Richard Venditti

Professor

North Carolina State University

Department of Forest Biomaterials

WHITE PAPER:

Effect of Methodology on the Life Cycle Analysis of Paper Products

February 7, 2012

Contact Information:

Dr. Richard Venditti, North Carolina State University, Biltmore Hall Rm 1204, 2820 Faucette Drive, Raleigh NC 27695-8005, (919) 515-6185, richard_venditti@ncsu.edu, website: go.ncsu.edu/venditti

Executive Summary:

Paper products are integral to the quality of life currently enjoyed in North America. These products have significant environmental benefits but also have environmental impacts. Life cycle analysis (LCA) is a method in which the potential impact of a product on the environment is evaluated from its cradle (raw material procurement) to grave (end-of-life). Standard methods of performing LCAs exist (ISO 14040, 14044); however, within those methods, many choices about the methodologies are made by the practitioner, which tend to be subjective and influenced by personal value judgments.

The Carbon Footprint of a product is defined herein as the overall greenhouse gas impact of a product during its life cycle, from cradle to grave and can be part of a full life cycle analysis. The effect of LCA methodology choices in determining Carbon Footprints of paper products are explored herein.

Three LCA's of paper were reviewed: a Paper Task Force study (2002), a Heinz study (2006) and a NCASI study (2010). The Paper Task Force study analyzed the LCA of printing and packaging paper materials with two separate systems: (1) virgin paper with disposal and (2) production of recycled paper with recycling, and has recently been revised to better reflect the actual flows of paper through recycling and waste management. The Heinz study performed a partial LCA on *Time* and *InStyle* magazines focusing only on the Carbon Footprint, with a significant amount of primary data but without any environmental burdens inherent in upstream production of input materials like bleaching chemicals or printing inks. It used a "cut off" allocation method for recycling. The NCASI study was a LCA on catalog product (among other printing and writing grades) that included upstream processing of materials as well as a complex open loop recycling allocation method. The Heinz study reported 1.1 ton CO_2e per ton of product whereas the NCASI study reported 3.5 ton CO_2e per ton of product. Several differences in the two studies were identified that could contribute to this.

Co-product and recycling allocation are important parts of a LCA for paper; the choice of recycling allocation methods can have a significant effect on the final result. The effect of the recycling allocation method was explored on the Carbon Footprint for catalog (coated freesheet) paper using the FEFPro model and North American average data. It was determined that the difference in the carbon footprint results for North American catalog between the cut off (not mentioned in ISO) recycling allocation method and the ISO 14049 number of uses recycling allocation method increased with recovery rate but was not sensitive to the utilization rate.

Recommendations are the following:

- The use of standard methods (ISO 2006a, b) is integral in producing valuable LCAs.
- When considering two related products in the same life cycle such as virgin or recycled materials, the choice of available allocation methods can determine whether virgin or recycled material is promoted; uncertainty and sensitivity analyses and external review are important in establishing the reasonableness of the chosen allocation method.

- The number of uses method in an open loop recycling model is appropriate for the Life Cycle Analysis of paper products, providing adequate partitioning of burdens that are derived from shared processes such as raw material procurement, pulping, and final disposal.
- As based on data in this paper, the recovery of used paper for manufacture of new materials or use in incineration to create energy is more desirable than landfilling. Recovery of used paper should be encouraged; the maximum amount of paper that is recovered is determined by economic/technical considerations.
- With respect to the utilization of recovered paper in specific products, the Carbon Footprint data in this paper demonstrate that a blanket statement such as "all paper products should maximize use of recovered paper" is not substantiated.
- Industry average data are useful for an industry to benchmark its overall performance.
- The use of industrial averages of environmental impacts to promote a specific paper product relative to other similar paper products is not reasonable. Simplified calculators using industry averages should not be used for specific product labeling. These calculators are useful for benchmarking an industry or understanding average impacts of paper products versus alternate materials like plastics. There are very large ranges of environmental performance for one type of paper product from manufacturing site to site. Due to this large range, it is imperative when product labeling to base the claims on site and product specific LCA utilizing established methods (ISO 2006a, b).

Table of Contents

2	**Executive Summary**
4	**Table of Contents**
5	**Introduction**
6	**Review of Some Major North American LCA's on Printing and Writing Papers**
21	**Allocation Methods Analysis**
27	**The Effect of the use of the Cut-off and the Number of Subsequent Uses Methods for Recycling Allocation: Net GHG Emissions for Catalog Versus Recovery Rate and Utilization Rate**
34	**The Use of Industry-wide Averages to Describe Individual Products**
37	**Recommendations**
38	**Acknowledgements**
39	**References**
41	**Appendix A. Paper Calculator Data for Uncoated Freesheet Before and After the 2011 Revision**
43	**APPENDIX B. Calculations of recycling allocations using the Paper Task Force (2002) data for office paper. Closed loop recycling process is assumed with three as the number of uses.**
45	**Appendix C. FEFPro modeling of a North American Average Catalog Product: Supporting Information**
48	**Appendix D. The Effect of the use of the Cut-off and the Number of Subsequent Uses Methods for Recycling Allocation: Net GHG Emissions for Magazine Versus Recovery Rate and Utilization Rate**

Introduction

Paper products are integral to the quality of life currently enjoyed in North America. Applications include printing and writing, packaging, towel and tissue, and a variety of personal care products that have all become important in our daily lives. These products are derived from renewable resources from forests, are produced in efficient manufacturing processes, and produce and consume renewable fuels in the dominant manufacturing process. The use of forest derived products is one method to alleviate issues concerning the depletion of fossil fuels. Further, paper products can be recycled effectively and disposed of in a safe and convenient way when necessary, such as bathroom tissue. Along with these advantages, there are some areas that must be carefully addressed, including responsible forestry, water-use, emissions from production, and emissions from landfilled paper products.

Life cycle analysis (LCA) is a method in which the potential impact a product has on the environment is evaluated from its cradle (raw material procurement) to grave (end-of-life). In a typical LCA, a goal and scope is set, a life cycle inventory of mass and energy flows is specified, and the potential environmental impacts of the product determined. At each step, interpretation is performed, evaluating assumptions and methods to develop appropriate conclusions and recommendations. Standard methods to perform an LCA exist (ISO 14040, 14044); however, those methods only outline a general methodology and steps that must be performed. Within these steps, calculation methods, data considered, boundaries, etc. are left to be determined by the LCA practitioner. Many of these decisions are subjective and are chosen based on the goals of the study, the resources available to the project, and individual value-based preferences. Standard methods require documenting and determining the sensitivity of the results to such choices, but do not identify those most appropriate.

Paper product LCAs are not unique in that there are many of these choices to make, all of which impact the results of the study. For instance, boundaries for the system, the life cycle stages, data included and sources used, allocation of burdens between co-products, allocation of burdens between different life cycle stages of a recycled product, and other methodology choices must be considered.

In this white paper, the impact of several of these LCA methodology choices are evaluated with respect to three major studies of North American printing and writing grades of paper. Specifically, the effect these LCA methodology choices have in determining Carbon Footprints of paper products is explored herein. The Carbon Footprint of a product is defined as the overall greenhouse gas impact of a product over its life cycle, from cradle to grave. (It is important to realize that the Carbon Footprint of a product, which recently has been very prominent, is simply one aspect of its environmental impact and that to make absolute environmental conclusions based only on a Carbon Footprint is not recommended.) This study uses Carbon Footprints as a reasonably simple partial LCA that can be discussed within the limits of this study. Differences in the studies are identified and some critical methodology choices are discussed that lead to differences in LCA results. Finally, some recommendations for methods used for the LCA of paper products are presented.

Review of Some Major North American LCA's on Printing and Writing Papers.

In this section, three of the major LCA studies of printing and writing grade papers, with special focus on the related Carbon Footprints, are discussed and contrasted. These studies were chosen as they cover the same geographical area, incorporate the same or similar writing/printing papers, are widely recognized, and represent substantial efforts associated with their development. This discussion highlights how different results come from different LCA methodology choices and the difficulty in comparing such studies and can serve to promote working towards consensus on appropriate methodologies and choices in LCAs.

Paper Task Force White Paper No. 3 Lifecycle environmental comparison: virgin paper and recycled paper based systems. Originally published Dec. 19, 1995 (Paper Task Force, 1995), updated February 2002 (Paper Task Force, 2002)

In this section, the results of the Paper Task Force (PTF) study updated in 2002 are discussed (Paper Task Force 1995, 2002). During the writing of this paper, updates to the Paper Calculator (an analytical tool based initially on the Paper Task Force findings) that occurred since 2008 were reported by the Environmental Paper Network, 2011. The updated Paper Calculator is discussed in the following section.

The main objective of this study was to compare the environmental burdens of recycling versus virgin production and waste management (i.e., landfilling and incineration). This study involved the basic descriptions of activities and environmental impacts of four types of paper: newsprint, corrugated containers, office paper, and paperboard. The only coated grade evaluated was coated unbleached kraft. Environmental indicators considered were solid waste output, energy use, release of air emissions, and waterborne wastes and water use/wastewater quantity. The study included end of life aspects of landfilling, incineration and recycling, but does not include printing operations. Of the material to be disposed, 80 percent was assumed landfilled and the rest incinerated. Net greenhouse gases (GHG) are reported as lbs of CO_2e /ton of product. Net GHG does not include any CO_2 from burning biomass.

Data. National industry averages were used (some data from the 1980s but other data from circa 1993-1994). The study states that the life cycle inventory data frequently do not represent actual measured releases but rather regulatory limits, estimates, or surrogate values.

Emission Factors. Net GHG are reported, which includes fossil fuel usage and methane from the landfills. It is not documented which data are actually from primary sources. Emissions of landfill methane use an estimated emission of 123 lbs of methane per ton of MSW landfilled. Methane is considered to have 21 times the global warming potential of CO_2 (lb/lb) (IPPC, 1996).

System Boundaries. This study treats the virgin and recycled paper making systems as completely separate**, shown in Figure 1a,** *which defines the boundaries of the different cases.* Virgin fiber is considered to be produced, used once and disposed. Three disposal scenarios are reported: landfilling, incineration, and waste management, using the assumed disposal splits. Transportation is included in both cases. The analysis cannot be identified as a cradle to gate or cradle to grave, as the stages of a paper product life cycle are synthetically separated into two systems. The temporal boundary is undefined but includes the air emissions from landfilling over the entire lifetime of the landfill. Paper products that have a blend of virgin and recycled content simply are assigned a weighted average of the burdens of the virgin and recycled fibers used in the product (a mass weighted average). The blended product is not described in the White Paper No. 3 but is a feature of the PaperCalculator based on the findings. Note that fillers and coating materials have no associated environmental burdens; non-fibrous material simply reduces the total amount of fiber in the product and thus reduce the environmental impact that the reduced fiber amount introduces per ton of product.

Recycling Allocation Assumptions. Virgin products are responsible for all raw material and disposal burdens. Recycled fibers are assumed to be produced, used, and then recycled. No assumption as to the recovery rate or utilization rate of recovered paper needed. Recycled fibers are not responsible for any raw material or disposal burdens.

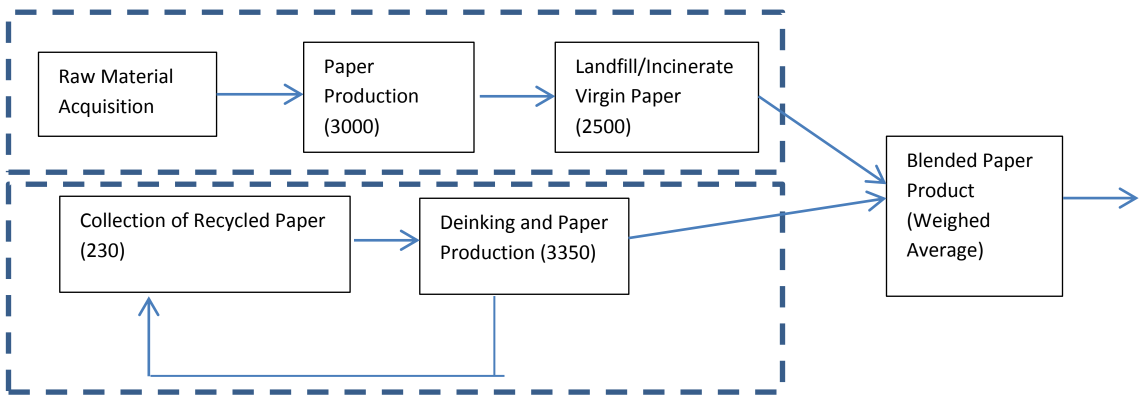

Figure 1a. Modeled Activities for the Paper Task Force White Paper No. 3. The paper industry is separated into two systems, a virgin paper system and a recycled paper loop. Numbers in parentheses indicate the net GHG emissions in lbs of CO_2e/ton of product for the office paper operations. A virgin/recycled paper product has the weighted average GHG of the inputs.

It is observed from **Table 1** that the study promotes the use of recycled fibers for office paper, coated UB Kraft Board and newsprint, with respect to net GHG emissions. This is in part due to the allocation assumption that all environmental burdens of raw material acquisitions and waste management are taxed to the virgin paper products. The recycled products are not charged any of these burdens. This results in 2.9 tons of CO_2e per ton of product for virgin office paper plus waste management versus 1.8 tons of CO_2e per ton of product for recycled office paper. It is clear that this study also promotes incineration over landfilling; for example, 1.3 and 3.4 CO_2e per ton of product are reported for office paper incineration and landfilling, respectively.

The results indicate also that incineration of the paper has more benefit than landfilling with regards to net GHG emissions. This is in agreement with a study that indicated virgin kraft paper production, followed by incinerating the paper with energy recovery, significantly decreased CO_2 emissions relative to several cases, including virgin paper or recycled paper without incineration and energy recovery (Gilbreath, 1996). Another study analyzing the waste management of newspapers indicated that energy recovery was superior to landfilling (Dahlbo et al, 2005).

