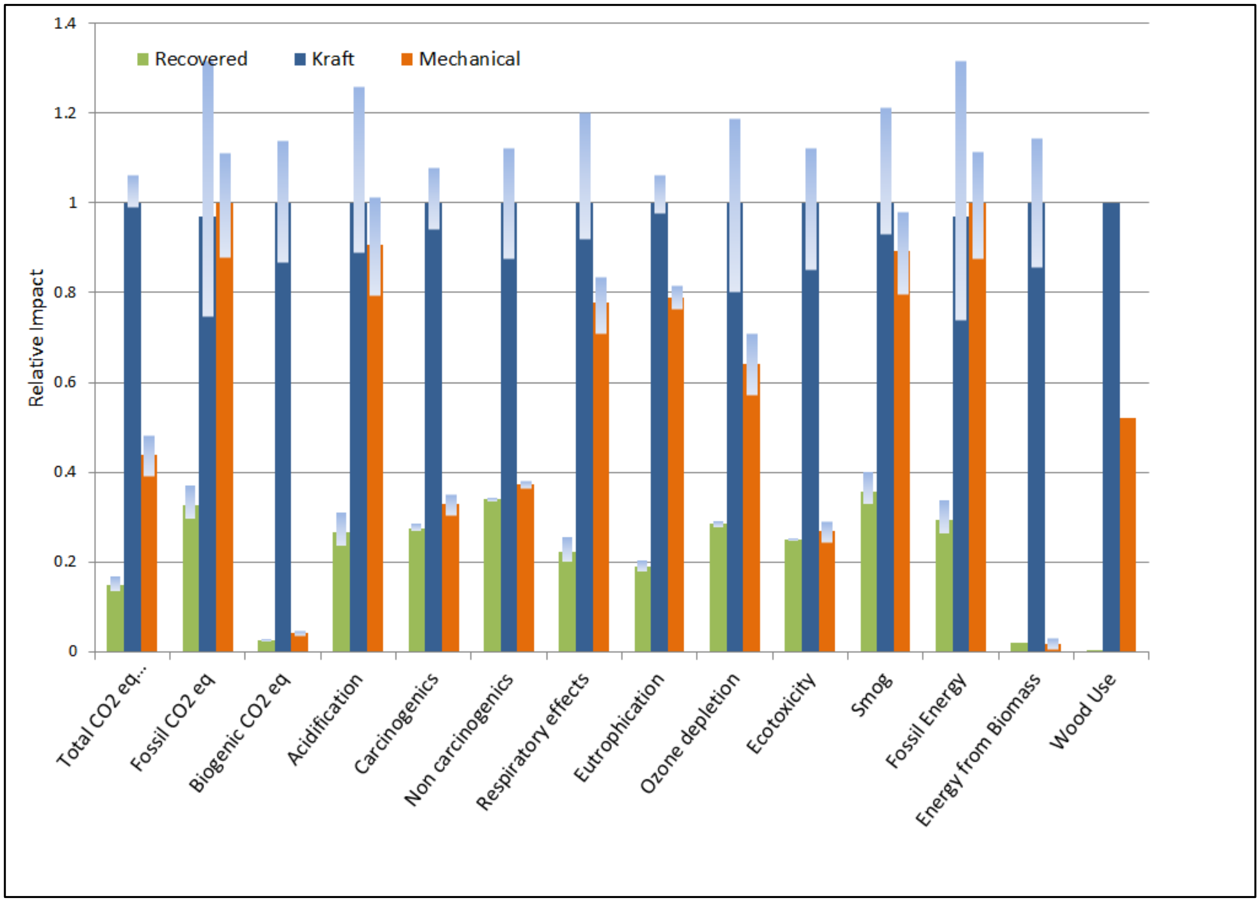


Table 11 provides a summary of the range in relative values considering variations in the mix of input fuels utilized. The dark green cells represent the pulp that consistently has the lowest relative environmental impact for each of the three input fuel scenarios evaluated. The dark blue cells represent the pulp that has the highest relative environmental impact for each of the three input fuel scenarios evaluated. If two the pulps can potentially have the lowest relative environmental impact depending on the input fuel scenario (i.e., the range of relative minimum impacts overlaps) then their cells are shaded light green. If two of the pulps can potentially have the highest relative environmental impact depending on the input fuel scenario (i.e., the range of relative maximum impacts overlaps) maximum then their cells are shaded light blue. If a cell is not shaded (e.g., mechanical pulp respiratory effects) then the relative impact for that pulp is neither the relative minimum or maximum of the three pulp types evaluated.

Table 11: Range of relative impacts based on variations in input fuels

	Deinked Pulp	Kraft Pulp	Mechanical Pulp
Total CO_2 eq (Fossil + Biogenic)	0.14-0.17	0.99-1.06	0.39-0.48
Fossil CO_2 eq	0.3-0.37	0.75-1.31	0.88-1.11
Biogenic CO_2 eq	0.02-0.03	0.87-1.14	0.04-0.05
Acidification	0.24-0.31	0.89-1.26	0.79-1.01
Carcinogens	0.27-0.29	0.94-1.08	0.3-0.35
Non Carcinogens	0.335-0.343	0.88-1.12	0.36-0.38
Respiratory effects	0.2-0.26	0.92-1.2	0.71-0.84
Eutrophication	0.18-0.2	0.98-1.06	0.76-0.81
Ozone depletion	0.277-0.292	0.8-1.19	0.57-0.71
Ecotoxicity	0.248-0.253	0.85-1.12	0.25-0.29
Smog	0.33-0.4	0.93-1.21	0.8-0.98
Fossil Energy	0.26-0.34	0.74-1.31	0.88-1.11
Energy from Biomass	0.021-0.021	0.86-1.14	0.0057-0.0301
Wood Use	0.0011-0.0013	1-1	0.5214-0.5217
Key			
Pulp that consistently has the lowest relative environmental impact for each of the three input fuel scenarios evaluated			
Pulps that can potentially have the lowest relative environmental impact depending on the input fuel scenario (i.e., the range of relative minimum impacts overlaps)			
Pulp that consistently has the highest relative environmental impact for each of the three input fuel scenarios evaluated			
Pulps that can potentially have the highest relative environmental impact depending on on the input fuel scenario (i.e., the range of relative maximum impacts overlaps)			
Pulp whose impact is neither the relative minimum nor maximum of the three pulp types evaluated			

Scenario 2 Analysis: Varying fuel mix can have a significant effect on impact results, although to a lower extent than the total pulp energy. Recovered fiber has a consistently lower environmental impact for all of the environmental impacts with the exception of ecotoxicity and Energy from Biomass. For these categories, mechanical pulp can have a relatively lower impact than recovered fiber, depending on the input fuel mix to both processes. Kraft pulp has a consistently higher impact in ten of the categories. As in scenario 1, kraft pulp has the highest relative impact for biogenic carbon dioxide equivalence, due to the large amount of biomass fuel, primarily black liquor, used to produce energy during its production. For four categories (primarily related to air emissions from energy consumption) the relative impact of kraft versus mechanical pulp depends on the fuel mix used for each production process. For these categories, mechanical pulp can have a relatively higher impact than kraft pulp, depending on the input fuel mix to both processes.

4.3 Scenario 3: Variations in Impact Characterization Method

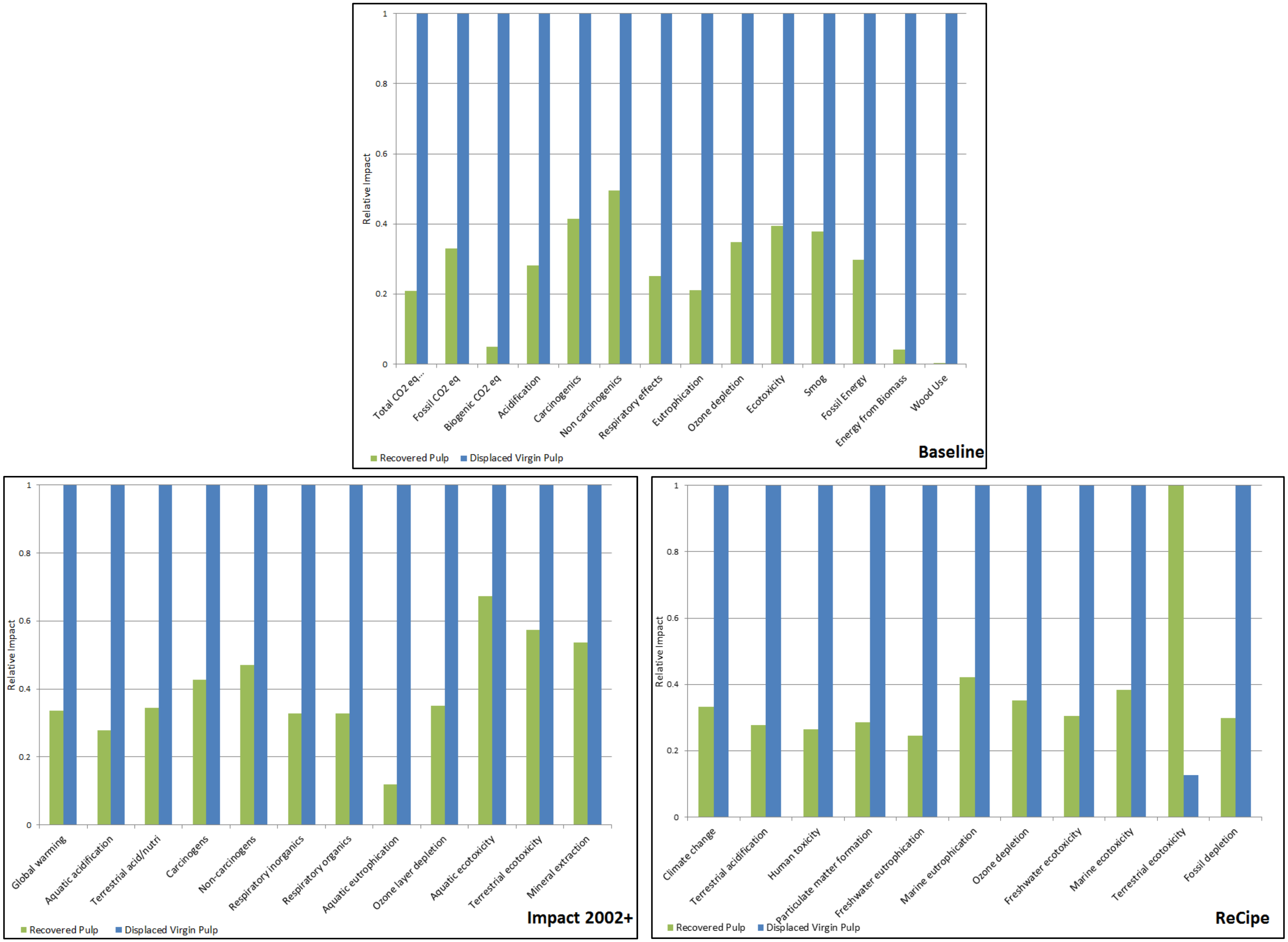
As discussed in Section 3.1, impact characterization methods translate the inventory results into environmental impact categories based on characterization factors. We applied the characterization factors listed in Table 3. In Scenario 3, we consider whether the choice of impact characterization method influences the results of the relative pulp comparison. To do this we apply two different internationally accepted impact characterization methods. These additional methods use a different set of substances and characterization factors. Because the different impact methods use a different set of substances and characterization factors the differences in results cannot be compared quantitatively with ranges across all the impact factors as illustrated in the other sensitivity scenarios. Thus, we show the results for the displaced pulp scenario basecase to demonstrate the qualitative difference between similar characterization factors of the alternative methods.