Table 1 Virgin and recycled systems considered and net GHG in lbs of CO_2e /ton of product (ton CO_2e /ton product) for Office Paper, Coated Unbleached Board and Newsprint (Paper Task Force, 2002, pg. 132). Waste management is an 80/20 combination of landfilling/ incineration.

		Net GHG Emissions
Virgin Office Paper	Landfill	6700 (3.4)
	Incineration	2500 (1.3)
	Waste Management	5800 (2.9)
Recycled Office paper	Collect/Process	3580 (1.8)
Virgin Coated UB Kraft Board Virgin	Landfill	5980 (1.8)
	Incineration	1690 (0.8)
	Waste Management	5100 (2.6)
Recycled Coated UB Kraft Board	Collect/Process	3240 (1.6)
Virgin Newsprint	Landfill	9030 (4.5)
	Incineration	4700 (2.4)
	Waste Management	8140 (4.1)
Recycled Newsprint	Collect/Process	3500 (1.7)

The following is reported in the study: *This paper addresses only environmental parameters relevant to* ***a comparison of paper recycling and waste management options****……. This paper does not contain purchasing recommendations* (Paper Task Force, 2002, pg. 132). The main question that is addressed by the structure of the LCA is, *should paper be landfilled, incinerated, or recycled*? This LCA readily addresses this common consumer question, but does not indicate if and to what level recycled paper fibers should be incorporated into specific products, nor does it definitively determine whether such products are better served by utilizing virgin or recycled material. Very high performance paper grades with strict cleanliness or optical properties may not be able to use recycled pulps in an effective manner. The incorporation of recovered paper into paper grades or other applications depend on the economics and technical practicality.

A model of this study were until recently shown on the internet as an environmental paper calculator for a specific type of paper with defined furnish, in which the benefits of increasing the utilization rate of recovered fibers are readily calculated. The use of the paper calculator to make environmental claims for a single product or to choose one product over another should be approached with great caution and is not recommended because the calculator uses industry averages that do not reflect the wide variability of the same products manufactured by different companies at different locations and with different processes (see also discussion later).

Environmental Paper Network (2011) Paper Calculator.

In 2008-2009 major updates to the Paper Calculator were made by the Environmental Defense Fund. Since then the tool was transferred to the Environmental Paper Network and minor updates were performed and reported in March of 2011 (Environmental Paper Network, 2011). The combined updates include updated fuel emissions data, updated landfill gas emissions practices, changes in the way paper is categorized for recycling, a simplified representation of open loop recycling for end of life considerations, inclusion of environmental burdens from coatings and fillers, updated accounting of the pulping and bleaching practices of the industry, and updated energy requirements for pulp and paper products. The overall results of the Paper Calculator continue to primarily show that virgin fibers have higher general environmental burdens than do recycled fibers; however, the difference in burdens between virgin and recycled fibers is smaller than with the previous version.

Of particular interest is that the overall system structure has been modified to include a simplified open loop recycling methodology for the end of life stage of the paper (Franklin, 2011), as Figure 1b depicts. Note that the previous model in the Paper Calculator had two separate systems for virgin and recycled content and used a simple linear addition of the respective burdens in a paper product with both virgin and recovered fibers (Figure 1a).

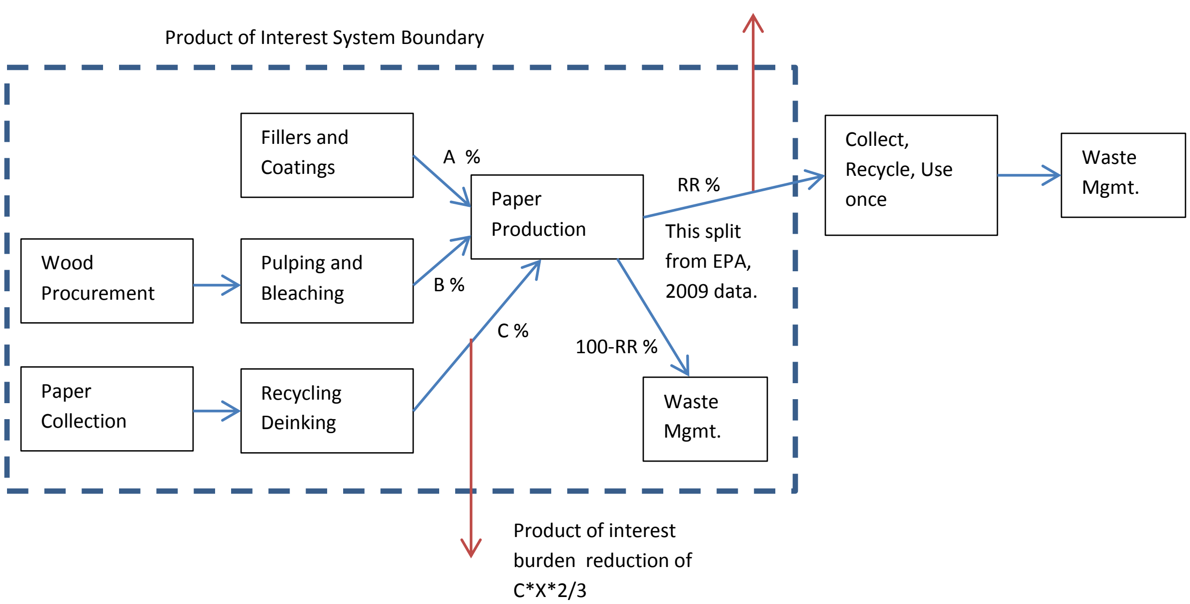

Figure 1b. Modified structure for the Paper Calculator (Environmental Paper Network, 2011). The environmental burden of one ton of the paper product of interest sent for waste management is designated as X. A, B, C are the weight percentages of the paper product furnish. Blue arrows indicate mass flows; red arrows represent environmental burden credits.

A simplifying assumption is that paper materials are recycled at a rate equal only to the product most commonly using that type of material, as based on data from the EPA (2009) on Municipal Solid Waste in the United States. As an example, uncoated freesheet is used to make books or office papers but the model treats all products made from uncoated freesheet as being recycled at the rate of its largest consuming category, office paper.

The new structure provides a credit for using post-consumer recovered paper. It is assumed that if post- consumer fiber is used in the product of interest that it has had two previous lives. For one ton of post-consumer fiber with a total of three lives, only one ton of paper is treated with waste management, so it is considered that two tons of paper have been diverted from the waste management process. Each life is then credited with avoiding the disposal burdens of 2/3 of a ton of paper.

If the product of interest is recycled, then a credit is also applied to the product of interest. The recovery rate of the product is determined by data from the EPA, 2009 and other published recovery rate data. In this case, it is assumed that the recovered material has only one subsequent life and is then treated with waste management. Based on this, over the two lives, one ton of paper is diverted from the landfill and thus each life is credited with avoiding the disposal burdens of ½ of a ton of paper.

A recycling LCA issue unaddressed by this new structure is that it is common among LCA practitioners to consider that the burdens of virgin manufacture of fibers should be shared by subsequent lives of the fibers. This is not included with the revised paper calculator due to a limitation of its computing structure.

Data for copy paper (uncoated free sheet) before the revisions in 2008-2011 and after the revisions instituted are shown in **Appendix A.** It can be observed in the data before the revision that in 15 of the 16 categories recycled fibers outperform virgin fibers, with the only exception being purchased electricity. Data were updated in 2011 to include energy use for harvesting and transport of trees, and reflect annual recycling rates from EPA data. This explains the increase in purchased energy for virgin papers in the 2011 updated Calculator. In the revised data, recycled fibers outperform virgin fibers in all but the chemical oxygen demand category. The main conclusions of the Paper Calculator are relatively unchanged due to the revision for uncoated free sheet.

The Heinz Center: Following the Paper Trail: The Impact of Magazine and Dimensional Lumber Grade Production on GHG Emissions: A Case Study, 2006. (Heinz, 2006)

The objective of the project was to conduct a net GHG LCA for magazine grade paper and for dimensional lumber. Two magazines, *Time* and *InStyle*, were tracked for GHG from cradle to grave for the year 2001. The project was rich in primary data and had high resolution in its detail for many of its processes. The furnish of the paper was a blend of virgin kraft and virgin mechanical pulps. No recycled content was used in the manufacturing of the magazines. It is unclear if the net GHG emissions of the coating materials was included, although there is mention of clay being considered. **Table 2** shows the activities in the life cycle that were considered. The chemically pulped and bleached fiber content of these products was approximately 60%.

Table 2. Activities in the net GHG Life Cycle tracked in the Heinz Center Study for the *InStyle* and *Time* magazines (ton CO_2e/ton product listed)

<table>
<tr><td>Forest Management and Harvesting</td><td>Transport</td><td>Paper Manufacturing</td><td>Transport to Printers and Printing and to Distribution Centers</td><td rowspan="2">Final Fate:
Landfill
Recycle
Incinerate</td><td>InStyle
(1.11)</td></tr>
<tr><td colspan="4">Purchased Power</td><td>Time
(1.17)</td></tr>
</table>

For *Time* the net CO_2e was 1.17 ton/ton product and for *InStyle* was 1.11 ton/ton product. The breakdown for the individual processes is shown in **Table 3** (Approximations taken from bar chart, Figure 11 in Heinz Study). Mill emissions seem to be the stage where there is a significant difference between the two magazines. The two major mills which supplied paper to the two magazines had products with different net GHG emissions, Biron mill with 0.9 t CO_2e/ton paper and Whiting Mill at 0.68 t CO_2e/ton paper. This suggests that *InStyle* received a larger percentage of its paper from the Biron Mill than did *Time*, which may have received all of its paper from the Whiting Mill. The study indicates that the ratio of mechanical pulp to chemical pulp was 38:62 for the Biron Mill and 42:58 for the Whiting Mill, However, no concrete compositional information about the individual magazines is provided, perhaps a trade secret. The difference in final fate emissions between the two magazines is due to *InStyle* having a higher recovery rate (35%) than *Time* (22%).

Table 3. Heinz study net GHG for various stages in the life cycle (CO_2e kg/kg product)

	Management and Harvest	Transp. To Mill	Mill Emissions	Transp. To Printer	Printer Emissions	Transp. To Customer	Final Fate
InStyle	0.02	0.04	0.85	0.01	0.03	0.08	.13
Time	0.02	0.08	0.68	0.03	0.05	0.09	.18
Average	0.02	0.06	0.77	0.02	0.04	0.08	.16

System Boundaries. This study was a cradle-to-grave treatment of two magazines with the operations listed in **Table 3** included. Neither recycled content nor recycling operations were considered. The temporal boundary for the accounting for carbon in this study is unclear. It is assumed that permanent carbon storage of the product occurs by recycling the magazines to be used as newsprint once, having a lifetime of at least one year. This suggests that a one year system boundary is used for recycling (or equivalently a cut off allocation assumption used for the recovered material). Conversely, the released emissions from landfilling were calculated over the lifespan of the paper in the landfill (Skog and Nicholson 2000) indicating that the temporal boundary is over decades for the landfill emissions. The boundary of the system is such that the upstream emissions from materials and supplies other than wood are not considered (assumed from the lack of data/discussion in the study).

Data. The project was rich in primary data and had high resolution in its detail for many of its processes. Data was taken from circa 2001. For example, forest, mill, and printing site specific data, as well as specific details for transportation and final fate of the two magazines were utilized. The major issue with the data utilized in this study is that a life cycle inventory is not presented, which prevents its duplication. For example, it is not known if the upstream net GHG emissions inherent in raw materials were included in the study, such as those for pulping chemicals; bleaching chemicals; papermaking chemicals; coating materials such as pigments, binders, modifiers and dyes; and printing and converting materials such as printing plates, chemicals for the plate development, inks, cleaning agents and lacquers.

Emission Factors. Carbon dioxide, methane and N_2O were considered with 1, 21 and 310 times the GWP correction factors, respectively (IPPC, 1996). Emission factors were determined for specific states in which the electricity was generated. Printers provided estimates of net GHG emissions based on annual electricity and natural gas use. Pulp and paper mills provided estimates of net GHG emissions. Neither details on the source of emissions reported by the printers or pulp and paper mills nor details on the fuel emissions for transportation were provided. In summary, the study is not presented with available documentation with respect to definitions of emission factors, material flows or product compositions, perhaps to conceal trade secrets.

Recycling Allocation Assumptions. No recycled content was used in the manufacture of the magazines. The split of landfilling, recycling and incineration was defined for each magazine. For both magazines a 17% recovery of sold subscription and 95% recovery of unsold newsstand magazines were estimated. For both of types of unrecovered magazines, 90% were assumed to be landfilled and 10% were assumed to be incinerated (based on PTF study from 1995, in contrast to the revised PTF study in 2002 with 80%/20% split). It was assumed that recovered magazine was used once for newsprint with a lifespan of one year. Recycling activities were not defined, but it was suggested that the burden of transportation of the recovered magazine to the recyclers was included within the system boundary.

The sell through rate for *InStyle* at the newsstand was estimated to be 59%. Thus, the final fate of the InStyle magazines was 35% recycled, 58.5% landfilled and 6.5% incinerated. The sell through rate for *Time* at the newsstand was estimated to be 35%. Thus, the final fate of the magazines was 22% recycled, 70% landfilled and 8% incinerated.

For the landfilled portion, 18% of the weight of a magazine was assumed to decay and release carbon dioxide and methane. Of the emitted gasses, 40% was assumed to be carbon dioxide and 60% methane.

The study stated that the old magazines recovered for recycling were estimated to be used once for newsprint, but no other information is given. Additionally, no statement on the allocation of environmental burdens with respect to the recovered magazine fractions was mentioned. It is probable that in this study the magazine product of interest was assigned all of the raw virgin material , virgin processing burdens and the burden of transportation of recovered magazines to their final fate (recycling site). It is also probable that in the study no burdens were exported to subsequent use systems. Thus, the analysis is surmised to be along the lines of a cut-off allocation method. If a number of uses allocation method were to be used with the Heinz Study, then the calculated net GHG emissions would be lower than those reported, since some of the environmental burdens of making the magazines from virgin fibers would be exported out of the system of interest to subsequent uses.

National Council for Air and Stream Improvement, Inc. Life Cycle Assessment of North American Printing and Writing Paper Products (NCASI, 2010)

The goal of the study was to characterize the environmental life cycle impacts associated with the industry average P&W paper products manufactured in U.S. and Canada and assumed to be used in the U.S. in 2006/2007 (NCASI, 2010, pg. 4). The report states that the study does not compare products but is intended to provide a basis for documenting changes over time, among other uses. The life cycle of four specific printing and writing grade products were investigated: copy paper, telephone directory made of uncoated mechanical paper, catalog made of coated free sheet, and magazine made predominantly of coated mechanical paper. The life cycle analysis covered a cradle-to-grave boundary, including forestry, materials, manufacturing, use, recovery, and end of life activities (**Table 4**). End-of-life activities included recycling, landfilling and incineration. Storage in use and storage in landfilling were also included as were cradle to papermill gate results.

Table 4. Life cycle stages considered in the life cycle analysis NCASI (2010) study.

Fiber Procurement	Transp	Paper Production	Transp	Catalog Production	Transp	Use	Transp	End of Life: Recycling, burning, landfill, storage

Co-product allocation methods were used. A sensitivity analysis on the allocation weighting methods was performed. The software SimaPro and the TRACI impact assessment method were used primarily. Impact indicator results for global warming, acidification, respiratory effects, eutrophication, stratospheric ozone depletion, smog and fossil fuel depletion were also tracked. The net ton of CO_2e per ton of product from cradle to grave was determined to be 1.88 for copy paper (uncoated free sheet), 3.45 for catalog (coated freesheet), 1.77 for telephone directory (uncoated mechanical sheet) and 2.36 for magazines (coated mechanical sheet).

The breakdown of net GHG reported for the stages of the life cycle for catalog are shown in **Figure 2,** alongside data from the Heinz Study. Note that the NCASI results are significantly larger than the Heinz Study. Further, the percentage breakdowns for the two studies are also different, **Figure 3.** However, several differences (quality of data, source of data, end of life assumptions, allocation methods) between the two studies do not allow for direct quantitative comparison.

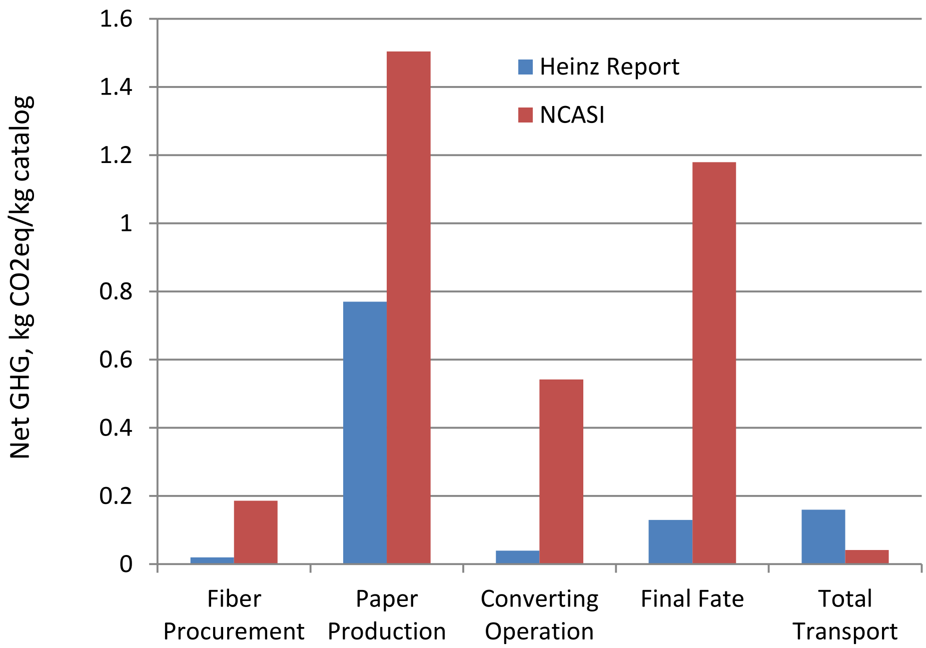

Figure 2. Net GHG reported for the individual stages of the life cycle for catalog of the Heinz (2006) and the NCASI (2010) studies.

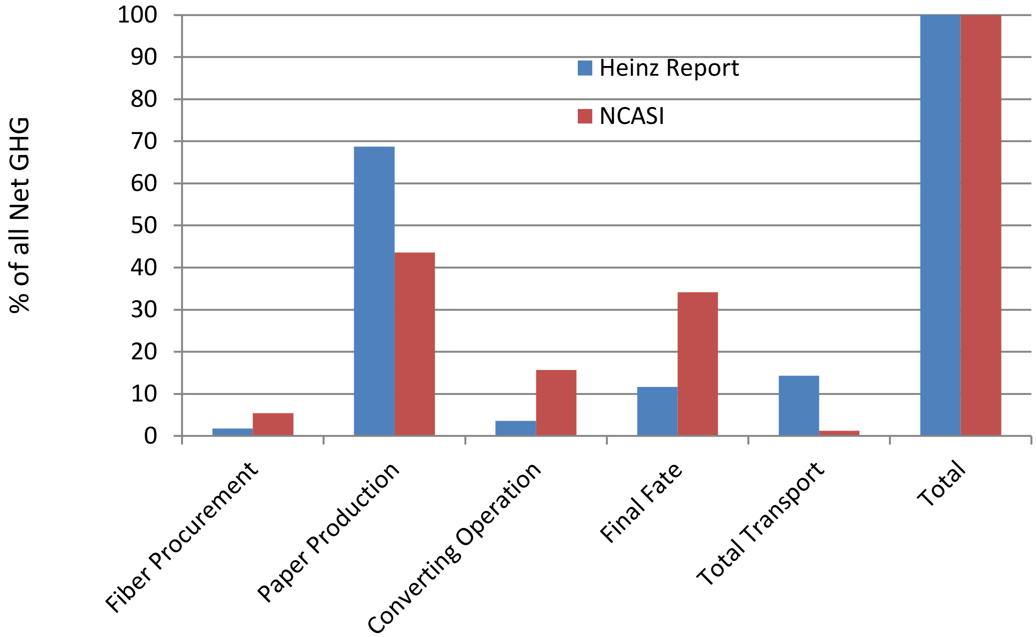

Figure 3. Percent contribution in Net GHG reported for individual stages of the life cycle for catalog for the Heinz (2006) and the NCASI (2010) studies.

System Boundaries. The life cycle analysis covered a cradle-to-grave boundary, including forestry, materials, manufacturing, use, recovery, and end of life activities (see **Table 4**). The study utilizes an open loop recycling analysis. The temporal boundary for the accounting for carbon in this study is one hundred years. Results are also reported for cradle to papermill gate.

Data. The study used industry data averages for North America to produce an analysis of an average product (year 2006). A number of mills representing 78% of the total North American production were used. However, the data for printing operations were obtained from a European LCA study (Larsen, et al., 2006; Larsen et al., 2008). The study utilized mainly USLCI LCA data but also used EcoInvent (European) data modified with the North American electricity grid when the US data were not available. It would be useful to collect primary data for North American manufacturing processes that serve the paper industry, including printing, raw chemical production, and recycling operations.

Emission Factors. The main source for emission factors came from the IPCC 2007 report (also see NCASI 2010,pg 30). Carbon dioxide, methane and N_2O were considered with 1, 25 and 298 times the GWP correction factors, respectively. Other emission factors were taken from the US LCI database preferentially, and from the EcoInvent database with a modification for the North American electricity grid.

Recycling Allocation Assumptions. The number of subsequent uses allocation approach for open loop recycling was used to partition the shared environmental burdens between the different uses of the fibers upon virgin and recycled stages. In the NCASI study the number of uses of various paper grades was estimated to be 2.19 for office paper, 1.85 for mixed paper, 2.52 for newsprint, 2.70 for corrugated container, 1.76 for magazines, 1.43 for telephone directory and 1.64 for catalogs. A number of uses of 2.19 indicates that for a ton of virgin pulp produced, another 1.19 tons of recovered paper will be produced from it. Note that these data are valid for the year 2006 and will change as the levels of paper recycling change.

If produced virgin material is used several times, then the burdens of its production are spread out over the number of its uses. Two important allocation considerations were included and are quoted from the report (NCASI, 2010):

A_v is the allocation factor for virgin production and represents the fraction of the environmental burden from the virgin production that stays within the studied system (1 – Av is the fraction of virgin production burden which is exported to another system because of subsequent recycling of the product). The virgin production burdens include growing and harvesting wood, pulping , bleaching and the resources involved in these operations.

A_r' is the allocation factor for recovered fiber inputs [Old newspapers (ONP), mixed papers, and old corrugated containers (OCC)] and reflects the quantity of virgin production burdens transferred to the studied system by importing recovered fiber.

Summary of the Three Studies

In this section the three studies of interest are compared. Note that ISO standards (ISO, 2006a, b) state that only studies with similar system boundaries, main assumptions and functional units can be compared. It is recognized that the three studies do not meet these requirements. Determining relative accuracy of each study is not the objective of this paper; rather, this paper aims to identify differences and discuss how these differences may affect the results. **Table 5** summarizes some of the key differences in the three studies.

Table 5. Summary of the Three LCA Studies for Paper

Study:	Last Year Published/Year of Data:	Products	Boundary	Disposal Scenario	Recycling Allocation Method	Coproduct Allocation Method	Data Sources:
Paper Task Force, prior to 2008-2011 revisions	2002/1994	NP – ONP Corrugated –OCC Office Paper –OWP Paperboard – Recycled Paperboard	Raw matl – virgin paper prod-disposal Deinking Process – collect/transport	Recycle Rate not required. 80% landfill 20% Incin.	A type of cut-off method (Extraction-Load). Virgin burdens not shared. Assume virgin is disposed and recycled paper is recycled.	None mentioned.	Industry averages. Frequently based on regulatory limits, estimates, or surrogate values. Emission Factors: Franklin Associates, 1994.
Paper Calculator, current	2011/ 1994-2011	NP – ONP Corrugated –OCC Office Paper –OWP Paperboard – Recycled Paperboard	Cradle to grave.	Recycle rate estimated from EPA 2009 study. 80% landfill 20% Incin.	Mixture of cut- off method and simplified number of uses method for waste mgmt. alone. Virgin burdens not shared.	None mentioned.	Industry averages. Frequently on regulatory limits, estimates, or surrogate values. Emission Factors: data from late 2000s.
Heinz	2006/2001	*Time* and *InStyle* magazines. About 60% bleached kraft and 40% mechanical pulp.	Cradle to grave.	Recycle rate of 22 and 35%, respectively. 90% landfill 10% Incin.	No recycled fiber used. Cut-off method for the recycled products.	None mentioned.	Forest, mill, printer, specific data for *Time* and *InStyle* magazines only. Lack of documentation. Emission Factors: US DOE 2002, mill and printer reports
NCASI	2010/2006	Office Paper Catalog Telephone Directory Magazine	Cradle-to-mill gate And Cradle-to-grave	Specific RR, LF and incineration for each grade. 80% landfill 20% Incin.	Number of subsequent use method.	Mass allocation for tall oil fatty acid, turpentine. Energy allocation for sold power.	Industry averages, based on 80 mills, representing approximately 78% of NA Production. Used SimaPro and USLCI databases. Emission Factor: IPCC 2006

Both the Paper Task Force/EPN and NCASI studies considered coated freesheet and uncoated mechanical papers. The original PTF study does not compare directly to the NCASI study, as the original PTF study separately analyzed fully recycled or virgin systems. However, comparing uncoated freesheet results for the NCASI study on a cradle to grave basis yields a net GHG emissions value of 1.88 (ton of CO_2e per ton of product), which is between the 1.79 for the recycling loop and the 2.29 for the virgin paper route in the original PTF study. The NCASI study reported a value of 1.77 for uncoated mechanical papers, in between the results for the original PTF study of 1.7 for the recycled loop and 4.7 for the virgin route (tons of CO_2e per ton of product). Due to the significant differences in methodology, the agreement between the studies should not be considered to determine equivalence in the studies, and may be due to chance.

The Heinz study considered both mechanically pulped (40%) and chemically pulped and bleached (60%) fibers within a product, with 1.11 and 1.17 tons of CO_2e per ton of product for *InStyle* and *Time* magazine, respectively. In contrast, the NCASI study resulted in significantly higher values of 3.45 and 2.36 for the uncoated freesheet and coated mechanical sheet, respectively. The distribution of the relative contributions of the life cycle stages to the overall emissions are also different for the two studies (**Figure 3**). These differences between the two studies are most likely due to differences in data (emission sources, times, mill specific versus continent averaged data), differences in what data was included, different assumptions, different boundary conditions, and different product compositions. Some of the suspected significant differences are discussed below.

An example of the differences in assumptions regards black liquor use, a renewable biofuel produced in the wood chemical pulping process. The Heinz study considers black liquor to be carbon neutral whereas the NCASI study considers it as contributing to the GHG emissions through N_2O or CH_4 generation, about 6 kg CO_2e per ton of catalog product (only 0.5% of total cradle to gate emissions). In a similar fashion, it is assumed that other biomass fuel sources such as hog fuel are not included in the Heinz study but are considered in the NCASI study (about 1% of total cradle to gate emissions). Without a life cycle inventory clearly documented in the Heinz study, it is not possible to confirm these exclusions .

In another example, it is suspected, but not known, whether or not the Heinz study includes upstream net GHG emissions from purchased raw materials. In the NCASI study of catalog paper, the contribution of upstream emissions of purchased materials other than wood/fiber (both in pulp and paper manufacturing and printing) represents 20% of the total cradle-to-gate emissions.