In Figure 11, we compare the baseline method to alternative method 1, and alternative method 2. Our baseline method is a combination of TRACI 2, the Greenhouse Gas Protocol, and wood use. Alternative method 1 is the IMPACT 2002+ life cycle impact assessment method,[20] and alternative method 2 is the ReCipe impact assessment method[21] with normalization to the world population and a hierarchical perspective. The hierarchical perspective describes the average or consensus impact model as it pertains to choices on issues such as time or potential improvements to environmental management or technology to reduce environmental impacts. Appendix A includes the numeric results for both analyses.

[20] Jolliet, O., Margni, M., Charles, R., Humbert, S., Payet, J., Rebitzer, G., & Rosenbaum, R. (2003). IMPACT 2002+: A new life cycle impact assessment methodology. *The International Journal of Life Cycle Assessment, 8*(6), 324-330.

[21] Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., & Van Zelm, R. (2009). ReCiPe 2008: A life cycle impact assessment method which comprises harmonized category indicators at the midpoint and the endpoint level.: Report I: Characterization. *Report I: Characterization, NL, from http://lcia-recipe. net*.

Figure 11 : Baseline method (top) vs. IMPACT 2002+ and ReCipe (bottom)



Scenario 3 Analysis: Although the relative impacts are slightly different than the basecase methods, deinked pulp consistently has a lower relative impact than virgin pulp produced from wood, with the exception of ReCipe terrestrial ecotoxicity. The high relative value for deinked pulp in this characterization method is due to emissions to soil of cypermethrin due to the cultivation of oil palms to make fatty acids[22]. This chemical also impacts the terrestrial ecotoxicity in the Impact 2002+ method, but does not have as relatively high of a characterization factor. The inventory dataset from US LCI for fatty acids assumes the use of palm oil; this material is listed as a data enhancement opportunity in Section 5.5. Based on this evaluation, we can infer than the results are not influenced by the selection of characterization method.

4.4 Scenario 4: Varying Assumptions Regarding Recycling Allocation

To test the impact on the results of the selection of the cut-off method for recycling allocation, we conducted a sensitivity analysis varying the assumption for recycling allocation. In the cut-off allocation method, no upstream inputs, outputs, or emissions associated with the production of waste paper are allocated to the deinked pulp process. We tested the following scenarios:

- Deinked pulp and virgin pulp are assigned allocation factors based on the number of subsequent uses method[23]. The allocation for deinked pulp represents the quantity of virgin production burdens associated with production of waste paper. The allocation for virgin represents the fraction of the environmental burden associated with the virgin pulp production, where the remaining environmental burdens are avoided due to subsequent uses/and recycling. We applied allocation factors of 0.21 (0.79 avoided) for deinked pulp (assuming high grade deinking) and 0.85 (0.15 avoided) for virgin pulp (assuming a magazine end product). The allocation factors were developed by NCASI (2010)[24] based on factors including the fraction of products recovered, the fractions recycled into different types of products, and the yield of repulped fibers, as illustrated in ISO 14049.
- Deinked pulp is given credit for avoiding the burden of waste paper emissions from a landfill

The light blue bars in Figure 12 and 13 illustrate the variability in results for applying these scenarios to the displaced pulp (50% mechanical and 50% kraft) and kraft and mechanical pulps separately, respectively. The lower range of the light blue bars for the deinked pulp represents the credit for avoiding disposing of waste paper in a landfill. The negative relative impact results for biogenic CO2 and eutrophication are due to the significant impact of paper disposal in landfills for these two categories that is credited to deinked pulp. The upper range of the light blue bar includes allocation for some of the impacts associated with the original virgin material. The lower range of the light blue bar on the virgin pulps represents the reduction in impacts if a percentage of the burden is allocated to other products produced from recycling.

[22] Fatty acids are used to produce fatty acid salts or soaps, which is one of the substances used in the deinking of pulp [Hannuksela and Rosencrance. Deinking Chemistry. Kemira Chemicals Inc. Available: http://www.cost-e46.eu.org/files/Deinking%20primer/Deinking%20Chemistry-FINAL.pdf], see Table 16.
[23] ISO 14044:2006, Section 4.3.4.3
[24] Application of the ISO 14049 "Number of Subsequent Uses" Allocation Procedure to the P&W Paper Product Systems, NCASI, 2010. These factors represent average conditions

The basecase virgin results represent the scenario in which no downstream recycling of the product occurs, such as for tissues.

Figure 12: Deinked Pulp vs. Displaced Virgin Pulp: Recycling allocation and credits.

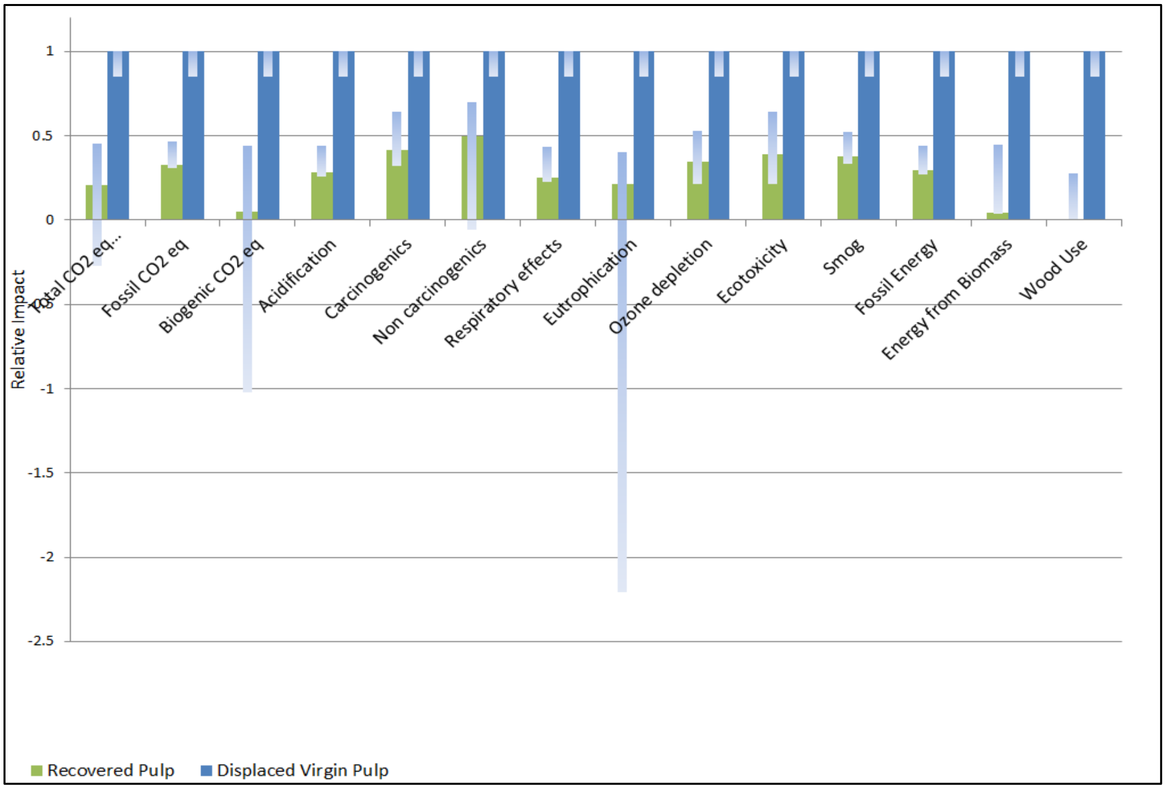


Figure 13: Deinked vs. Kraft vs. Mechanical Pulp: Recycling allocation and credits.

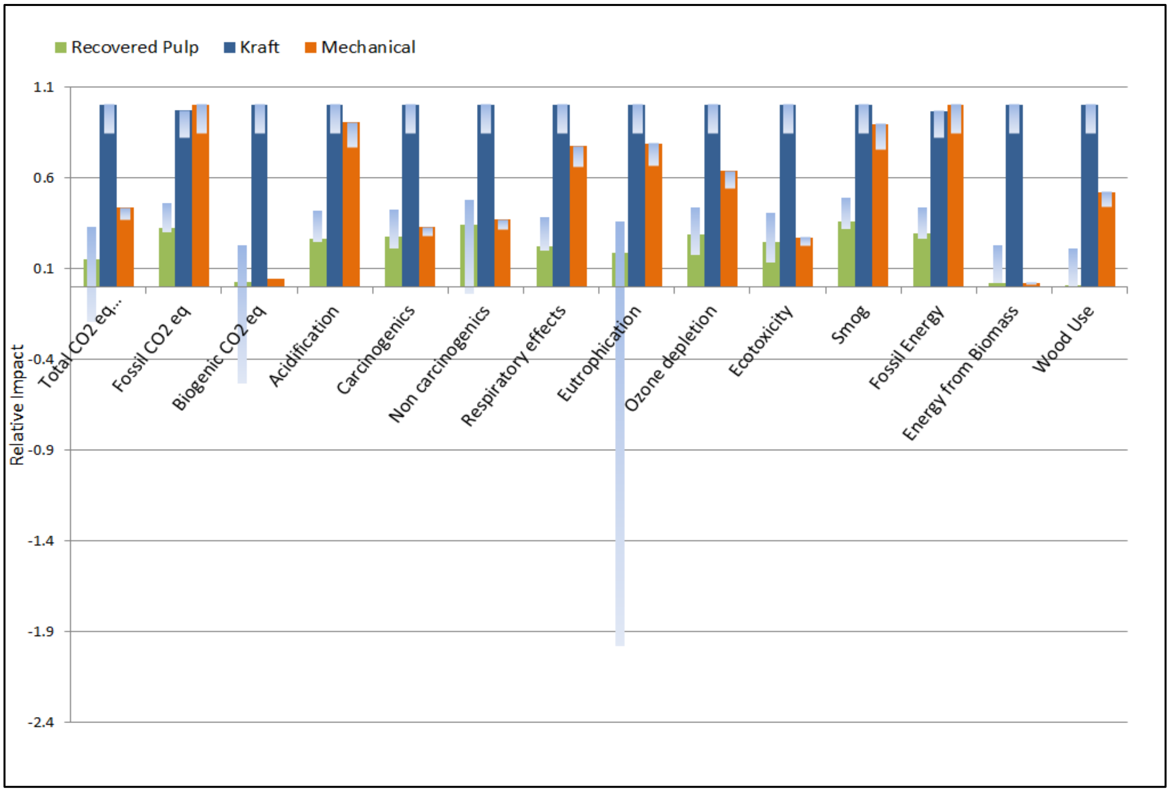


Table 12 provides a summary of the range in relative values that result from varying recycling allocations assumptions.