Similarly, it is probable that the Heinz study did not include upstream emissions of printing materials. For the Heinz study it is probable that printing/converting operations only reported electricity and natural gas use; in the NCASI study the upstream emissions of printing materials account for approximately 2.5% of the total cradle to grave emissions. These additional considerations in the NCASI study produce a more complete model of the system.

Another difference between the Heinz and NCASI studies involves the Heinz study reporting CO_2 from landfills as a net GHG emission whereas the NCASI study only includes methane from landfills as contributing to net GHG emissions. The studies also differ in the amount and type of GHG emissions per unit product landfilled.

Table 6 summarizes some key indicators of the scientific rigor of the life cycle assessments. The arena of life cycle assessment has evolved significantly since the early 1990s. Standardized methods to practice LCA are followed to a much greater extent currently (ISO 2006a,b). With this development has come more rigorous studies. The three studies discussed here reflect this evolution from the early 1990s to present day.

Table 6. Indicators of Scientific Rigor in the Three LCA Studies for Paper.

Study:	Followed ISO 14040 methods	3rd Party Review	Published in a Peer Reviewed Journal	Clarity of Data	Impact Assessment	Uncertainty Analysis	Sensitivity Analysis	Allocation methods
Paper Task Force, 2002	No.	Reviewed by outside experts. Comments not provided in the report.	No.	Extensive presentation of the inventory data.	Net GHG.	None.	None.	A type of cut- off method (Extraction-Load). Virgin burdens not shared. No coproduct allocation mentioned.
Paper Calculator, current	No.	Reviewed by outside experts. Comments not provided in the report.	No.	Revised data not documented..	Net GHG.	None.	None.	Inconsistent application of open loop recycling. No coproduct allocation mentioned.
Heinz	No.	Reviewed by outside experts. Comments not provided in the report.	No.	Did not define what data was included. Data in inventory results not presented.	Only GHG emissions reported.	None. Weaknesses in study discussed.	Not done. Results for individual printing operations presented.	Cut off for recycling. No coproduct allocation.
NCASI	Yes	External peer review panel. Panelists' comments and the responses to the comments appear in the full report.	No.	Extensive flowsheeting of processes and lists of data appear in report.	SimaPro software running TRACI.	Conducted with respect to inventory data.	Sensitivity on process conditions, allocation methods, impact assessment method, others	Co-product and recycling allocation methods used.

It is important at this point to reinforce the concept that quantitative comparisons of emissions between different studies is fraught with error and uncertainty. For this discussion, these differences are being identified and explored. A summary of main points follows.

- The original PTF study uses an artificial separation of virgin and recycled flows. Based on assigning all the burdens of raw material and disposal to the virgin products, it is concluded that it is beneficial to recycle rather than landfill/incinerate at the 80/20 ratio with respect to net GHG. Revisions in 2008-2011 for the Paper Calculator do not change these conclusions.

- The NCASI results involving North American average net GHG data are bracketed by the PTF results for 100% virgin plus waste management and 100% recycled paper making processes. Again, due to the significant differences in methodology, the agreement between the studies should not be considered to determine equivalence in the studies, and may be due to chance.
- The Heinz net GHG emissions for *Time* and *InStyle* catalog grade are about half of that reported for the NCASI study for catalog (coated freesheet) grades. This appears to indicate that surface-level comparisons between the two are not reasonable, and that significantly different assumptions, data and methodologies were utilized. A potential source of difference is that the Heinz study relies heavily on data rich in site specific detail whereas the NCASI study uses industry averages and uses more data over the entire life cycle. The Heinz study uses the cut off method for recycling whereas the NCASI study does not.
- The Heinz Study does not present a documented life cycle inventory, supposedly due to an attempt to not divulge trade secrets, which would be required for the study to be repeatable. It is suspected that inherent net GHG emissions in raw materials like printing and bleaching chemicals are not included in the Heinz study.

Allocation Methods Analysis

There are two important allocation methods that should be considered when analyzing net GHG emissions with respect to paper products: co-product allocation and recycling allocation.

Co-product allocation. A paper mill produces many products and wastes. Major co-products that may be considered include the paper, turpentine, tall oil fatty acid and sold electricity or steam. Waste streams are not typically considered coproducts; however, their environmental burdens must be considered. The PTF/EPN and the Heinz studies either did not account for co-product allocation or did not document it.

In the NCASI study, mass allocation was used to partition the burdens of turpentine (1.5 kg), tall oil (19.3 kg) and machine-dry coated freesheet (862 kg). Using the mass fractions of these co-products, 97.64% of total net GHG emissions are assigned to the paper product. This correction factor is close to the level of uncertainty in the results. Uncertainty analysis resulted in an about +/-10% uncertainty (NCASI, 2010, Figure 8-21, pg 114)

With respect to allocation of sold electricity or steam as coproducts, it can be assumed that the sold energy coproduct should bear the emissions burden of an equal amount of energy needed to produce it. As an example of an industry average in the NCASI study, sold electricity and steam are equal to about 0.1 GJ per machine dry short ton of coated freesheet. Total energy expenditures (renewable and non-renewable) are equal to about 25.1 GJ per machine dry short ton of coated freesheet. Thus, of the emissions that the mill generates from energy sources, only 0.8% are attributed using mass allocations to producing the sold electricity or steam and 99.2% are due to the paper, turpentine and tall oil. Further, when considering all emissions, not just from energy sources, the significance of sold electricity or steam is reduced even more. In this case, the correction due to the allocation factor is below the level of expected uncertainty in the results (and may be chosen to be ignored for this case). However, mill specific data may require consideration of this allocation factor for co-products.

Recycling Allocation. When faced with multiple products in an LCA, the first option should be to use system expansion to avoid allocation methods, but in some cases this is not possible or practical. Several recycling allocation methods can be used; however, while the cut-off method is often used for paper LCA studies, the number of subsequent use methods is specifically mentioned in the ISO standard as an option.

- In the cutoff method, environmental burdens for shared processes (such as raw material procurement, transportation between two life stages or final disposal) that are required for different stages of product life are not shared between the different product lives. In this case, recycled materials consumed in the product only have the environmental burden of the used paper collection, processing to make suitable for incorporation into paper products, and transportation. Also, the recycling of the product of interest simply serves to avoid the environmental burdens of disposal.

- In the number of subsequent uses allocation method, some burdens are shared among the different stages of product life. To be specific, open loop recycling involves recycled fibers which carry with them into the system of interest a portion of the environmental burdens that are associated with the original production of the virgin material from which they originated. Accordingly, if the studied system is a product recycled for subsequent use, some of the virgin material production burdens can be exported out of the system to the subsequent uses. For the open loop recycling process of paper, the calculation of allocation factors can be quite complicated. However, increased number of uses generally decreases the overall burdens of fiber over its multiple lives (assuming recycling has less burden than virgin production).

Different allocation methods between virgin and recycled products will result in different results with respect to the net GHG emissions attributed to the virgin versus recycled products. To explore, allocation methods presented by Baumann and Tillman (2004) were applied to the data from the Paper Task Force (2002) for office paper for net GHG emissions.

The different net GHG emissions for various life cycle stages of office paper are shown in **Table 7** per the Paper Task Force (2002). In this case the office paper is assumed to be recycled twice (arbitrarily chosen herein for demonstration purposes at a collection rate of 50%) and then disposed. This example simplifies the discussion by assuming that the entire process follows a closed loop recycling model, in which all of the material is recycled within the system. Of course, this is an idealized case that allows the allocation methods to be observed clearly. Note that the life cycle of printing and writing paper grades (and other grades) and its recycling is not closed loop; printing and writing grades are recovered and used for several different products, each with their own yields and subsequent recycling.

It is observed that virgin raw material procurement and processing has a slightly lower net GHG than recovered fiber procurement and processing in this example from the Paper Task Force (2002). This might be interpreted as suggesting that the use of virgin material is associated with lower environmental burdens than using the recycled material, but this is not the case for all allocation calculation methods.

For the life cycle stages of office paper, the raw material procurement and waste management processes can be considered life cycle stages in which the burdens are shared for all three of the product uses. Further, it is not unreasonable to consider that the collection/transport and even the virgin production steps could be shared by multiple product uses (denoted in **Table 7** as Potentially Shared Operation).

Table 7. Net GHG of office paper from various life cycle stages from the Paper Task Force (2002, p. 132), waste management is 80/20 landfill/incineration.

	Raw Matl	Virgin Prod	Collect/transp	Recycle Process	Collect/transp	Recycle Process	Waste Mgmt
	V1	P1	R1	P2	R2	P3	W3
	Shared Operation	Potentially Shared Operation	Potentially Shared Operation	Not Shared Operation	Potentially Shared Operation	Not Shared Operation	Shared Operation
CO_2e lb/ton product	300	3000	230	3350	230	3350	2500
CO_2e ton/ton product	0.15	1.50	0.12	1.68	0.12	1.68	1.25

Table 8 and Figure 4 display the results of several prominent allocation methods to assign burdens on the virgin and recycled products. Details of the equations that determine the burdens appear in the **Appendix B.**

Table 8. Allocation methods for recycling: based on data for copy paper from the Paper Task Force (2002) lb CO_2e/ton of product. Calculations as defined by Baumann and Tillman (2004) for closed loop recycling allocation. V/R is the virgin burden divided by the average recycled burden.

Recycling Allocation Method	**Virgin Burden**	**Recycled Burden**	**V/R**
Cutoff Method. Promotes virgin production since burdens of waste management fall on last recycled product made.	3300	4830	0.7
Quality Loss Method (no quality loss) = Closed Loop Recycling. Therefore, virgin production is promoted since recycled manufacturing has higher Net GHG. However shared burdens make Net GHG very close.	4090	4440	0.9
Quality Loss Method (quality loss: Q1=1, Q2=0.5, Q3=0.5). Therefore, recycled paper production is promoted due to higher attributed shared burdens to virgin since the value/quality of virgin is assumed to be higher.	4630	4160	1.1
Raw Material Acquisition Generates Waste Treatment. (RMAGWT) Therefore, recycled paper production is promoted, as recycling is a way to “delay” waste disposal.	5800	3580	1.6
Material Lost as Waste Must Be Replaced. (MLWMBR) Therefore, virgin paper production is promoted, as the raw material procurement and waste management burden is placed on the last product.	3230	4865	0.7
50/50 Method: Raw Material Procurement and Waste management to 1st and Last Product and Recycling to upstream and downstream Product (50/50 splits). Therefore, recycled paper production is promoted, but there is not much difference as raw materials and waste management are spread over two recycled products.	4515	4220	1.1

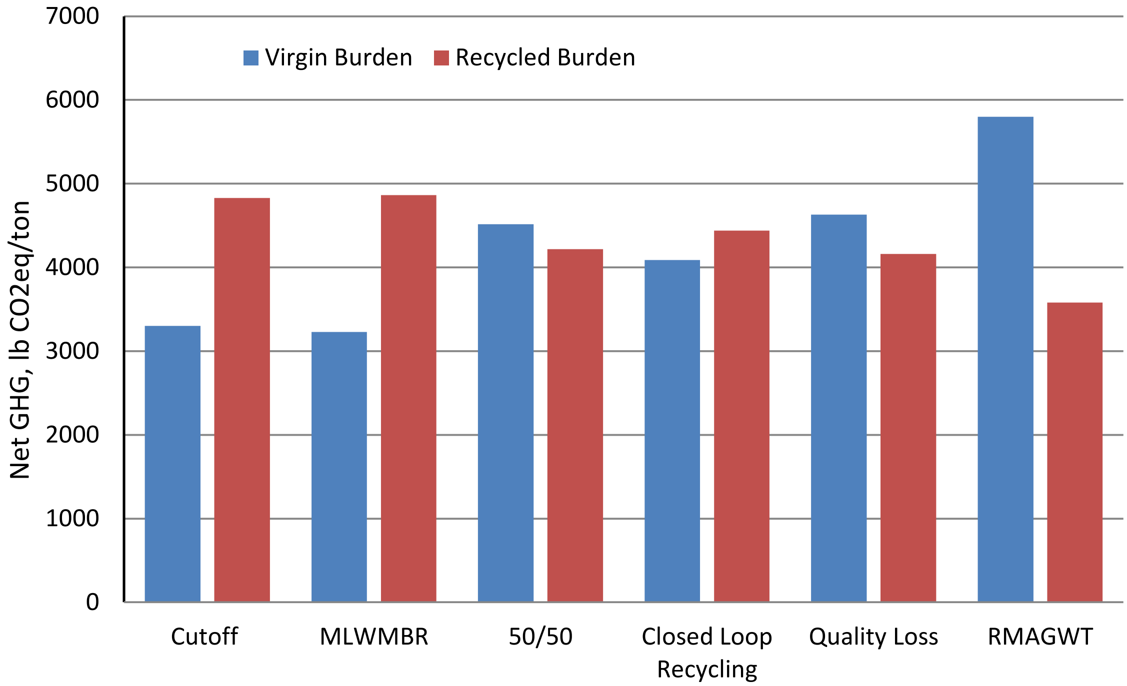

Figure 4. The net GHG emissions attributed to virgin and recycled paper products based on the allocation method used (see **Table 8** for nomenclature and **Appendix B** for allocation methods and calculations).

Half of the allocation methods promote recycling as recycled material is attributed less GHG emissions than virgin material (V/R greater than 1); the other half promote the use of virgin material. The percent difference between the highest and lowest assigned virgin burden is 80%. For recycled virgin it is 35%. The appropriateness of each allocation method is not always clear. Note how subjectively weighted factors, such as quality loss, can change the outcome of the result. (eg., closed loop recycling versus quality loss). However, there has been a general trend in LCA that reused or recycled materials share their common stage burdens amongst the different lives of the materials rather than it being placed only upon the virgin or recycled material. Note that the RMAGWT is the same method as used in the original study by the Paper Task Force (2002).

It is very clear that if a product has significant environmental burdens in raw material acquisition or end-of-life scenarios (termed *shared burdens*), and the recycling manufacturing step has an environmental burden similar to or less than the primary manufacturing step, an increased recycling rate (or number of uses) makes the overall system more efficient. For instance, taking the environmental burdens as listed in **Table 7** for office paper but varying the number of times recycled results in a decreased average environmental burden per use as shown in **Figure 5** for the actual shared burden. Again, this discussion assumes that the system is a closed recycling loop. The most significant benefit from recycling is realized by the first recycle; thereafter each recycle step has a decreasing amount of benefit. It is instructive to compare the actual case (**Table 7**) to a case in which the shared burden is twice (designated as higher) or half (designated as lower) the actual shared burden. The higher the shared burden, the more benefit is realized by recycling and the significant benefit of recycling persists for a greater number of uses. With zero shared burden, there is little benefit claimed for recycling. This simplified analysis demonstrates that there is significant potential environmental benefit to recycle paper products multiple times under the conditions and assumptions used for net GHG emissions (**Table 7**).

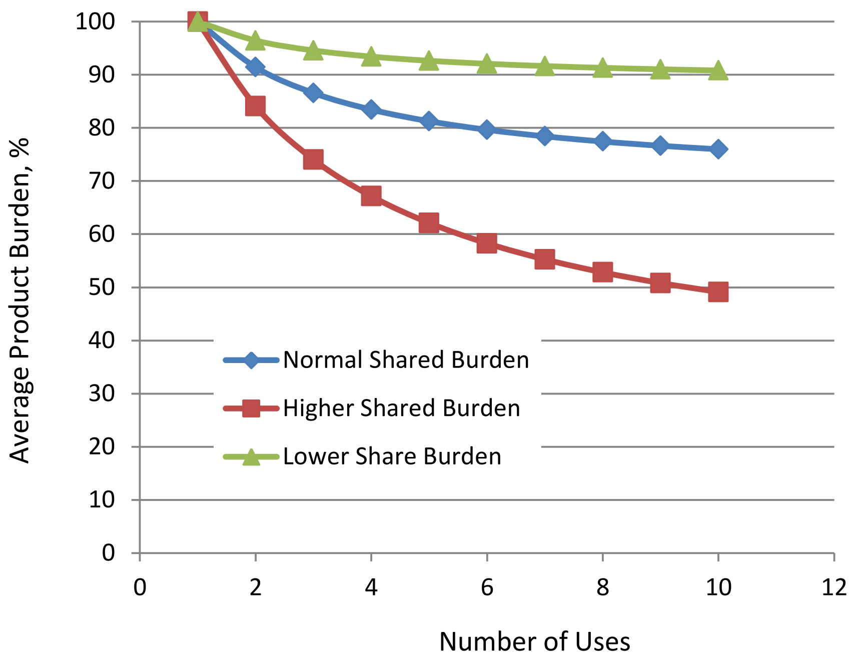

Figure 5. Average product environmental burden (net GHG) as a percent of the product burden for the case with no recycling versus number of uses (data from **Table 7)**. The normal shared burden is equal to 2800 lb CO_2e/ton product, the higher shared burden is set at twice that value and the lower shared burden is set as half that value. The simplified system is modeled as a closed loop.

Promotion of virgin or recycled material is not only affected by the environmental burdens of primary manufacturing of virgin versus recycled material manufacturing, but also how shared processes in the life cycle are allocated. With this example of paper recycled in a closed loop, the chosen method of allocation is observed to significantly alter the environmental burdens associated with the first use or the subsequent uses of a material after recycling. Further, when considering two related products in the same life cycle such as virgin or recycled materials, the choice of available allocation methods can determine whether virgin or recycled material is promoted. This has also been shown by Nicholson et al. (2009) for open loop recycling. LCA methods (ISO 2006a, b) do not dictate which allocation method to use; it is up to the LCA practitioner to choose a method, explain the rationale of the choice, and also to evaluate the sensitivity of the result to the allocation method. External review of the LCA is also very useful in establishing the reasonableness of the chosen allocation method.

It should be stated that another option to allocation is to consider the consequences of making one decision over another. For instance, when trying to determine if using more recycled fiber has societal benefit, the consequences of using less virgin fiber, such as perhaps lower demand for trees and thus less planting of trees might be considered within the analysis framework. The potential consequences in this scenario include important environmental, economic and societal implications. However, it can be difficult in some cases to predict the consequences of such actions or to validate or test the hypotheses behind the predicted consequences. Further, valuing multiple consequences produces the same type of allocation issues that are addressed for the primary issues at hand. Although important, the consequential results of the virgin versus recycled fiber promotion cannot be addressed within the framework of this study.

The Effect of the use of the Cut-off and the Number of Subsequent Uses Methods for Recycling Allocation: Net GHG Emissions for Catalog Versus Recovery Rate and Utilization Rate

In this section, the impact on the net GHG emissions (Carbon Footprint) of using a cut-off or a number of subsequent uses recycling allocation method of a coated chemically pulped and bleached paper product (catalog) is explored with respect to recovery and utilization rates.

Methods

An Excel™-based tool to assist in the calculation of the carbon footprint for paper and paperboard products was utilized, FEFPro V1.3 (FEFPro, 2010). As stated in the user manual, *There is no single official definition for a carbon footprint but it can be seen as a picture of the overall greenhouse gas impact (not just CO_2) of a product over its lifecycle (cradle-to-grave). The accounting begins with emissions associated with extracting or growing raw materials and finishes with the emissions associated with reusing or disposing of the product.* Some carbon footprint analyses do not consider product disposal and use. These studies are referred to as “cradle–to-gate” and can be useful when analyzing different production processes for the same product or for business-to-business communications. Carbon footprints can be performed at different levels (FEFPro, 2010):

- Carbon footprint of a specific product often defined via a functional unit;
- Carbon footprint of a mill;
- Carbon footprint of a company; or
- Carbon footprint of a sector.

The FEFPro model was populated with data from the study published by NCASI (2010), *Life cycle assessment of North American printing and writing paper products*. Average North American data for catalog paper (coated freesheet) was used. The average North American industry catalog product utilized 3% recycled fiber furnish (utilization rate) and had a 38.8% recovery rate. Two types of cradle-to-grave cases were explored herein

- Varied recovery rate with the utilization rate constant
- Varied utilization rate with recovery rate constant

The modeling steps and assumptions are further discussed in Appendix C.

Results

The model was used to calculate the GHG emissions using both the cut off and the number of subsequent uses recycling allocation methods. The base case GHG results for the North American average for catalog production are shown in **Table 9** as calculated with the FEFPro program. Also shown are the NCASI data (NCASI, 2010). The results from FEFPro modeling adequately match those produced by NCASI (2010) using SimaPro software. This suggests that the FEFPro model has the fidelity and robustness to capture the significant contributors to the GHG emissions in a paper product life cycle, as judged against the NCASI (2010) study.

Table 9. FEFPro Modeling Results of industry average for catalog for two recycling allocation methods. The values of the net GHG emissions depend on the allocation method, utilization rate, and recovery rate. In this case the utilization rate is 2% and the recovery rate of the product is 38.8%. Numbers in parentheses are the % difference between number of uses and cut off allocation methods. One catalog is 0.135 OD kg.

Case	FEFPro	NCASI, SimaPro	% Difference
	kg CO_2e/bdst catalog	kg CO_2e/bdst catalog	
Cradle-to-Gate, # Uses	1658	1469 *	13
Cradle-to-Gate, cut off	1947 (17% increase)	(not reported)	Not applicable.
	kg CO_2e/ catalog	kg CO_2e/ catalog	
Cradle-to-Grave, # Uses	0.51	0.49 **	4
Cradle-to-Grave, cut off	0.56 (10% increase)	(not reported)	Not applicable.

* from Table 9-2, NCASI (2010) study. ** from Table 9-1, NCASI (2010) study.

The net GHG for the studied system for cradle-to-gate and cradle-to-grave scenarios using the cut off method are greater than for the number of subsequent uses allocation methods, by 17% and 10%, respectively, **Table 9**. These decreases are due to the fact that the number of subsequent uses allocation method exports more virgin burdens out of the system of study due to the product's high recovery rate (38.8%) than it imports into the system of study due to a low percentage of recycled fiber used in the product (3%).

These types of results are case-specific and depend on the particular values of the recovery rate and utilization rate. The effect of the utilization and recovery rates on the GHG results with the two allocation methods are further explored in this section.

Effect of the Recovery Rate on net GHG emissions

For the base case, 38.8% of the catalogs were recovered (the utilization rate was 2%). This considers both pre- and post-consumer recovery; 81.4% is landfilled and 18.6% is incinerated for energy of the unrecovered catalogs. The net GHG emissions per catalog are calculated versus recovery rate using the cut-off and the number of uses recycling allocation method, **Figure 6.** With a recovery rate of zero the two allocation methods result in a similar value, as expected. There is a slight difference at 0% recovery rate due to the number of uses allocation importing a small amount of burden into the system from its virgin production. It can be observed that the cut-off method decreases linearly simply by reducing the end of life emissions in proportion to the recovery rate, i.e., an increase in recycling reduces the amount of paper landfilled and incinerated along with their associated emissions. In contrast, the number of uses method shows a more dramatic decrease than the cut off method. This makes sense, for as the recovery rate increases, more of the environmental burdens from the virgin fiber production are exported out of the system to the subsequent uses (in addition to the reduction of landfilling and incineration).

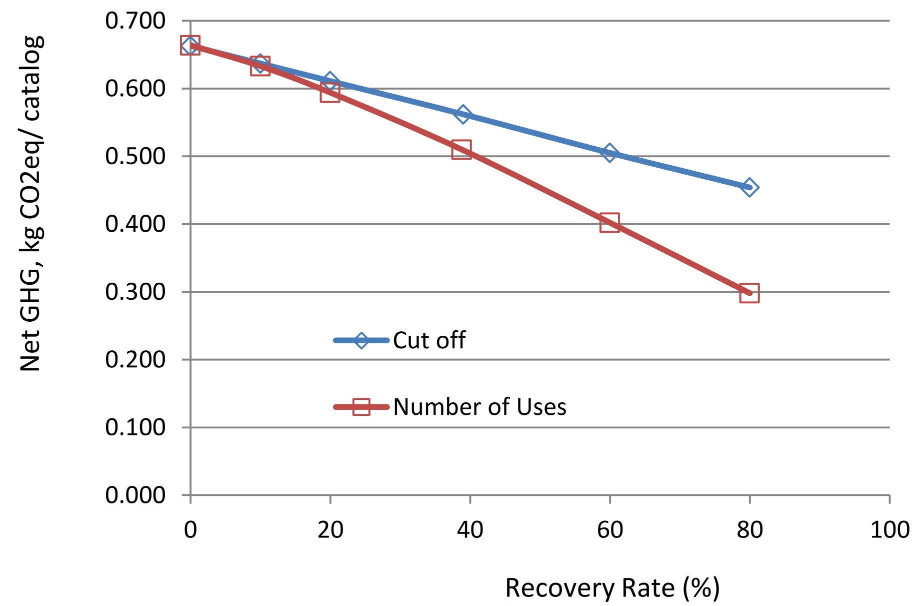

Figure 6. The net GHG emissions per catalog versus recovery rate using the cut-off and the number of uses recycling allocation method for cradle-to-grave.

The actual fraction of the burden associated with making the virgin materials for the product of interest not exported out of the system is plotted versus recovery rate in **Figure 7.** This non-linearity is a contributor to the non-linearity of the net GHG emissions versus recovery rate, **Figure 6.**

These trends are in agreement with a recent study conducted in Finland on a magazine product (Pikhola, et. al., 2010). The product was made entirely from virgin materials and an 85% recovery rate for the magazine was assumed. The cradle-to-grave carbon footprint was calculated to be 1.6 kg CO_2e/OD kg catalog with a cut-off method and 1.0 kg CO_2e/OD kg catalog with a number of uses allocation method, a percent difference of 60%, of the same order as the percent difference shown in **Figure 6.** In that study, the number of uses allocation method was considered to be more relevant than the cut off method, since the production of a recyclable product has environmental benefit in other, sometimes not fully known, uses.

If a recyclable product brings benefit to subsequent uses then it is recommended that the number of uses recycling allocation method be used, since the subsequent use of the material is entirely dependent on the virgin production process. This type of thinking is an increasingly accepted way to allocate burdens in life cycle analyses (Nicholson, et al. 2009; Nicholson, et al. 2010).

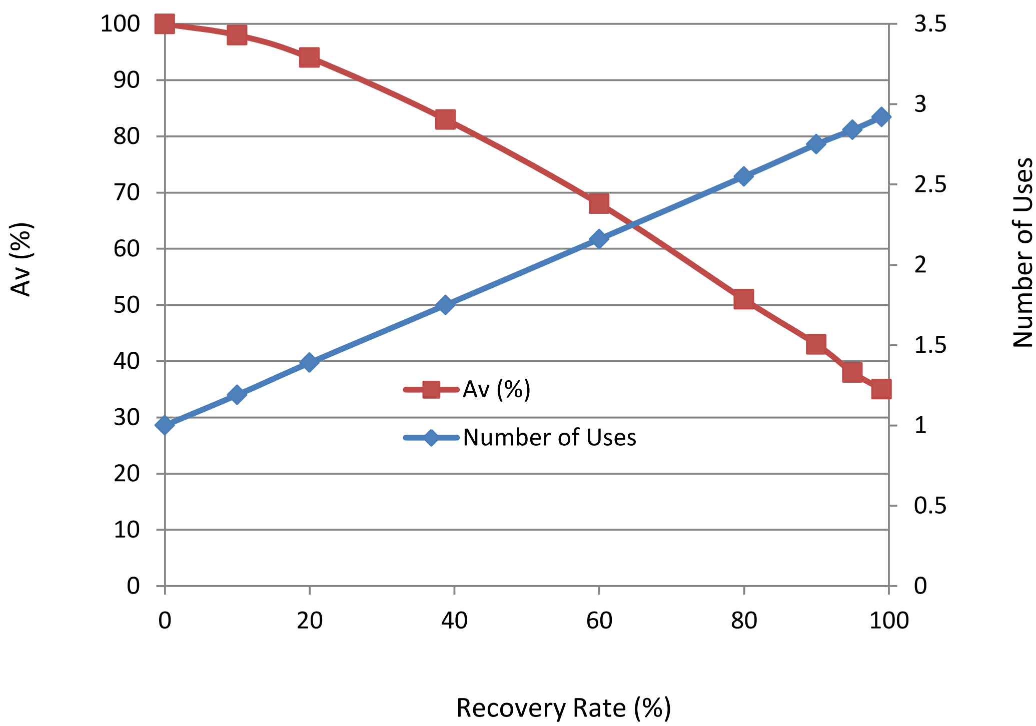

Figure 7. The fraction of the burden associated with making the virgin materials for the product of interest that is not exported out of the system (Av) and the number of uses versus recovery rate.