Table 12: Range of relative impacts based on variations in recycling allocation assumptions

	Deinked Pulp	Kraft Pulp	Mechanical Pulp
Total CO_2 eq (Fossil + Biogenic)	-0.19-0.33	0.85-1	0.37-0.44
Fossil CO_2 eq	0.3-0.46	0.82-0.97	0.85-1
Biogenic CO_2 eq	-0.53-0.23	0.85-1	0.04-0.04
Acidification	0.24-0.42	0.85-1	0.77-0.91
Carcinogens	0.21-0.43	0.85-1	0.28-0.33
Non Carcinogens	-0.04-0.48	0.85-1	0.32-0.37
Respiratory effects	0.2-0.39	0.85-1	0.66-0.78
Eutrophication	-1.98-0.36	0.85-1	0.67-0.79
Ozone depletion	0.17-0.44	0.85-1	0.55-0.64
Ecotoxicity	0.14-0.41	0.85-1	0.23-0.27
Smog	0.32-0.49	0.85-1	0.76-0.89
Fossil Energy	0.27-0.43	0.82-0.97	0.85-1
Energy from Biomass	0.02-0.23	0.85-1	0.015-0.017
Wood Use	0-0.21	0.85-1	0.44-0.52
Key			
Pulp that consistently has the lowest relative environmental impact for each of the recycling allocation scenarios evaluated			
Pulps that can potentially have the lowest relative environmental impact depending on the recycling allocation scenario (i.e., the range of relative minimum impacts overlaps)			
Pulp that consistently has the highest relative environmental impact for each of the recycling allocation scenarios evaluated			
Pulps that can potentially have the highest relative environmental impact depending on the recycling scenario (i.e., the range of relative maximum impacts overlaps)			
Pulp whose impact is neither the relative minimum nor maximum of the three pulp types evaluated			

Scenario 4 Analysis: Deinked pulp has a lower relative impact than displaced pulp (50% mechanical, 50% kraft) for all of impact categories evaluated for all of the recycling allocation scenarios evaluated. Deinked pulp also has a consistently lower relative impact when compared against 100% kraft pulp. Deinked pulp has a relatively lower impact than 100% mechanical pulp for ten of the fourteen categories; the lowest relative impact of deinked pulp and mechanical pulp vary in the other four categories, due to the impacts from virgin kraft pulp production allocated to the deinked pulp. Kraft pulp has the highest impact in ten of the categories; the highest relative impact of kraft and mechanical pulp vary in the other four categories.

5 Input and Outputs: Life Cycle Inventory

This section describes the materials and energy used (the "inputs") as well as the environmental emissions (e.g., releases to air, water and soil) and wastes (the "outputs") associated with each of the processes included in the fiber acquisition through the pulp production stages for recovered deinked pulp, bleached mechanical and bleached kraft pulp. This life cycle inventory data is simply a catalog of input and output flows, we assess the associated environmental relevance in a separate step. We use this LCI data in conjunction with characterization factors to estimate the potential effects on the environment during the life cycle analysis phase, as discussed in Section 3.

This section describes the data sources used, how values were derived for each process step, and reviews the key inventory inputs and outputs that contribute significantly to the environmental impact assessment results. Life cycle inventories and the resulting assessments are limited by the availability and quality of the data. In addition, data values (such as amount and type of energy used) can vary significantly due to local conditions. We evaluated the data precision, completeness, and representativeness as detailed in Section 2.3.3. Section 5.5 provides a summary of data enhancement opportunities.

5.1 Data Sources Overview

This study utilized inventory data from academic and industry studies (i.e. existing "secondary" data). We reviewed available secondary sources to apply the best available data to meet the goals and objectives of the study. We sought relevant and timely industry average data from North America. We obtained and refined the LCI data sources through the following iterative process:

1. Conducted a literature review to identify readily-available secondary sources for deinked, kraft and mechanical pulp life cycle inventory inputs and output materials and amounts
2. Developed detailed process maps to catalog the inputs and outputs associated with each pulp lifecycle process step included in the study boundaries
3. Refined the detailed process maps based on feedback from the stakeholder group and technical advisors
4. Developed draft basecase analysis results to determine the significant inputs and outputs
5. Evaluated these significant inputs and outputs to identify data enhancement opportunities and candidates for sensitivity analysis
6. Refined the LCI values to address data enhancement opportunities, if possible. Conducted sensitivity analyses to analyze the effects of variable inputs on results.

Table 13 summarizes the data sources considered in the analysis, assigning each a reference number (e.g. "S1"). Each input and/or output on the detailed process maps in Figures 14 through 18 then cites the relevant reference number. Literature and industry references cited (S1-S10 below) provided "activity" inventory data that describe the amount (e.g., MJ of fuel, mass of input chemicals) of and type of each process step input and output. Along with direct activity inventory data, the LCI databases (USLCI and Ecoinvent) also incorporate all of the "embodied" inventory data associated with acquiring and producing the input and/or disposing of the waste products upstream or downstream of the specific pulp system process—i.e., the "cradle-to-paper mill" inventory. For example, the amount of hydrogen peroxide used to produce deinked pulp was based on the IFEU reference (S2), while the life cycle inventory of all of the inputs and outputs associated with producing the hydrogen peroxide (such as the energy and materials used to produce this chemical) are obtained from the Ecoinvent LCI database.

Table 13: Summary of Secondary Data Sources

Reference #	Study	Source	Processes Addressed
S1	*Life Cycle Inventories of Packaging and Graphical Paper. Part III: Paper and Board. Final report ecoinvent data v2.0 No. 11. Swiss Centre for Life Cycle Inventories, Dübendorf, CH*	Ecoinvent (2007)	Waste paper sorting and collection, wood production, kraft pulp production and mechanical pulp production
S2	*Ecological comparison of office papers in view of the fibrous raw material (Deinked Pulping Only)*	IFEU Heidelberg, (2006)	Deinked pulp production, including energy use.
S3	*White Paper No 10A., Environmental Comparison-Manufacturing Technologies for Virgin & Recycled-Content Printing & Writing Paper of Bleached Kraft Pulp Manufacturing Technologies*	Paper Task Force (1995)	Recycled and kraft pulp production
S4	*Pulp and Paper Industry Bandwidth Study*	American Institute of Chemical Engineers (AIChE) (2006)	Electricity and thermal energy consumption for pulp production
S5	*Sector Report for the Pulp and Paper Industry, Methodology for the free allocation of emission allowances in the EU ETS post 2012*	Ecofys (2009)	Electricity and thermal energy consumption for pulp production.
S6	*Documentations for the Paper Calculator*	Franklin Associates submitted to the Environmental Paper Network (2011)	Electricity and thermal energy consumption for pulp production.
S7	*Benchmarking Energy Use in Canadian Pulp and Paper Mills*	Natural Resources Canada (2008)	Electricity and thermal energy consumption for pulp production.
S8	*Life Cycle Assessment of North American printing and writing paper products*[25].	National Council for Air and Stream Improvement, Inc. (NCASI). Prepared for American Forest & Paper Association (AF&PA) and Forest Products Association of Canada (FPAC) (2010)	Life cycle inventory data for kraft pulp production.

[25] National Council for Air and Stream Improvement (NCASI). 2010. Life cycle assessment of North American printing and writing paper products. Final report prepared for American Forest and Paper Association (AF&PA), Forest Products Association of Canada (FPAC). June 18, 2010. 292 p.

Reference #	Study	Source	Processes Addressed
S9	*Energy and Environmental Profile of the US Pulp and Paper Industry*	US Department of Energy: Energy Efficiency and Renewable Energy Industrial Technologies Profile (2005)	Electricity and thermal energy consumption for pulp production.
S10	*Life Cycle Environmental Performance of Renewable Materials in Context of Residential Building Construction: Phase I Research Report.*	Bowyer et al (2004)	Life cycle inventory for wood extraction used for virgin fiber acquisition
S11	*US Life-Cycle Inventory Database (USLCI)*[26]	National Renewable Energy Laboratory (NREL)	The USLCI database provides individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the U.S. Appendix B lists the specific processes applied in the analysis.
S12	*Ecoinvent v2.2 database*[27]	Swiss Centre for Life Cycle Inventories	The ecoinvent database provides individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly internationally. Appendix B lists the specific processes applied in the analysis.

5.2 Inputs and Outputs Associated with Pulp Processes

This section illustrates the specific inputs and outputs associated with each pulp process step for deinked and virgin pulp (for both kraft and mechanical pulp). These detailed process maps are shown in Figures 14 through 18. These process maps include the "cradle-to-paper mill" processes associated with the three different types of pulp production and exclude the magazine production (including paper production), use and disposal phases, as discussed in Section 2.1. Fuel and energy inputs are shown in purple, other chemical and material inputs are shown in blue. Emissions and wastes are shown in red. Direct process emissions (such as organic matter emissions to water causing BOD-5, and particulate emissions) specified in the references are listed on the process maps. The process maps list the generic, but not the specific emissions to air, water and soil from fuel combustion and "embodied" emissions from input fuel, energy and material acquisition and manufacture separately on the process maps; these emissions and inputs are listed generically (e.g., emissions to air, water and soil from diesel combustion) because the associated inputs and output can contain hundreds of substances. These emissions and inputs are accounted for in the inventory and obtained from the USLCI and Ecoinvent lifecycle database process datasets detailed in Appendix A. The process maps identify the potential sources of the inventory activity data corresponding to the references in Table 13 (e.g "S1"). Section 5.3 details the "best available" specific data

[26] National Renewable Energy Laboratory. *US Life-Cycle Inventory*. Available: http://www.nrel.gov/lci/database/
[27] Ecoinvent database version 2.2. Available: http://www.ecoinvent.org/.

selected for the analysis from these references based on the study objectives, scope and data requirements.

Figure 14 : Deinked Pulp Inputs and Outputs by Unit Process: Fiber Acquisition

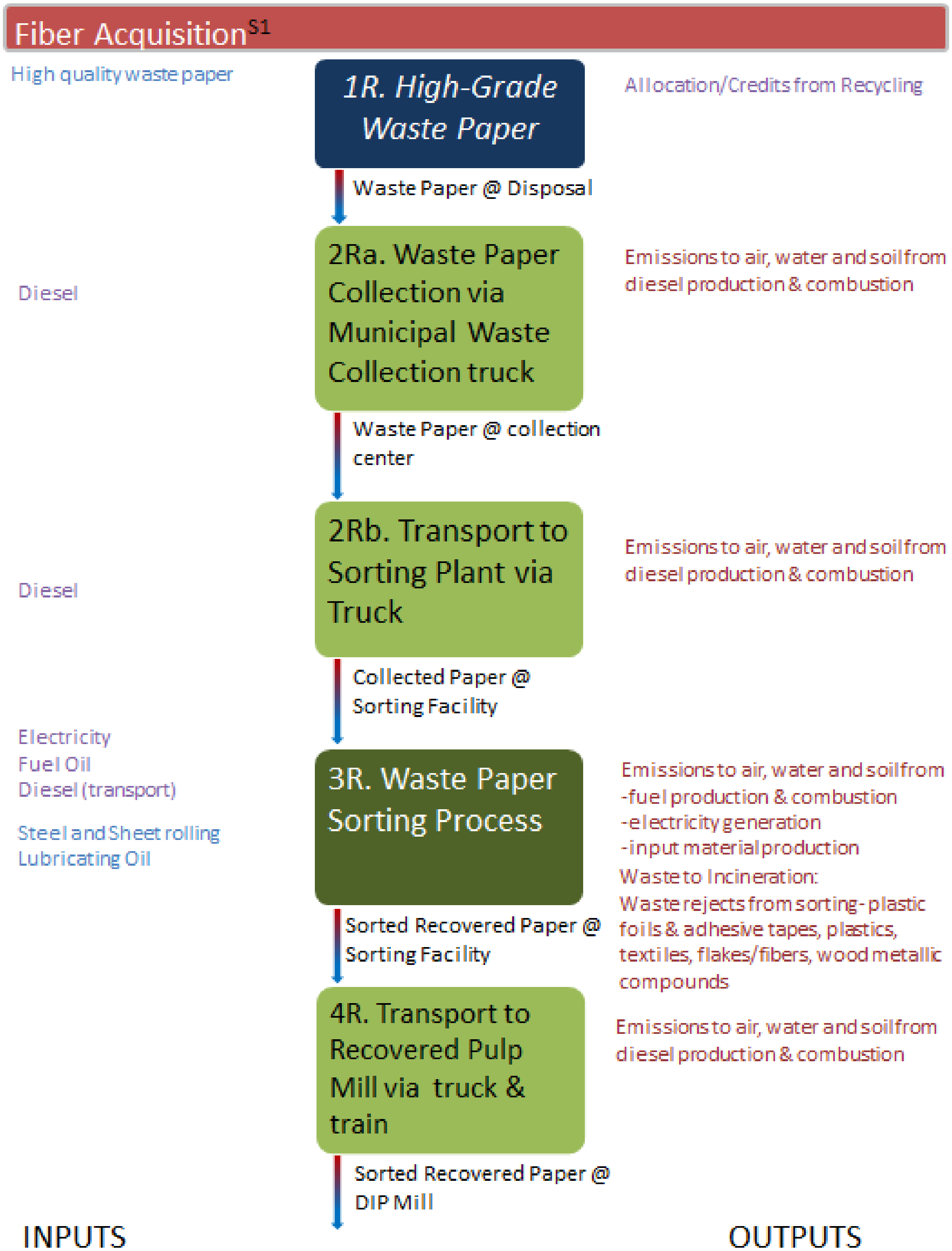


Figure 15 : Deinked Pulp Inputs and Outputs by Unit Process: Pulp Production and Transport to Mill

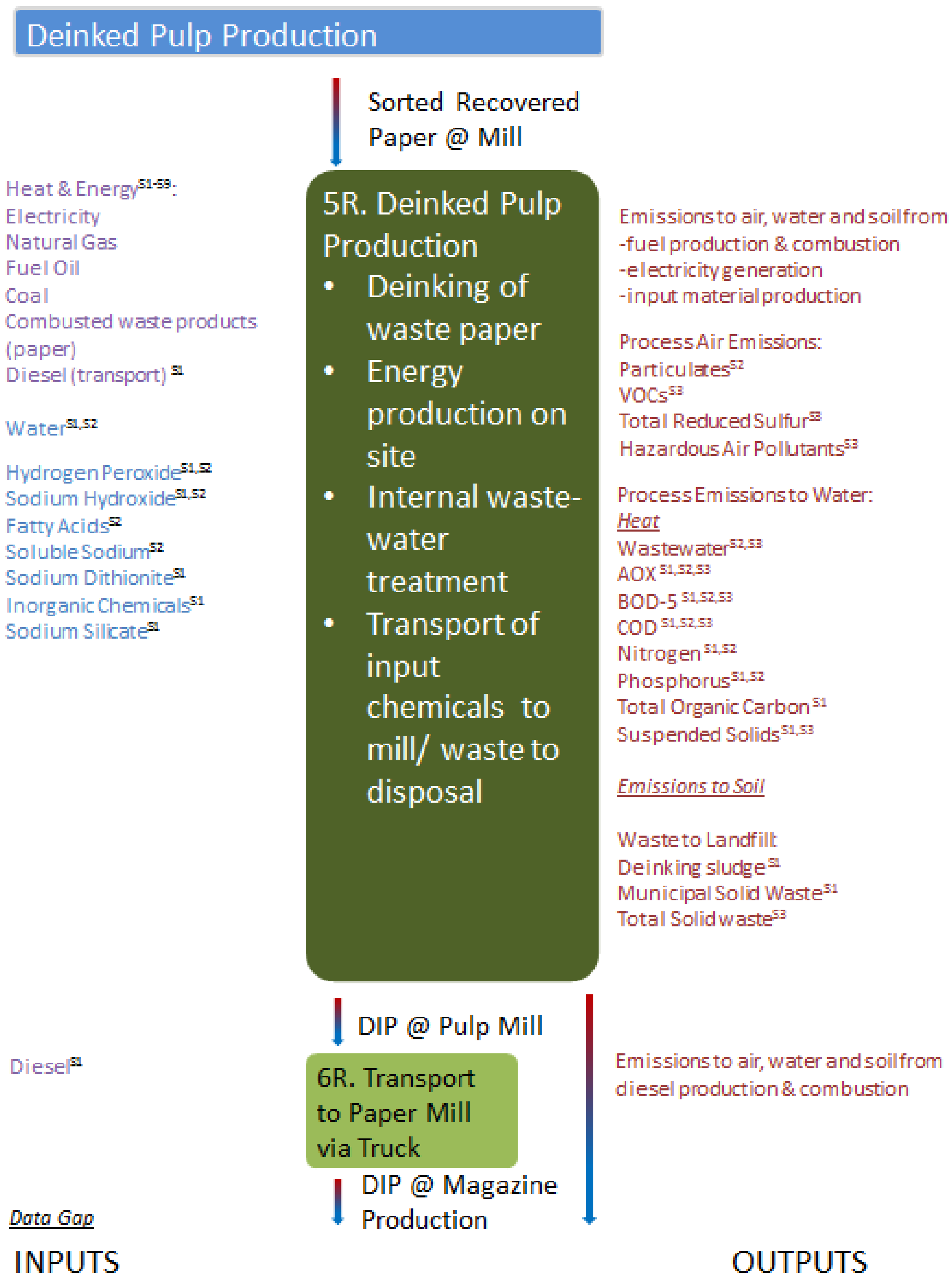


Figure 16 : Virgin Pulp Inputs and Outputs by Unit Process: Fiber Acquisition

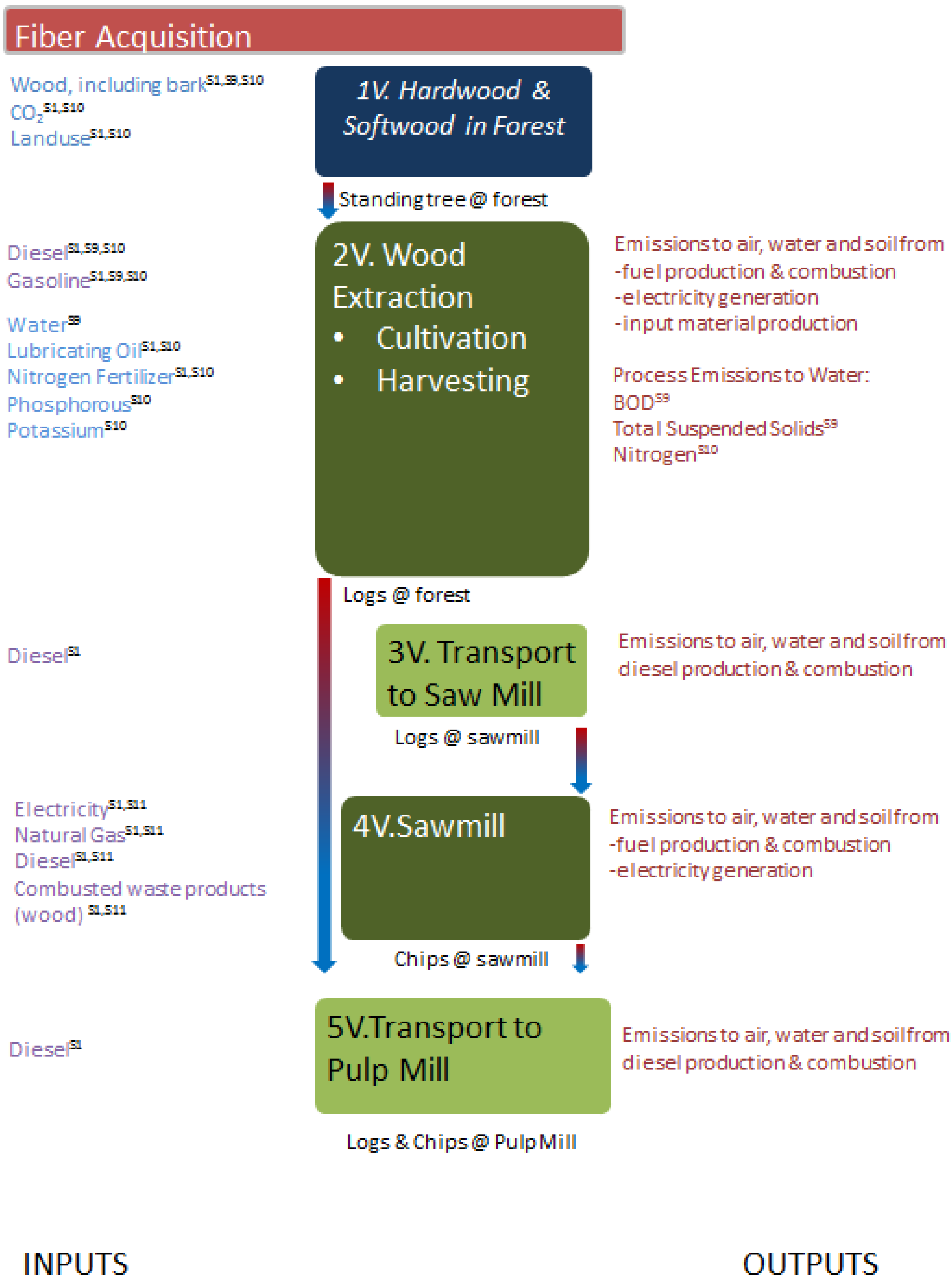


Figure 17 : Virgin Pulp Inputs and Outputs by Unit Process: Bleached Kraft Pulp Manufacturing