Also plotted in **Figure 7** is the number of uses versus the recovery rate which is observed to be linear with respect to recovery rate. This is a reflection of the fact that the FEFPro system models the paper industry as an open loop recycling system, not a closed loop recycling system. The recovery rate for the particular paper product does not impact the recycling rate of subsequent uses; the recycling rate of various products is set by documented industry averages and is not a function of the product-specific recovery rate that the practitioner inputs for the product of interest.

It is instructive to consider an ideal case of closed loop recycling and the effect of the recovery rate on the number of uses. It is known that if the paper was in a closed loop recycling system (with no yield losses on recycling) that the number of uses would equal N=100/(100-RR%), **Figure 8.**

However, the paper industry is not one with closed loop recycling and losses exist over time so it is more appropriate and accurate to utilize the open loop recycling allocation methods as used in FEFPro. The linearity displayed by the number of uses versus recovery rate for a product using current open loop recycling data in the paper industry is in stark contrast to the simplified, non-linear closed loop model seen in **Figure 8**. This demonstrates how important it is to utilize a realistic open loop recycling model.

The downside to the open loop recycling assumption (versus the cut-off method) is that it is difficult to determine (1) all of the flows between a specific product of interest and the percentage of uses in all of the various recycled products and (2) yield information concerning the recycling of all the recycled products. This data needs to be updated as trends in recycling change in the industry. Communicating the math/methodology to those not experts in LCA methods is also difficult.

Generally speaking, for open loop recycling of paper, as the recovery rate increases, the number of uses increases, and if shared burdens such as raw material acquisition and final disposal are significant, then the net environmental burdens to all products within the recycling loop improves. This depends on the recycling process being similar in environmental burden or less than other alternative options. This is exemplified in **Figure 5** for an ideal closed loop system, but the concept extends generally to open loop recycling also.

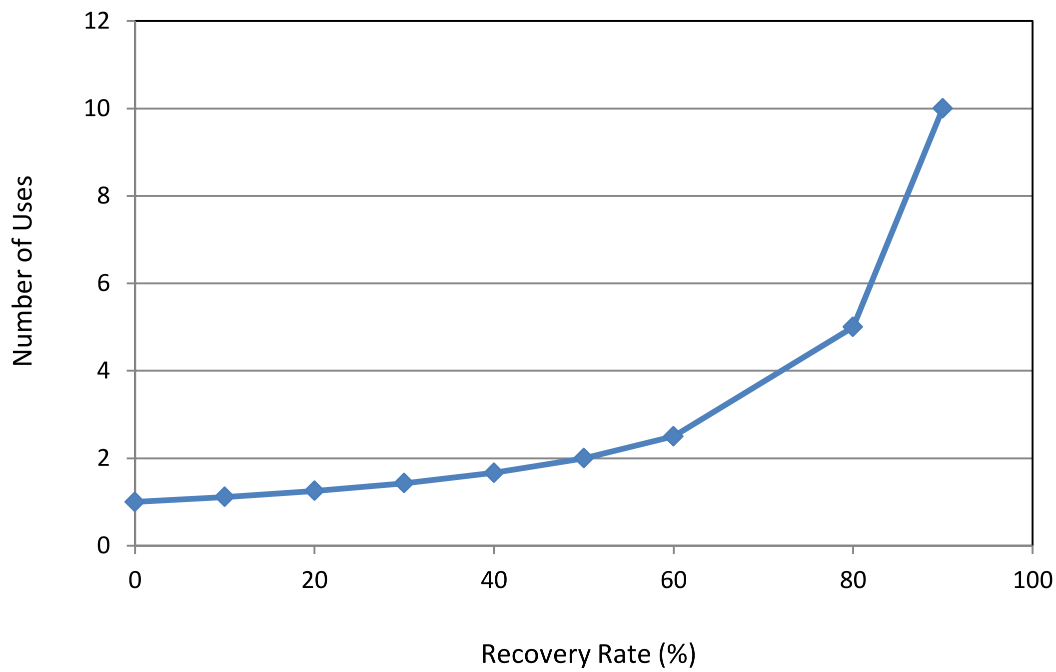

Figure 8. The theoretical number of uses versus recovery rate for a strictly closed recycling system.

To summarize, it has been shown that the choice of recycling allocation method is important to the assignment of environmental burdens between the product of interest and subsequent products that utilize recovered material from the product of interest. It can be observed in **Figure 6** that the number of uses allocation method (with a recovery rate of about 38.8%) assigns about 10% fewer emissions to the product of interest than does the cut off method. This reduction increases to 60% if the recovery rate is 80%. These are significant reductions to the net GHG emissions for the product of interest and have strong implications for future material preferences based on environmental burdens.

Effect of the Utilization Rate on net GHG emissions

It is also of interest to understand how the recycling allocation method impacts the emissions as a function of the utilization rate of recycled paper in the product of interest. For the base case, the utilization rate was 3% and the recovery rate of the catalogs was 38.8%. It is not straightforward in FEFPro to simply change the utilization rate into the system based on the North American industry average data. For instance, when the utilization rate is increased, then all mill operations must be adjusted. These include virgin fiber sources, fuels used in manufacturing, pulping and bleaching chemicals used, electricity and purchased steam, manufacturing wastes, lime kiln CO_2 capture and other variables. FEFPro is not able to make these changes automatically. The user must have some mill knowledge to predict these changes, which is not an easy task. To explore the effect of different utilization rates using FEFPro and the North American industry average data, purchased virgin market pulp was substituted by purchased deinked pulp in the model. By simply switching one purchased pulp by another, then all of the information about the average mill operations would still be valid and would not need to be adjusted.

The net GHG emissions per catalog have been calculated versus utilization rate at the constant recovery rate of 38.8% using the cut-off and the number of uses recycling allocation method, **Figure 9**. Note that the changes in GHG emissions over the span of utilization rate investigated (15%) are much smaller than those for the recovery rate changes (40%). It is expected for most common types of paper that this will generally be true.

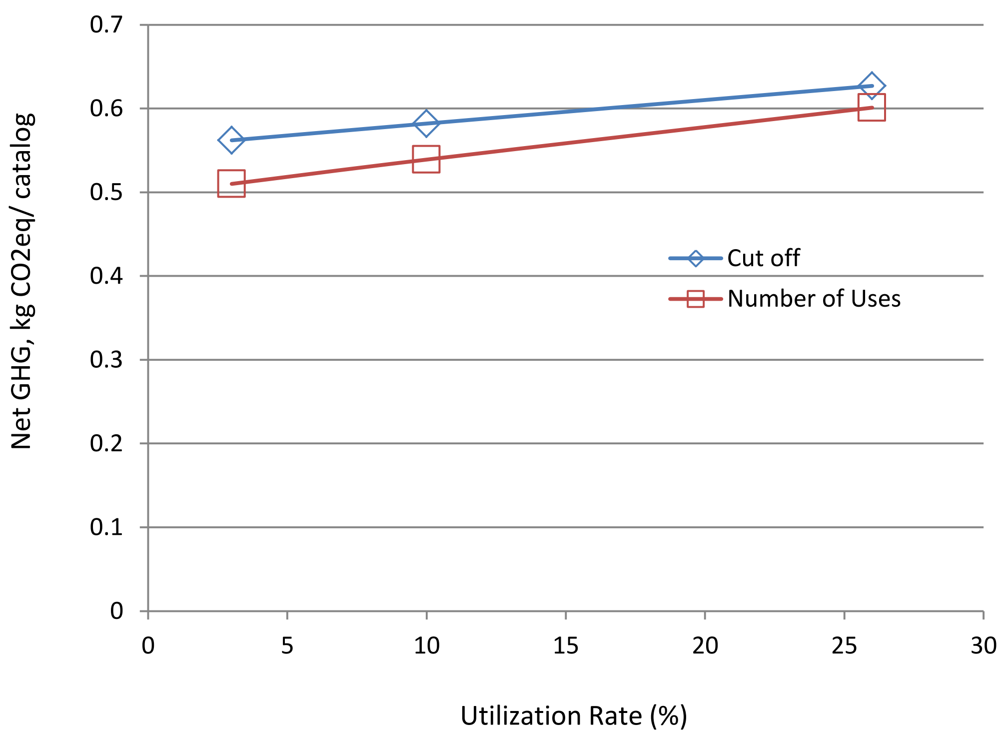

Figure 9. The net GHG emissions per catalog versus utilization rate using the cut-off and the number of uses recycling allocation method (recovery rate equal to 38.8%).

As the utilization rate increases, the major impact on the net GHG that occurs is due to the increased amount of deinked market pulp (emission factor of 3.5 kg CO2e/kg) and the decreased amount of purchased virgin pulp (emission factor of 1.0 kg CO2e/kg).   It is interesting to note that the GHG burdens of the deinked market pulp are significantly higher than for the virgin market pulp. Due to the sensitivity of these results to the emission factor of deinking operations, it is very important to further investigate the GHG emissions from deinking recycling operations.

It is noticed that the number of uses allocation method estimates about a 10% lower net GHG emissions than the cutoff method; this lower net GHG emissions is due to a larger export of burdens out of the system with the number of subsequent uses allocation relative to the added imported burdens due to the utilization of recycled fiber.

Although the results in **Figure 9** are just an example, it is expected that the results roughly approximate the current state of the North American catalog production, in which recycled fiber is sparingly used, a 3% utilization rate, but the product is significantly recycled, 38.8% recovery rate. Based on these findings, in considering the overall GHG life cycle analysis of a typical catalog, the results are expected to be more significantly related to the recovery rate than the utilization rate when considering recycling allocation methods. This might not be true for other types of paper or board, for example recycled paperboard products have very high utilization rates and relatively lower recovery rates.

Coated Mechanical Sheets Used in Magazine: Effect of Recycling Allocation Method

A similar exercise was performed for coated mechanical sheets used in magazine. The modeling steps, assumptions, and findings are discussed in **Appendix D**. For magazine paper the recycling allocation method chosen also had a significant impact on the carbon footprint. In fact, for magazine paper for the cradle-to-grave system, the choice of allocation method can cause the effect of increased recovery rate of magazine paper on the overall carbon footprint to change from a positive one to a negative one.

The Use of Industry-wide Averages to Describe Individual Products

Both the NCASI (2010) and the Paper Task Force study (2002)/Environmental Paper Network Paper Calculator (2011) are based on industry average information. These types of studies have value in benchmarking the industry and for comparing a product with an alternate product, such as a paper cup versus a plastic cup. However, it is not reasonable to make claims about a specific paper product (product labeling) based on these average results. It is expected that specific commercial products can have significantly different carbon footprints relative to other sources of the same type of product and to the industry average. The environmental impacts of a specific product are a function of the company, mill site, raw material sources, mill processes, fuel choices, equipment efficiencies, transportation distances, etc., For example, the original Paper Task Force study (1995) states that *the data used show significant variability because of the range of ages and geographical locations of the mills, as well as differences in the processes that mills use to produce a given type of pulp.*

The same type of paper or pulp can be manufactured in many different ways. For instance, types of bleaching processes, methods of mechanical refining, and methods of pressing and drying, among other examples, can have a significant effect on the overall energy consumption or emissions from a process. As an example, the range of total CO_2 emissions from fossil fuels to produce bleached kraft pulp for different bleaching sequences is shown in **Figure 10 (**Paper Task Force, 1995, pg. 1).