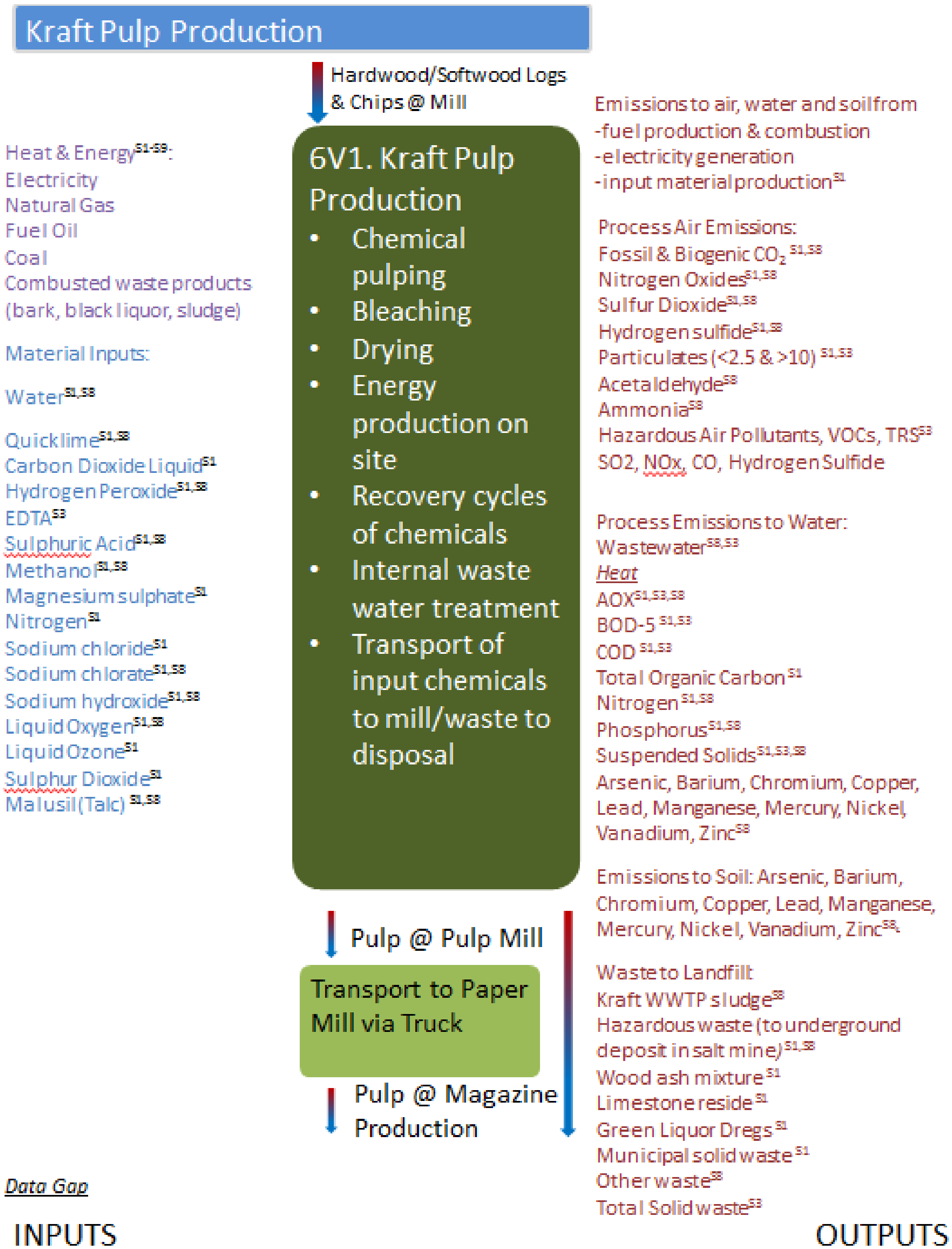
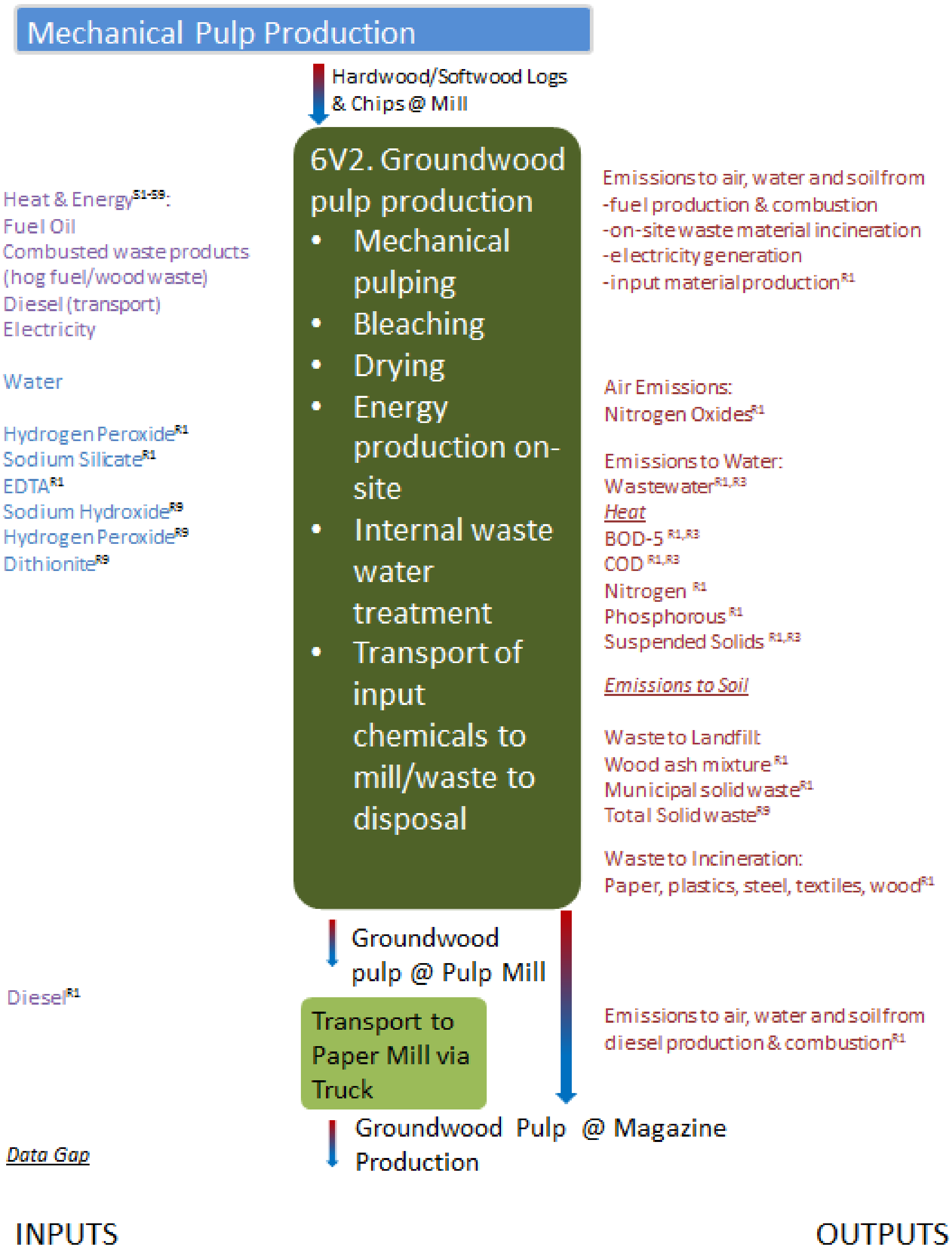


Figure 18 : Virgin Pulp Inputs and Outputs by Unit Process: Bleached Mechanical Pulp Manufacturing



5.3 “Best Available” Data Sources Used in the Analysis

Tables 14 and 15 summarize the activity data sources and assumptions used to develop the life cycle inventories for deinked, kraft and mechanical pulp. Each table also includes comments on the quality and relevance of the inventory data. Where available, we prioritized North America-specific data published within the last ten years. In Section 4, we applied a sensitivity analysis to examine the range of impacts due to input values that have a significant variability, such as pulp production energy use and input fuel mix to evaluate if the potential range in input values influences the study results.

Table 14: Data Sources Used in the Deinked Pulp Analysis

#	Process Step	Activity data sources	Assumptions and Comments on Quality/Relevance
1R	Waste Paper input	Ecoinvent	Cut-off allocation includes no burden/impacts for waste paper prior to collection. See Section 4.4 for Sensitivity Analysis of various recycling allocation approaches
			1.025 kg of waste paper produces 1 kg of sorted paper
2Ra	Waste Paper Collection via Municipal Collection truck	Distance to collection center (50km): Ecoinvent	No North American secondary inventory data identified for these stages. Emissions from transportation fuel use can significantly contribute to multiple impact categories. Transport distances can be highly variable depending on local conditions.*
2Rb	Transport to Sorting Plant via Truck	Distance to sorting plant (200km): Ecoinvent	
3R	Waste paper sorting	Material Inputs, Energy Use and Wastes: Ecoinvent	
4R	Transport to Sorting Plant via Truck	Distance to pulp mill (400km via rail or 100km via truck): Ecoinvent	
5R	DIP Pulp Production	Material Inputs: IFEU	No North American secondary inventory data identified for material inputs. Sodium dithionite and fatty acids can significantly contribute to some impact categories.*
			1.38 kg of sorted waste paper yields 1 kg of pulp.
		Energy Use: Average of DOE, IFEU, and Natural Resources Canada	Electricity use is responsible for the majority of impacts across a range of categories. Values can have high variability- see Sections 4.1 and 4.2 for Sensitivity Analysis of total pulp energy and energy fuel mix
		Wastes: Ecoinvent	Data only available for process that includes paper production from European data. Disposition of deinked sludge can significantly contribute to some categories*.

#	Process Step	Activity data sources	Assumptions and Comments on Quality/Relevance
		Process direct emissions to water: IFEU	Limited information on emissions to water available from U.S. pulp producers COD from releases of organic matter to water, phosphorous and nitrogen emissions contribute to eutrophication. Chlorophenols used as a proxy for AOX*. [28]
		Process direct emissions to air: From fuel combustion emissions	See Sections 4.1 and 4.2 for Sensitivity Analysis of total pulp energy and energy fuel mix.
6R	Transport to Paper Mill via Truck	Distance to paper mill (1550km) : Environmental Paper Network[29]	Based on an average of distances deinked pulp mills to paper manufactures. Distances can be highly variable depending on local conditions. Emissions from fuel use can significantly contribute to multiple impact categories.*

**Data enhancement opportunity (See Table 16)*

[28] According to the CPCB, chlorophenols are a type of AOX formed in the pulping process: Central Pollution Control Board. 2007. Development of AOX Standards for Large Scale Pulp and Paper Industries. Ministry of Environment and Forests. Available: http://cpcb.nic.in/newitems/34.pdf

[29] Environmental Paper Network (2008) *Pulpwatch*. Pulpwatch.org. [Accessed May, 2012]

Table 15: Data Sources Used in the Virgin Pulp Analysis

#	Process Step	Activity data sources	Assumptions and Comments on Quality/Relevance
2V	Wood Extraction	Hardwood input materials and fuels: USLCI	Average forest intensity for North East/North Central US regions[30]; 650kg/m3 dry density
		Softwood input materials and fuels: USLCI	Average forest intensity for South East and Pacific North West regions[31] ; 450kg/m3 dry density
3V	Transport to Saw Mill	Distance to saw mill: USLCI	Includes weight of bark and water content*
4V	Sawmill	Energy Use: USLCI	Particulate process emissions and air emissions from fuel combustion
5V	Transport to Pulp Mill	Distance to pulp mill: USLCI	Transport of green logs with 87% moisture content and 10% bark over 125km.
6V1	Kraft Pulp Production	Input wood: Paper Task Force[32]	Yield of bleached kraft pulp from dry wood = 45%
		Energy Use, Input Materials and Wastes: NCASI	North America average industry data for bleached kraft production. Energy values can have high variability- see Sections 4.1 and 4.2 for Sensitivity Analysis of total pulp energy and energy fuel mix
		Process direct emissions to water: NCASI, COD: Ecoinvent	Chlorophenols used as a proxy for AOX*. [33] COD values from Ecoinvent are average of TCF and ECF sulphate pulp data*.
		Process direct emissions to air: NCASI, fuel combustion emissions	Black liquor combustion emissions from multiple sources. Biogenic carbon dioxide emissions from The Climate Registry[34], carbon monoxide, hydrogen sulfide, nitrogen oxides, PM10, sulfur oxides, VOCs from Larson[35] and other black liquor air emissions from wood waste combustion (used as a proxy, consistent with NCASI).
		Process direct emissions to soil: NCASI	Arsenic, barium, chromium, copper, lead, manganese, mercury, nickel, vanadium, zinc

[30] Elaine Oneil, Leonard R. Johnson, Bruce Lippke, James McCarter, Marc McDill, Paul Roth, James Finley (2010) Life-Cycle Impacts of Inland West And NE/NC Forest Resources. Wood and Science. Volume: 0. Issue: TBA. Page: TBA. Madison WI US.