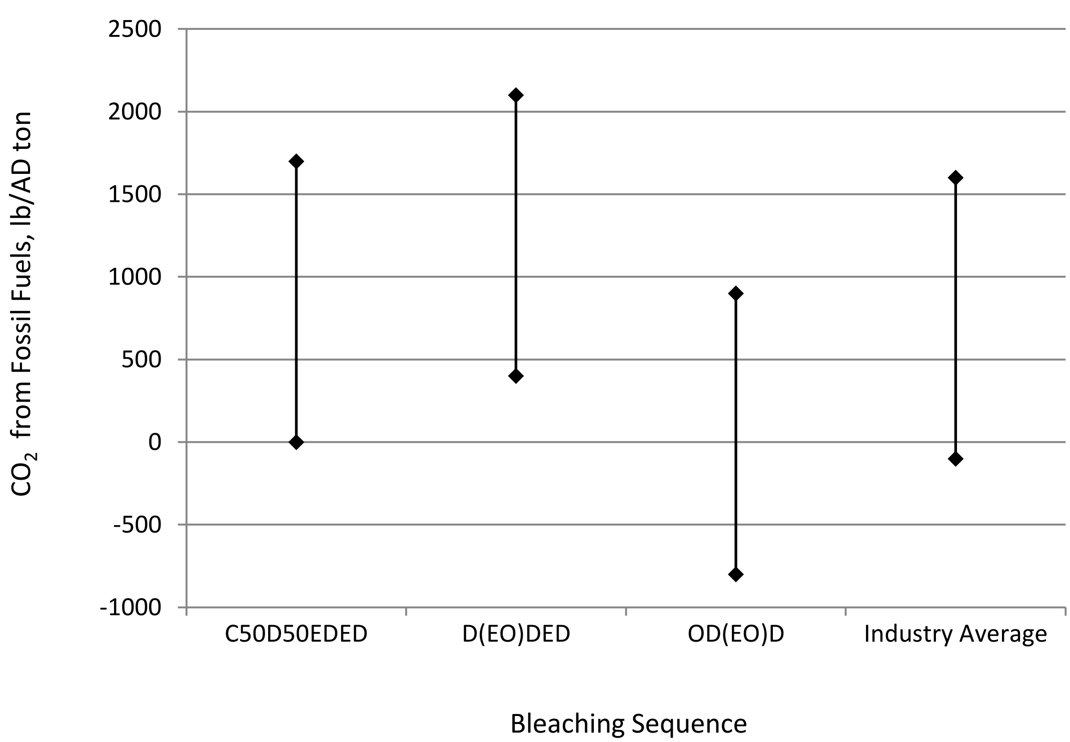

Figure 10. The range of total CO_2 emissions from fossil fuels to produce bleached kraft pulp for different bleaching sequences. **(**Paper Task Force, 1995)

The industry average is estimated to be 850 lbs CO_2/air dry ton of product (unweighted results since mill emissions data were available but did not contain the associated production rate for each mill), but the range of the overall results are from -800 to 2,100 lbs CO_2/air dry ton of product. Negative results indicate the use of non-petroleum fuel sources that displace petroleum fuel sources. The range of the results is 340% of the average. It is clear that for all manufacturers of bleached kraft pulp to claim the industry average as representing their product would be grossly misleading, with some manufacturers underestimating environmental claims and others exaggerating claims. More recent data from 85 North American integrated bleached kraft pulp and paper mills confirm that there is an equally large spread reported for CO_2 emissions from fossil fuels about 15 years after the Paper Task Force report in 1995 (Mannisto, 2011).

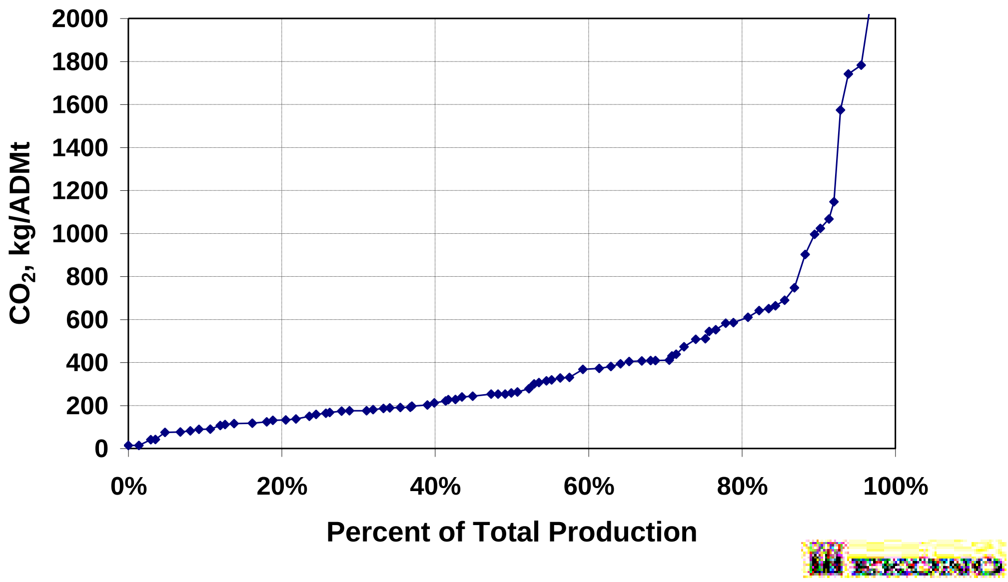

Figure 11. Distribution of CO_2 emissions from fossil fuel use in 85 integrated bleached kraft pulp and paper mills worldwide. Emissions do not include those from the purchase of electricity or any other upstream emission. Total production represented by the data is 48 million metric tonnes/year. Data from 2008 (Mannisto, 2011).

In the Paper Task Force study (1995), the average and ranges of CO_2 emissions from fossil fuels were reported for other types of pulp and paper manufacturing processes, **Figure 12.** It is clear that the range of results is large, further evidence that the use of industry averages by a manufacturer of pulp or paper products can be misleading.

As another example, printing/converting/delivery pathways for the carbon footprint of *Time* magazine production were determined via five actual specific pathways (Heinz, 2006). The kg CO_2e/kg magazine ranged from 1.01 to 1.25 for the different pathways, a difference of 25% for the entire cradle-to-grave life cycle for the exact same product within one consistent LCA.

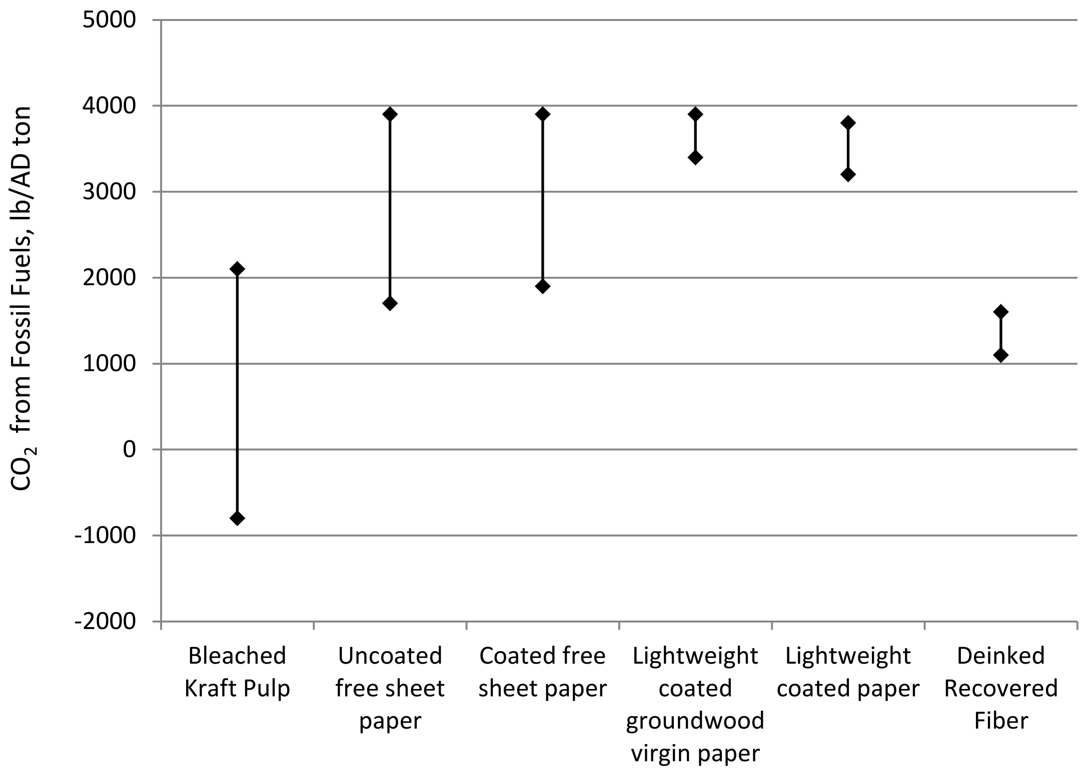

Figure 12. The range of total pounds of CO_2 emissions from fossil fuels to produce an air dry ton of different pulp and paper products. **(**Paper Task Force, 1995)

Recommendations

- Developing meaningful comparisons of different LCA studies can be extremely difficult. Issues arise when studies use different boundaries, LCA calculation methods, type and quality of data, and assumptions. Further, a lack of adequate documentation, mainly arising from not presenting a well-documented life cycle inventory further complicates interpretations of the meaning, limitations and results of different studies. The use of standard methods (ISO 2006a,b) is necessary to produce LCAs of clarity and value.
- When considering two related products in the same life cycle such as virgin or recycled materials, the choice of available allocation methods can determine whether virgin or recycled material is promoted. LCA methods (ISO 2006a, b) do not dictate which allocation method to use; it is up to the LCA practitioner to choose a method, explain the rationale of the choice, and evaluate the sensitivity of the result to the allocation method.
- In choosing allocation methods, an understanding of the industry, its processes, and the relationships between players in the industry, should be used; practitioners of LCA should be sensitive to biases rising from self-promotion. A sensitivity analysis should be presented for allocation methods. External review of the LCA is also very useful in establishing the reasonableness of the chosen allocation method.
- The number of uses method is an appropriate model for the life cycle assessment of paper products, which is most reasonably modeled as an open loop recycling process. This method of allocation reasonably allows a sharing of environmental burdens with respect to virgin and recycled life stages of the fibers. This method rewards the production of virgin materials that are made to be recyclable. However, the allocation method is very complex and more difficult to communicate than the cut-off method. Only sophisticated LCA practitioners are able to utilize and discuss with understanding the number of uses method, reducing the utility of the method.
- For the paper products studied herein, the number of uses method results in a carbon footprint of about 10-20% lower than the cut off method for the same product. The ease of use and ability to communicate the cut-off method are two of its strengths. More research needs to be performed to understand if the decrease between the two methods is significant or if it is within the uncertainty of the calculations.
- As based on data in this paper, the recovery of used paper for manufacture of new materials or use in incineration to create energy is in general more desirable than landfilling. Recovery of used paper should be encouraged; the ceiling on the limit of how much can be recovered is an economic/technical one. Based only on GHG emissions, it is generally considered that incineration with energy recovery is the preferred end of life scenario.
- With respect to the utilization of recovered paper in specific products, the data in this paper demonstrate that a blanket statement that all paper products should maximize the use of recovered paper for environmental advantage is not substantiated. In the simplified case for coated paper, there is not a significant carbon footprint advantage for increased utilization of recovered paper, assuming that recovered paper has more effective and economical uses than

incorporation into coated paper. This optimum level to incorporate recycled fibers into a product is product- specific. High performance paper products with strict cleanliness or optical properties may not be able to incorporate recycled pulps in an environmental or economically effective manner. Ultimately, the incorporation of recovered paper into paper products or other applications will depend on the economics/technical practicality.

- Further GHG emission data is required for paper recycling operations, especially deinked market pulp production. This data is critical to understanding trade-offs between the use of virgin versus recycled fibers for many mills that purchase recycled fibers.
- Industry average data are useful for an industry to benchmark its overall performance. This is helpful to understand how new technologies, sources of energy, raw materials, and other trends in the industry impact the industry average performance. In another reasonable application, industrial averages are useful to compare with non-paper alternative products, assuming that the basis and methodology for the LCAs of the two products are comparable.
- The use of industrial averages of environmental impacts to promote a specific paper product relative to other similar paper products is not reasonable. As discussed, the same type of paper may have environmental burdens that vary greatly from the industry average, in a positive or negative direction. Simplified calculators using industry averages should not be used for product labeling. It is imperative when product labeling for promotion to base the claims on product specific LCA utilizing established methods (ISO 2006a, b).

Acknowledgements

The support of Sappi is appreciated. Helpful discussions with Dr. Caroline Gaudreault, Senior Scientist at NCASI, pertaining to FEFPro are appreciated. Data supplied by Eva Mannisto, Vice President EKONO Inc., PO Box 2005, Bellevue, WA 98009 is also appreciated.

Environmental impact estimates for the Paper Calculator discussion were made using the Environmental Paper Network Paper Calculator. For more information visit www.papercalculator.org.

References

Baumann, H. and Tillman, A. M. (2004) The Hitch Hikers Guide to LCA, Studentlitteratur, Lund, Sweden.

Dahlbo, H., Koskela, S., Laukka, J., Myllymaa, T., Jouttijarvi, T., Melanen, M. Thenhunen, J., (2005) Life Cycle Inventory Analyses for Five Waste Management Options for Discarded Newspaper, Waste Management Resources, 23: 291-303.

Environmental Paper Network (2011) Paper Calculator, Retrieved May 12, 2011. Available at http://www.papercalculator.org/.

EPA (2009). Municipal Solid Waste in the United States, 2009 Facts and Figures, EPA 530-R-10-012, December 2010.

FEFPro (2010) FEFPro V1.1 *User's Manual and Documentation. Copyrighted by* National Council for Air and Stream Improvement, Inc., Montreal, QC, 2010. This document is not publically accessible, access only for members/subscribers of American Forest and Paper Association. For the most comprehensive publically accessible please see the LCA Summary and Q&A Document on the webpage titled, Printing & Writing Papers Life Cycle Assessment, American Forest and Paper Association, http://www.afandpa.org/PWLCAMaterials/, accessed November 7, 2011.

Franklin Associates, A Division of ERG (2011) Documentation for the Paper Calculator, Retrieved May 16, 2011, Available at http://www.papercalculator.org/resources_and_tools.

Gilbreath, K. R. (1996) Life Cycle Assessment, Energy, and the Environment from a Pulp- and Papermill's Perspective, in Life Cycle Environmental Impact Analysis for Forest Products, Forest Products Society, Proceedings No. 7294, pp. 61-106.

Heinz (2006), The Heinz Center: Following the Paper Trail: The Impact of Magazine and Dimensional Lumber Grade Production on GHG Emissions: A Case Study, Copyrighted by The H. John Heinz III Center for Science, Economics and the Environment, Washington DC, 2006.

IPCC (1996), Intergovernmental panel on climate change (IPCC), Climate change 1995, the science of climate change. New York, Cambridge University Press.

IPCC (2007), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

ISO (2006a) Environmental management - Life cycle assessment - Principles and framework. ISO 14040. Geneva: International Organization for Standardization.

ISO (2006b) Environmental management - Life cycle assessment - Requirements and guidelines. ISO 14044. Geneva: International Organization for Standardization.

Larsen, H. F., Hauschild, M. and Hansen, M. S. (2006) Ecolabelling of printed matter-part II-life cycle assessment of model sheet fed offset printed matter, Working Report No. 24 2006, Danish Ministry of the Environment, Environmental Protection Agency.