[31] SE/NW region reference

[32] Paper Task Force (1995), White Paper No 10A., Environmental Comparison-Manufacturing Technologies for Virgin & Recycled-Content Printing & Writing Paper of Bleached Kraft Pulp Manufacturing Technologies.

[33] According to the CPCB, chlorophenols are a type of AOX formed in the pulping process: Central Pollution Control Board. 2007. Development of AOX Standards for Large Scale Pulp and Paper Industries. Ministry of Environment and Forests. Available: http://cpcb.nic.in/newitems/34.pdf

[34] The Climate Registry. (2012). *General Reporting Protocol. Version 2.0*. [Available online] http://www.theclimateregistry.org/resources/protocols/general-reporting-protocol/

[35] Larson (2006) *A Cost-Benefit Assessment of Gasification-Based Biorefining in the Kraft Pulp and Paper Industry*. U.S. Department of Energy and the American Forest and Paper Association.

#	Process Step	Activity data sources	Assumptions and Comments on Quality/Relevance
			results available for kraft pulp, but not available for deinked or mechanical pulp. Therefore these were not included in the results for consistency.
6V2	Groundwood Pulp Production	Wood Yield: Paper Task Force[36]	Yield of bleached mechanical pulp from dry wood = 90%
		Material inputs and wastes: Ecoinvent	Data from a Swiss and German LCA study
		Energy Use: Average of DOE, Natural Resources Canada and Ecoinvent	Energy use responsible for the majority of impacts across a range of categories. Values can have high variability- see Sections 4.1 and 4.2 for Sensitivity Analysis of total pulp energy and energy fuel mix
		Process direct emissions to water: Ecoinvent*	Chlorophenols used as a proxy for AOX*. Based on average Swedish data.
		Process direct emissions to air: Based on fuel combustion emissions	Electricity use responsible for the majority of impacts across a range of categories. Values can have high variability- see Sections 4.1 and 4.2 for Sensitivity Analysis of total pulp energy and energy fuel mix
7V	Transport to Paper Mill via Truck	Distance to mills: US Census[37]	Assumed 90% integrated (0km transport distance) 10% non-integrated[38] (1030km transport distance kraft; 1460km transport distance mechanical pulp)*

**Data enhancement opportunity (See Table 16)*

[36] Paper Task Force (1995), White Paper No 10A., Environmental Comparison-Manufacturing Technologies for Virgin & Recycled-Content Printing & Writing Paper of Bleached Kraft Pulp Manufacturing Technologies.
[37] U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics and U.S. Census Bureau, 2007 Commodity Flow Survey.
[38] Information acquired from conversation with NCASI.

The specific lifecycle database process datasets applied from USLCI and Ecoinvent are detailed in Appendix B.

5.4 Significant Inventory Characterization Substances: Contribution Analysis

After we created an initial inventory, we calculated draft basecase results to determine which inputs and outputs significantly impacted the results. In this contribution analysis, we investigated the inventory substances that have the highest relative contribution in each impact *category* to achieve the following to:

- Assess the life cycle inventory for potentially significant data gaps and consistency, and
- Identify processes associated with the significant inventory substances to target potential actions, sensitivity analysis and data enhancement opportunities.

Figure 19 lists the significant inventory characterization substances by impact category and percent contribution to the total impacts of kraft, mechanical, and deinked pulp for the initial model inventory. The results for each pulp type are specific to the relative contributions of substances within the individual pulp processes only and should **NOT** be used in direct comparisons between pulp products. For example, biogenic CO2 emissions have a significant contribution to the biogenic CO2e impact category for all three types of pulp, but the relative impact of biogenic CO2e is significantly higher for virgin pulp, as illustrated in Figure 5. Each category can include up to hundreds of substances that contribute to the associated environmental impact. Figure 19 lists those substances that contributed 2% or more to any of the pulp products impacts for a given category. Inventory substances such as sulfur dioxide can contribute to more than one impact category. In these situations, the total amount of the substance is applied in each impact category and is weighted based on its relative contribution to the specific category.

We compared the characterization results across the different pulp products to identify potential inconsistencies by examining those substances that are significant in one or more pulp processes, but not in the other(s). This analysis identified data gaps as well as situations where one pulp process includes a unique input or process that results in significant impacts. For example:

Data Gaps:

- Soil emissions of chromium and zinc have a significant contribution to kraft pulp carcinogens, non-carcinogens and ecotoxicity impacts; however corresponding soil emissions for mechanical and deinked pulp were not available. Thus, we did not include soil emissions in the revised life cycle inventory for consistency, and documented soil emissions as a data gap
- COD from organic matter releases to water was lower for kraft pulp than mechanical pulp. We determined that our data source for Kraft paper didn’t comprehensively allocate COD to mill discharge, and so we integrated an additional study that appropriately allocates COD.

Significant Substances:

- Acrolein (non-carcinogen), CFC-10 (ozone depletion) and particulates (respiratory effects) have a significant contribution to kraft impacts compared to mechanical and deinked pulp. This is caused by wood waste combustion which is used in this study as a proxy for Black Liquor Combustion. Thus, we refined the black liquor emissions inventory based on combustion emission values found in Larson (2006)[39]
- Sulfur dioxide (SO_2) emissions have a significant contribution to mechanical and deinked pulp respiratory effects, but not to kraft pulp. This difference is due to the fact that SO_2 emissions result primarily from electricity use. Mechanical and deinked pulps consume a larger amount of purchased electricity than kraft pulp. Electricity use can be flagged for reduction opportunities in mechanical and deinked pulp operations reductions in SO_2 are desired for these products. Zinc air emissions have a high contribution to deinked pulp non-carcinogens, but not kraft or mechanical pulp. This is caused by the zinc used to produce sodium dithionite, a chemical used in deinking in the recovered fiber pulping process. Sodium dithionite can be flagged as a key contributor and a reduction opportunity for deinked pulp producers.

39 Larson (2006) A Cost-Benefit Assessment of Gasification-Based Biorefining in the Kraft Pulp and Paper Industry. U.S. Department of Energy and the American Forest and Paper Association.

Figure 19 : Significant Inventory Characterization Parameters associated with the Preliminary Life Cycle Inventory

Impact Category	Key Contributor	Media	Kraft	Mechanical	Recovered
Fossil CO2e (Global Warming Potential)	Carbon Dioxide	Air	93%	94%	94%
	Methane	Air	6%	5%	5%
Biogenic CO2e	Carbon Dioxide	Air	98%	70%	90%
	Methane	Air	2%	30%	10%
*Human Health: Carcinogens**	Chromium VI	Water	67%	67%	77%
	Chromium	Soil	13%	0%	0%
	Chromium	Water	13%	13%	10%
	Chromium, ion	Water	3%	14%	10%
*Human Health: Non-Carcinogens**	Barium	Water	31%	38%	24%
	Mercury	Air	24%	35%	21%
	Arsenic, Ion	Water	12%	13%	21%
	Zinc	Soil	10%	0%	0%
	Acrolein	Air	9%	2%	0%
	Arsenic	Soil	3%	0%	0%
	Lead	Air	2%	2%	0%
	Zinc	Air	0%	0%	30%
	Lead	Water	0%	4%	0%
*Ecotoxicity**	Barium	Water	35%	49%	37%
	Zinc	Soil	22%	0%	0%
	Silver	Water	12%	20%	12%
	Chromium VI	Water	12%	12%	16%
	Zinc	Water	3%	3%	2%
	Copper	Soil	3%	0%	0%
	Vanadium	Water	2%	0%	0%
	Chromium	Soil	2%	0%	0%
	Chromium	Water	2%	2%	2%
	Antimony	Water	0%	8%	18%
	Arsenic, Ion	Water	0%	0%	3%
	Zinc	Air	0%	0%	3%
	Chromium, ion	Water	0%	2%	2%
Impact Category	**Key Substance**	**Media**	**Kraft**	**Mechanical**	**Recovered**
Eutrophication (Excess nutrients/plant growth)	BOD5	Water	30%	19%	4%
	Phosphate	Water	29%	11%	27%
	Nitrogen	Water	11%	3%	6%
	Phosphorus	Water	11%	3%	5%
	COD	Water	9%	53%	28%
	Nitrogen oxides	Air	7%	8%	10%
	Nitrate	Water	2%	2%	17%
	Ammonium, ion	Water	0%	2%	2%
Ozone depletion	CFC-10	Air	87%	21%	9%
	Halon 1211	Air	8%	59%	49%
	CFC-114	Air	2%	4%	4%
	R-40	Air	2%	6%	7%
	Halon 1301	Air	0%	7%	25%
	CFC-12	Air	0%	0%	2%
	Halon 1001	Air	0%	0%	3%
Acidification (Acid rain)	Sulfur dioxide	Air	63%	67%	61%
	Nitrogen oxides	Air	28%	27%	32%
	Sulfur oxides	Air	3%	4%	4%
Respiratory Effects	Particulates, > 2.5 um, and < 10 um	Air	70%	11%	11%
	Sulfur dioxide	Air	27%	81%	70%
	Nitrogen oxides	Air	2%	6%	7%
	Particulates, > 10 um	Air	0%	0%	0%
	Particulates, < 2.5 um	Air	0%	0%	10%
Smog (Ground level air pollution)	Nitrogen oxides	Air	97%	94%	96%
	Isoprene	Air	0%	5%	3%
	VOCs	Air	0%	0%	0%

<5%
5%-10%
10%-25%
25%-50%
>50%

5.5 Data Enhancement Opportunities

During the life cycle inventory, impact assessment and subsequent contribution analyses we evaluated data quality precision, completeness and representativeness. We identified several data enhancement opportunities that could be leveraged to refine the analysis and provide more accurate, precise results; these recommendations are summarized in Table 16.

Table 16: Data Enhancement Opportunities

Data Enhancement Opportunity	Significance
Obtain values for emissions to soil for deinked and mechanical pulp	Available inventory data for emissions to soil for kraft pulping contributed to ecotoxicity, carcinogen and non-carcinogen impact categories
Refine the type of and source for fatty acids used in deinked pulp production	Fatty acid input is a significant input to several impacts due primarily to the fact that the available U.S. LCI dataset includes the impact of cultivating palm oil for vegetable oil, which may not be used in deinked pulping[40]
Examine the type and disposition of deinking pulp waste	De-inked pulp waste is a significant contributor, because the Ecoinvent dataset assumes it is solidified using cement. We have not been able to identify data to validate this assumption, but advise that this may vary by pulp producer.
Refine values for water process emissions for mechanical pulp and kraft pulp	Process organic matter releases to water causing COD and BOD drive pulp eutrophication impacts
Refine proxy values for pulp water process emissions of AOX	Inventory data for all three pulps considered included releases of AOX. Chlorophenols, which contributed significantly to the ecotoxicity results, were used as proxy chemical, as the TRACI methodology does not include AOX.
Refine values for sodium dithionate and other bleaching chemical input for pulp production	Zinc process emissions from the production of sodium dithionate (used for bleaching) drive non-carcinogen impact values, and can affect if mechanical or kraft pulp has a higher relative impact than deinked pulp.
Specific energy consumption and fuel mix values are key to accurately estimate local mill impacts	Energy contributes the majority of impacts across a range of categories; variations in total energy and/or fuel mix can significant impact pulp impacts, as illustrated in Sections 4.1 and 4.2.
Refine estimates for pulp yield and conduct sensitivity analysis	Pulp yield information identified in the secondary data sources may be outdated
Refine estimates for transportation distances associated with waste paper collection and wood acquisition and conduct sensitivity analysis	Waste paper collection can have significant impact across a range of categories. Likewise, wood acquisition distances can be highly variable.

[40] Hannuksela and Rosencrance. *Deinking Chemistry.* Kemira Chemicals Inc. Available: http://www.cost-e46.eu.org/files/Deinking%20primer/Deinking%20Chemistry-FINAL.pdf

Data Enhancement Opportunity	Significance
Refine estimates for distances associated with pulp to mill transportation and conduct sensitivity analysis. Apply specific transportation distances for transport of specific pulp to specific mill to accurately estimate local mill impacts for using pulp..	Impacts due to pulp transport to the mill can be highly variable and can have a significant impact for a range of impact categories, particularly for deinked pulp. Pulp transport is not as significant for virgin pulp, due to the relatively higher impact of other system processes. For relative impacts of deinked, kraft, and mechanical pulp, see Figures 6, 7, and 8, respectively.

6 Summary and Conclusions- Interpretation

We conducted a life cycle assessment to evaluate the relative impacts of deinked pulp derived from waste paper versus the impacts of pulp produced from virgin wood sources that would be displaced by the use of the deinked pulp to address the question: *Is it better for the environment to use recovered fiber for magazines versus virgin fiber in isolation?* As illustrated in Section 4, the analysis and multiple sensitivity analyses demonstrated that yes, recovered fiber is better for the environment when it displaces 50% kraft and 50% mechanical pulp.

Table 17 and Figure 20 summarizes the relative impacts of displacing mechanical or kraft pulp taking into considerations potential variations due to pulp production energy use, fuel input mix and recycling allocation methodology. These ranges represent the maximum and minimum relative impact results obtain among all of the sensitivity analysis scenarios evaluated and do not include potential cumulative effects (e.g., the relative impact of combining a higher total energy and different fuel mix). In addition, other variables, such as transportation distances, could also impact the result variability. The dark green cells represent the pulp that consistently has the lowest relative environmental impact for all of ranges of variables considered in the sensitivity analysis scenarios evaluated. If two the pulps can potentially have the lowest relative environmental impact depending on the scenario (i.e., the range of relative minimum impacts overlaps) then their cells are shaded light green. The dark blue cells represent the pulp that has the highest relative environmental impact for all of the sensitivity analysis scenarios evaluated If two of the pulps can potentially have the highest relative environmental impact depending on the input fuel scenario (i.e., the range of relative maximum impacts overlaps) maximum then their cells are shaded light blue. If a cell is not shaded (e.g., mechanical pulp wood use) then the relative impact for that pulp is neither the relative minimum nor maximum of the three pulp types evaluated.

Table 17: Relative impact ranges for deinked, kraft and mechanical pulp

	Recovered Pulp	Kraft Pulp	Mechanical Pulp
Total CO2 eq (Fossil + Biogenic)	-0.19-0.33	0.39-1.53	0.37-0.57
Fossil CO2 eq	0.28-0.46	0.48-1.41	0.85-1.3
Biogenic CO2 eq	-0.53-0.23	0.33-1.59	0.04-0.06
Acidification	0.23-0.42	0.71-1.26	0.77-1.18
Carcinogens	0.21-0.43	0.85-1.13	0.28-0.39
Non Carcinogens	-0.04-0.48	0.5-1.44	0.32-0.47
Respiratory effects	0.19-0.39	0.6-1.36	0.66-1.02
Eutrophication	-1.98-0.36	0.85-1.06	0.67-0.86
Ozone depletion	0.17-0.44	0.6-1.35	0.55-0.79
Ecotoxicity	0.14-0.41	0.7-1.26	0.23-0.34
Smog	0.32-0.49	0.8-1.21	0.76-1.14
Fossil Energy	0.25-0.43	0.46-1.41	0.85-1.3
Energy from Biomass	0.02-0.23	0.32-1.6	0.01-0.03
Wood Use	0-0.21	0.85-1	0.44-0.52
Key			
Pulp that consistently has the lowest relative environmental impact for each the scenarios evaluated			
Pulps that can potentially have the lowest relative environmental impact depending on the scenario (i.e., the range of relative minimum impacts overlaps)			
Pulp that consistently has the highest relative environmental impact for each of the scenarios evaluated			
Pulps that can potentially have the highest relative environmental impact depending on the scenario (i.e., the range of relative maximum impacts overlaps)			
Pulp whose impact is neither the relative minimum nor maximum of the three pulp types evaluated			

Figure 20 : Summary of relative impacts for deinked, kraft and mechanical pulp

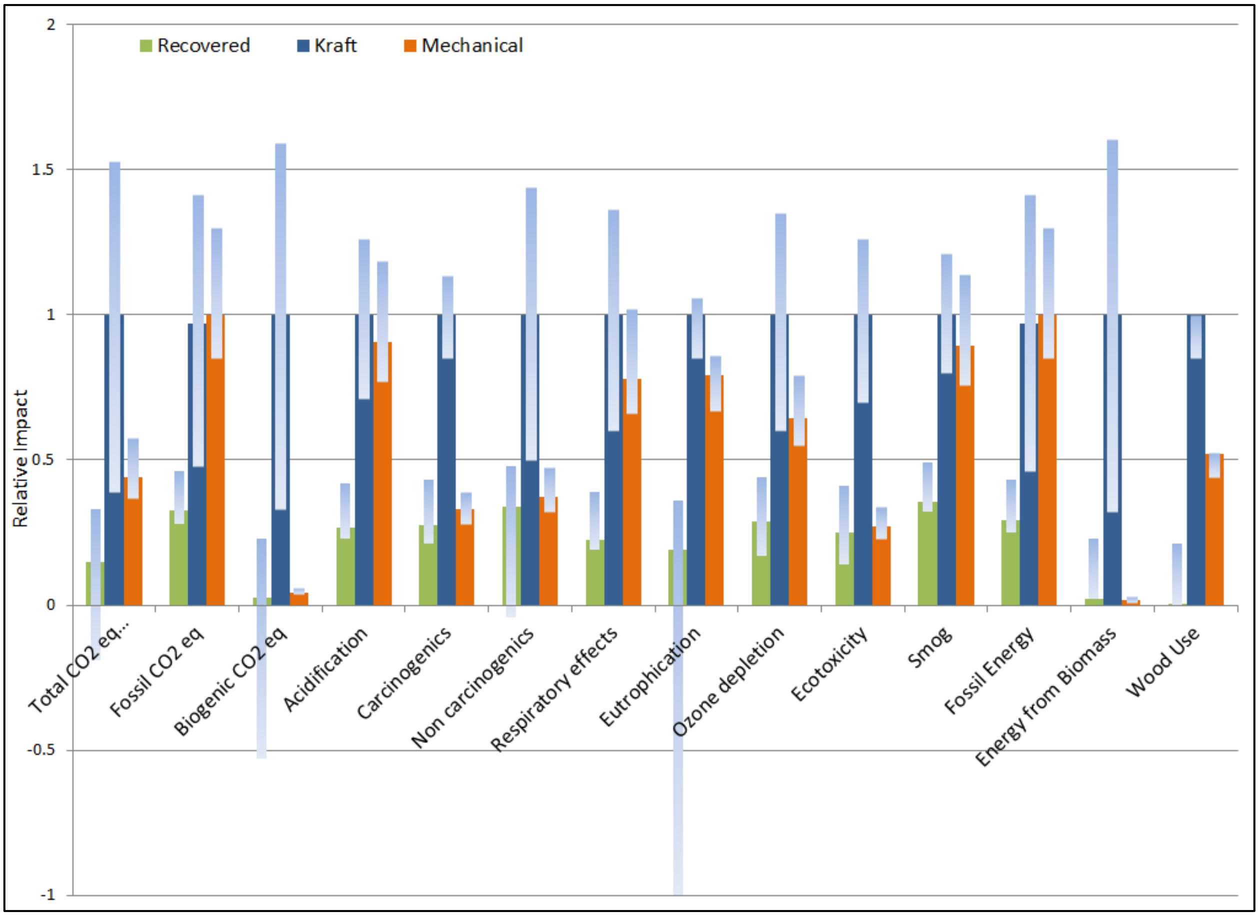


Table 17 and Figure 20 shows that the results are highly variable depending on the input data and assumptions applied. Kraft pulp has consistently higher relative impacts for the following impact categories:

Impact Category	Significant Contributing Factors
Biogenic CO2	Large amount of biomass fuel generated and used onsite
Carcinogens	Chromium emissions associated with sodium chlorate production
Non-Carcinogens	Large amount of black liquor biomass fuel generated and used onsite
Ecotoxicity	Arsenic water emissions associated with Kraft processes.
Energy from Biomass	Large amount of biomass fuel generated and used onsite
Wood Use	Lower yield of wood used in kraft vs. mechanical pulping

If the impact categories listed above are considered priorities, displacing a higher percentage of kraft pulp would be environmentally preferable. Alternatively, either kraft or mechanical pulp can have a relatively higher impact for the following impact categories (shown in light blue in Table 17 and those with overlapping relative maximum impact results on Figure 20.):

Impact Category	Significant Contributing Factors: Kraft Pulp	Significant Contributing Factors: Mechanical Pulp
Fossil CO2 eq	Large amount of purchased electricity and residual fuel oil used.	Large amount of purchased coal electricity used.
Acidification	NOx and SO_2 associated with kraft pulp mill emissions.	Large amount of purchased coal electricity used.
Carcinogens	Chromium VI process emissions associated with sodium chlorate.	Large amount of purchased coal electricity used.
Respiratory Effects	NOx and SO_2 associated with kraft pulp mill emissions and particulates associated with black liquor combustion.	Large amount of purchased coal electricity used.
Eutrophication	Phospate associated with Sodium Chlorate and COD and Nitrogen associated with kraft pulp process emissions.	COD and BOD associated with mechanical pulp process emissions.
Ozone Depletion	Large amount if electricity use associated with sodium chlorate production and natural gas fuel used in kraft pulping.	Large amount of purchased coal electricity used.

While this study did not specifically contrast use of pulp in alternative products, the results are useful for exploring this topic. For example, the sensitivity analysis shows that we cannot distinguish between impacts of alternative products produced from any combination of the mechanical or kraft pulp considered in this analysis. This is due to the overlap in potential impacts between pulps as illustrated in Table 17, which is caused by the range of mill specific characteristics. For the impact categories, displacing either mechanical or kraft pulp can be the environmentally preferable option, depending on specific pulp mill characteristics and assumptions. As illustrated above, the majority of the impacts are significantly influenced by the amount and type of energy used. Thus, for example, if a mechanical pulp mill uses a high total energy and higher percentage of purchased electricity it will have a relatively higher environmental impact and displacing that pulp instead of kraft may be the environmentally preferable option in that specific instance. In the reverse case, that is where there is a more energy intensive kraft mill, then displacing the pulp in a product that uses kraft would be the environmental choice instead of a product that uses mechanical. Furthermore, this study did not investigate potential differences in treatment for different grades of pulp as used in varied product applications. Therefore, results may differ if a subsequent study were to evaluate specific pulp grades. Such a study would need to evaluate both deinked and virgin pulp of that grade to determine the net impact of displacing virgin pulp with deinked. For example if unbleached pulp is used in a product, then a net impact study would consider the difference between using unbleached deinked pulp and unbleached virgin pulp. Finally, given that the range of mill specific characteristics challenges the ability to definitely state that displacing the bleached mechanical or kraft pulp in one product is beneficial over displacing some ratio in another product, another approach to the question could be to use mill-specific activity data to more precisely estimate the relative impacts of using a specific grade of deinked pulp to displace a specific grade of virgin pulp for use in alternative products.

Appendix A

Basecase Impact Results Applying Impact 2002+ and ReCiPe Characterization Factors

Comparing Deinked Pulp, Mechanical Pulp, and Kraft Pulp with IMPACT 2002+

Impact category	Unit	Deinked Pulp	Mechanical Pulp	Kraft Pulp
Carcinogens	kg C2H3Cl eq	0.01	0.01	0.02
Non-carcinogens	kg C2H3Cl eq	0.02	0.02	0.05
Respiratory inorganics	kg PM2.5 eq	4.8E-4	1.39E-3	1.53E-3
Ozone layer depletion	kg CFC-11 eq	9.86E-9	2.34E-8	3.29E-8
Respiratory organics	kg C2H4 eq	2.44E-4	8.64E-4	6.28E-4
Aquatic ecotoxicity	kg TEG water	47.61	39.85	1.01E+2
Terrestrial ecotoxicity	kg TEG soil	1.58	1.52	3.99
Terrestrial acid/nutri	kg SO2 eq	0.01	0.04	0.04
Aquatic acidification	kg SO2 eq	4.01E-3	0.01	0.02
Aquatic eutrophication	kg PO4 P-lim	7.8E-5	6.15E-4	6.87E-4
Global warming	kg CO2 eq	0.53	1.6	1.55
Mineral extraction	MJ surplus	9.91E-4	2.68E-3	1.02E-3

Comparing Deinked Pulp, Mechanical Pulp, and Kraft Pulp with World ReCiPe H

Impact category	Unit	Deinked Pulp	Mechanical Pulp	Kraft Pulp
Climate change	kg CO2 eq	0.55	1.68	1.62
Ozone depletion	kg CFC-11 eq	9.9E-9	2.34E-8	3.29E-8
Human toxicity	kg 1,4-DB eq	0.15	0.26	0.87
Photochemical oxidant formation	kg NMVOC	2.53E-3	0.01	0.01
Particulate matter formation	kg PM10 eq	1.04E-3	3.28E-3	4.05E-3
Terrestrial acidification	kg SO2 eq	3.69E-3	0.01	0.01
Freshwater eutrophication	kg P eq	2.9E-5	5.32E-5	1.84E-4
Marine eutrophication	kg N eq	2.55E-4	4.54E-4	7.57E-4
Terrestrial ecotoxicity	kg 1,4-DB eq	8.62E-4	4.36E-5	1.74E-4
Freshwater ecotoxicity	kg 1,4-DB eq	2.48E-3	4.44E-3	0.01
Marine ecotoxicity	kg 1,4-DB eq	1.84E-3	3.13E-3	0.01
Fossil depletion	kg oil eq	0.16	0.55	0.53

Appendix B

Life Cycle Inventory Unit Process Sources

Deinked Pulp Raw Materials Extraction and Preprocessing Unit Process Sources

Life Cycle Process #	Life Cycle Process	Unit Process(es)	Database
2Ra	Waste Paper Collection via Municipal Waste Collection Truck	Transport, combination truck, average fuel mix NREL /US	U.S. LCI
2Rb	Transport to Sorting Plant via Truck	Transport, single unit truck, diesel powered NREL /US	U.S. LCI
3R	Waste Paper Sorting Process	Electricity, at grid, US/US	U.S. LCI
		Light fuel oil, burned in boiler 100kW, non-modulating/CH WITH US ELECTRICITY U	Ecoinvent
		Steel, converter, unalloyed, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Sheet rolling, steel/RER WITH US ELECTRICITY U	Ecoinvent
		Lubricating oil, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Waste paper sorting plant/RER/I WITH US ELECTRICITY U	Ecoinvent
		Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, paper, 11.2% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, packaging cardboard, 19.6% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, textiles, soiled, 25% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, wood untreated, 20% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, steel, 0% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent

Recovered Pulp Manufacturing Unit Process Sources

Life Cycle Process #	Life Cycle Process	Unit Process(es)	Database
4R	Waste paper collection via municipal waste collection truck and transport to sorting plant via truck	Transport, combination truck, average fuel mix NREL /US	U.S. LCI
		Transport, train, diesel powered NREL /US	U.S. LCI
		Transport, single unit truck, diesel powered NREL /US	U.S. LCI
5R	Deinked Pulp Production	Hydrogen peroxide, 50% in H2O, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Sodium hydroxide, production mix, at plant/kg NREL /RNA	U.S.LCI
		Sodium chloride, at plant NREL /RNA	U.S.LCI
		Sodium dithionite, anhydrous, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Fatty acids, from vegetarian oil, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Electricity, at grid, US NREL /US	U.S.LCI
		Energy- Residual fuel oil, combusted in industrial boiler NREL /US	U.S.LCI
		Energy- Natural gas, combusted in industrial boiler	U.S.LCI

Life Cycle Process #	Life Cycle Process	Unit Process(es)	Database
		NREL /US	
		Energy- Bituminous coal, combusted in industrial boiler NREL /US	U.S.LCI
		Pulp plant/RER/I WITH US ELECTRICITY U	Ecoinvent
		Disposal, municipal solid waste, 22.9% water, to sanitary landfill/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, ash from deinking sludge, 0% water, to residual material landfill/CH WITH US ELECTRICITY U	Ecoinvent

Deinked Pulp Transportation Unit Process Sources

Life Cycle Process #	Life Cycle Process	Unit Process(es)	Database
6R	Transport to Paper Mill via Truck	Transport, combination truck, average fuel mix NREL /US	U.S. LCI

Virgin Pulp Raw Materials Extraction and Preprocessing Unit Process Sources

Life Cycle Process #	Life Cycle Process	Unit Process(es)	Database
2V/4V	Wood Extraction/ Sawmill	WOOD- Softwood logs with bark, avg, PNW & SE	U.S. LCI
		WOOD@mill_Roundwood, hardwood, average, at forest road, NE-NC/RNA	U.S. LCI
		WOOD- Softwood-Pulp Chips, SE &PNW	U.S. LCI
		WOOD_ Wood chips, hardwood, green, at sawmill, NE-NC/kg/RNA	U.S.LCI
3V	Transport of logs to the sawmill	Transport, combination truck, average fuel mix NREL /US	U.S.LCI
5V	Transport of logs to the pulpmill	Transport, combination truck, average fuel mix NREL /US	U.S.LCI

Kraft Pulp Manufacturing Unit Process Sources

Life Cycle Process #	Life Cycle Process	Unit Process(es)	Database
6V1	Kraft Pulp Production	Electricity, at grid, US NREL /US	U.S. LCI
		KRAFT-Energy- Bituminous coal, combusted in industrial boiler NREL /US	U.S. LCI
		KRAFT- Energy- Residual fuel oil, combusted in industrial boiler NREL /US	U.S. LCI
		KRAFT- Energy- Natural gas, combusted in industrial boiler NREL /US	U.S. LCI
		KRAFT- Energy-Black Liquor- Wood waste, unspecified, combusted in industrial boiler NREL /US	U.S. LCI
		Hydrogen peroxide, 50% in H2O, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Sodium hydroxide, production mix, at plant/kg NREL /RNA	U.S. LCI
		Sodium chlorate, powder, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Sulphuric acid, liquid, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Malusil, at plant/RER WITH US ELECTRICITY U	Ecoinvent

Life Cycle Process #	Life Cycle Process	Unit Process(es)	Database
		Disposal, hazardous waste, 0% water, to underground deposit/DE WITH US ELECTRICITY U	Ecoinvent
		Disposal, municipal solid waste, 22.9% water, to sanitary landfill/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, wood ash mixture, pure, 0% water, to sanitary landfill/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, green liquor dregs, 25% water, to residual material landfill/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, limestone residue, 5% water, to inert material landfill/CH WITH US ELECTRICITY U	Ecoinvent

Mechanical Pulp Manufacturing Unit Process Sources

Life Cycle Process #	Life Cycle Process	Unit Process(es)	Database
6V2	Mechanical Pulp Production	Electricity, at grid, US NREL /US	U.S. LCI
		Energy- Bituminous coal, combusted in industrial boiler NREL /US	U.S. LCI
		Energy-Wood waste, unspecified, combusted in industrial boiler NREL /US	U.S. LCI
		Energy- Residual fuel oil, combusted in industrial boiler NREL /US	U.S. LCI
		Hydrogen peroxide, 50% in H2O, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Sodium silicate, spray powder 80%, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		EDTA, ethylenediaminetetraacetic acid, at plant/RER WITH US ELECTRICITY U	Ecoinvent
		Pulp plant/RER/I WITH US ELECTRICITY U	Ecoinvent
		Disposal, municipal solid waste, 22.9% water, to sanitary landfill/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, wood ash mixture, pure, 0% water, to sanitary landfill/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, paper, 11.2% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, steel, 0% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, textiles, soiled, 25% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent
		Disposal, wood untreated, 20% water, to municipal incineration/CH WITH US ELECTRICITY U	Ecoinvent

Virgin Pulp Transportation Unit Process Sources

Life Cycle Process #	Life Cycle Process	Unit Process(es)	Database
7V	Transport to Paper Mill via Truck	Transport, combination truck, average fuel mix NREL /US	U.S. LCI