Larsen, H. F., Hansen, M. S., and Hauschild, M. (2008) Life cycle assessment offset printed matter with EDIP97: how important are emissions of chemicals? Journal of Cleaner Production, 17, 115-128.

Mannisto, E. (2011) Private Communication. Data provided by EKONO Inc., PO Box 2005, Bellevue, WA 98009.

NCASI (2010) Life Cycle Assessment of North American Printing and Writing Paper Products. Unpublished Study. Copyrighted by the National Council for Air and Stream Improvement, Inc. Research Triangle Park, NC, 2010. This document is not publically accessible, access only for members/subscribers of American Forest and Paper Association. For the most comprehensive publically accessible please see the LCA Summary and Q&A Document on the webpage titled, Printing & Writing Papers Life Cycle Assessment, American Forest and Paper Association, http://www.afandpa.org/PWLCAMaterials/, accessed November 7, 2011.

Nicholson, A. L, Olivetti, E. A. Gregory, J. R., Field, F. R. and Kirchain, R. E. (2009) End-of-life LCA allocation methods: Open loop recycling impacts on robustness of material selection decisions. Sustainable Systems and Technology, 2009. ISSST '09. IEEE International Symposium on. 2009. 1-6.

Nicholson, A, Smith, K., Morin, R. (2010), Allocation of greenhouse gas emissions in open-loop recycling: case study. Unpublished report. ClearCarbon, Arlington VA, info@clearcarboninc.com.

Paper Task Force (1995) White Paper No. 10A Environmental comparison –manufacturing technologies for virgin and recycled-content printing and writing paper. Copyrighted by the Environmental Defense, 1995.

Paper Task Force (2002) White Paper No. 3 Lifecycle environmental comparison: virgin paper and recycled paper based systems. Originally published Dec. 19, 1995, updated February 2002. Copyrighted by the Environmental Defense, 1995 and 2002.

Pikhola, H., Nors, M., Kujanpaa, M., Helin, T. Kariniemi, M., Pajula, T., Dahlbo, H., Koskela, S. (2010) Carbon footprint and environmental impacts of print products from cradle to grave. Results from the LEADER project (part 1). Espoo 2010. VTT Tiedoltteita – Research Notes 2560.

Appendix A. Paper Calculator Data for Uncoated Freesheet Before and After the 2011 Revision

Paper Calculator Data for Uncoated Freesheet Before the 2008-2011 Updates (Data accessed from a pre-2008 version of the Paper Calculator). Basis of 1000 tons of paper.

	Uncoated free sheet	50% Post consumer	100% Post consumer
Wood Use	3,467 tons	1,733 tons	0 tons
		1,733 tons less	3,467 tons less
Total Energy	38,364 million BTU's	30,011 million BTU's	21,658 million BTU's
		8,353 million BTU's less	16,707 million BTU's less
Purchased Energy	18,206 million BTU's	19,932 million BTU's	21,658 million BTU's
		1,726 million BTU's more	3,452 million BTU's more
Sulfur dioxide (SO2)	26,088 pounds	25,823 pounds	25,557 pounds
		265 pounds less	530 pounds less
Greenhouse Gases	5,690,196 lbs CO_2 equiv.	4,636,154 lbs CO_2 equiv.	3,582,112 lbs CO_2 equiv.
		1,054,042 lbs CO_2 equiv. less	2,108,084 lbs CO_2 equiv. less
Nitrogen oxides (NOx)	18,417 pounds	16,415 pounds	14,414 pounds
		2,002 pounds less	4,003 pounds less
Particulates	12,433 pounds	9,889 pounds	7,345 pounds
		2,544 pounds less	5,088 pounds less
Hazardous Air Pollutants (HAP)	2,150 pounds	1,151 pounds	151 pounds
		1,000 pounds less	1,999 pounds less
Volatile Organic Compounds (VOCs)	5,559 pounds	3,693 pounds	1,826 pounds
		1,867 pounds less	3,733 pounds less
Total Reduced Sulfur (TRS)	340 pounds	170 pounds	0 pounds
		170 pounds less	340 pounds less
Wastewater	19,075,196 gallons	14,700,098 gallons	10,325,000 gallons
		4,375,098 gallons less	8,750,196 gallons less
Biochemical Oxygen Demand (BOD)	6,288 pounds	6,174 pounds	6,060 pounds
		114 pounds less	228 pounds less
Total Suspended Solids (TSS)	10,143 pounds	8,522 pounds	6,900 pounds
		1,622 pounds less	3,243 pounds less
Chemical Oxygen Demand (COD)	91,744 pounds	59,672 pounds	27,600 pounds
		32,072 pounds less	64,144 pounds less
Adsorbable organic halogens (AOX)	932 pounds	466 pounds	0 pounds
		466 pounds less	932 pounds less
Solid Waste	2,278,349 pounds	1,716,525 pounds	1,154,701 pounds
		561,824 pounds less	1,123,648 pounds less

979 Paper Calculator Data. Uncoated Freesheet After the 2008-2011 Updates. Basis of 1000 tons of paper.

	Uncoated Freesheet	**50% Post Consumer**	**100% Post Consumer**
Wood Use	3,733 tons	1,867 tons	0
		1866 tons less	3733 tons less
Net Energy	32,299 million BTU's	27,023 million BTU's	21,747 million BTU's
		5276 million BTU's less	10552 million BTU's less
Purchased Energy	22,173 million BTU's	21,722 million BTU's	21,270 million BTU's
		451 million BTU's less	903 million BTU's less
Sulfur dioxide (SO2)	26,682 pounds	25,605 pounds	24,529 pounds
		1077 pounds less	2153 pounds less
Greenhouse Gases	6,022,786 pounds CO_2 equiv.	4,709,157 pounds CO_2 equiv.	3,395,527 pounds CO_2 equiv.
		1,313,629 pounds CO_2 equiv. less	2,627,259 pounds CO_2 equiv. less
Nitrogen oxides (NOx)	9,514 pounds	8,958 pounds	8,401 pounds
		556 pounds less	1113 pounds less
Particulates	6,173 pounds	4,649 pounds	3,124 pounds
		1524 pounds less	3049 pounds less
Hazardous Air Pollutants (HAP)	2,789 pounds	1,821 pounds	853 pounds
		968 pounds less	1936 pounds less
Volatile Organic Compounds (VOCs)	3,011 pounds	2,222 pounds	1,434 pounds
		789 pounds less	1577 pounds less
Total Reduced Sulfur (TRS)	454 pounds	352 pounds	250 pounds
		102 pounds less	204 pounds less
Wastewater	22,218,868 gallons	16,295,285 gallons	10,371,702 gallons
		5,923,583 gallons less	11,847,166 gallons less
Biochemical Oxygen Demand (BOD)	9,915 pounds	8,298 pounds	6,681 pounds
		1617 pounds less	3234 pounds less
Total Suspended Solids (TSS)	17,335 pounds	13,747 pounds	10,160 pounds
		3588 pounds less	7175 pounds less
Chemical Oxygen Demand (COD)	19,798 pounds	24,195 pounds	28,591 pounds
		4397 pounds more	8793 pounds more
Solid Waste	1,921,806 pounds	1,546,314 pounds	1,170,821 pounds
		375,492 pounds less	750,985 pounds less

APPENDIX B. Calculations of recycling allocations using the Paper Task Force (2002) data for office paper. Closed loop recycling process is assumed with three as the number of uses.

Table 7. Net GHG of office paper from various life cycle stages from the Paper Task Force(2002, pg. 132), waste management is 80/20 landfill/incinerate.

	Raw Matl	Virgin Prod	Collect/transp	Recycle Process	Collect/transp	Recycle Process	Waste Mgmt
	V1	P1	R1	P2	R2	P3	W3
$CO2_e$ lb/ton product	300	3000	230	3350	230	3350	2500
$CO2_e$ ton/ton product	0.15	1.50	0.12	1.68	0.12	1.68	1.25

Cutoff Method. Promotes virgin production since burdens of waste management fall on last recycled product made.

Product 1=V1+P1=3300

Product 2=R1+P2=3580

Product 3=R2+P3+W3=6080

Avg Product 2+3=4830

Quality Loss Method (no quality loss) = Closed Loop Recycling. Therefore, virgin production is promoted since recycled manufacturing has higher Net GHG (emissions?). However, shared burdens make net GHG very close.

Product 1=1/3(V1+R1+R2+W3)+ P1=4090

Product 2=1/3(V1+R1+R2+W3)+ P2=4440

Product 3=1/3(V1+R1+R2+W3)+ P3=4440

Avg Product 2+3=4440

Quality Loss Method (quality loss: Q1=1, Q2=0.5, Q3=0.5). Therefore, recycled paper production is promoted due to higher attributed shared burdens to virgin since the value/quality of virgin is assumed to be higher.

Product 1=1/2(V1+R1+R2+W3)+ P1=4630

Product 2=1/4(V1+R1+R2+W3)+ P2=4160

Product 3=1/4(V1+R1+R2+W3)+ P3=4160

Avg Product 2+3=4160. Raw Material Acquisition Generates Waste Treatment. Therefore, recycled paper production is promoted, as recycling is a way to “delay” waste disposal.

Product 1=V1+P1+W3=5800

Product 2=R2+ P2=3580

Product 3=R3+ P3=3580

Avg Product 2+3=3580.

Material Lost as Waste Must be Replaced. Therefore, virgin paper production is promoted, as the raw material procurement and waste management burden is placed on the last product.

Product 1=P1+R1=3230

Product 2=P2+ R2=3580

Product 3=P3+ V1+W3=6150

Avg Product 2+3=4865.

50/50 Method: Raw Material Procurement and Waste management to 1st and Last Product and Recycling to upstream and downstream Product (50/50 splits). Therefore, recycled paper production is promoted, but there is not much difference as raw materials and waste management are spread over two recycled products.

Product 1=1/2(V1+W3) +1/2R1+P1=4515

Product 2=1/2R1+1/2R2+P2=3580

Product 3=1/2(V1+W3) +1/2R2+P3=4865

Avg Product 2+3=4220

Appendix C. FEFPro modeling of a North American Average Catalog Product: Supporting Information

In order to set up a calculator to evaluate allocation assumptions and for Sappi's use to evaluate paper products, FEFPro V1.3 was utilized. FEFPro is an Excel™-based tool to assist in the calculation of the carbon footprint for paper and paperboard products (FEFPro, 2010). As appearing in the user manual, *There is no single official definition for a carbon footprint but it can be seen as a picture of the overall greenhouse gas impact (not just* CO_2*) of a product over its lifecycle (cradle-to-grave). The accounting begins with emissions associated with extracting or growing raw materials and finishes with the emissions associated with reusing or disposing of the product.* Some carbon footprint analyses do not consider product disposal and use. These studies are referred to as "cradle–to-gate" and can be useful when analyzing different production processes for the same product or for business-to-business communications. Carbon footprints can be performed at different levels:

- Carbon footprint of a specific product often defined via a functional unit;
- Carbon footprint of a mill;
- Carbon footprint of a company; or
- Carbon footprint of a sector.

To evaluate FEFPro V1.1, data from the study published by NCASI (2010), *Life cycle assessment of North American printing and writing paper products* was inputted into FEFPro and the results compared to the results in the study. In doing so, several complications occurred. There were problems with FEFPro V1.1 in that some of the calculations in the program (allocations, final fate) were in need of updating, and were revised. It was then recognized that data from the original NCASI LCA study needed to be adjusted and a revised LCA study was provided. Dr. Caroline Gaudreault, Senior Scientist at NCASI was integral to these efforts.

The data from the NCASI LCA study was inputted into the updated FEFPro V1.3. The concept was to input the average North American data for catalog paper as reported in the NCASI LCA study and to compare with the FEFPro output to the NCASI LCA study, which were calculated in the SimaPro software program. Several significant issues had to be addressed in the development of the FEFPro V1.3 model:

- FEFPro requires co-product allocation to be performed outside of the program. A mass allocation was determined to allocate emissions to turpentine, tall oil fatty acid, and to the coated paper product. A percentage of 97.64% of the paper manufacturing emissions were allocated to the paper product
- FEFPro requires co-product allocation to be performed outside of the program. Sold electricity can be considered a co product of the paper manufacturing process. The emissions from all fuel sources was allocated to the sold electricity co-product by taking a ratio of the sold electricity energy to the total energy produced by fuels in the paper manufacturing process. The result allocated 99.2% of the fuel emissions to the paper product.
- FEFPro does not have emission factors for most printing chemicals/supplies. To incorporate the printing process emissions to the cradle to grave analysis Dr. Gaudreault provided SimaPro results of the printing process not present in the supplied NCASI LCA study (NCASI, 2010). Essentially, the emissions that are present with the printing chemicals/supplies were known to be 7% and the electricity use emissions were known to be 41.8% of the total emissions of

the converting process. This information was combined with the LCA study result of total emissions from 187 kg CO_2e/1 machine dry short ton of catalog paper at 5% consistency converted to electricity. The emissions from all printing chemicals/supplies were determined to be 72 kg CO_2e/1 machine dry short ton of catalog paper at 5% consistency (not adjusted for recycling allocations).

- The overall recovery rate, including both pre-consumer scrap from converting and post-consumer recovered material was calculated to be 38.8%. This number is based on a 9% loss of material during converting. All converting losses are recycled. A value of 32.7% recovery rate of catalogs, as reported in the NCASI LCA study was used.
- Printing/Converting Notes: The final manufacturing operation input cells in FEFPro were reserved for the printing/converting operations. Data in the fuel final manufacturing input section of the model reflect printing/converting. Other material input sections of FEFPro include a single lumped/estimated grouping for the printing/converting materials. Data in the electricity/steam final manufacturing input area reflect printing/converting.
- Electricity/steam. FEFPro did not have enough entry places in primary manufacturing in the electricity and steam sections of the model to accommodate the North American averages, so both the primary and secondary manufacturing categories were used for the pulp/paper manufacturing process to input electricity/steam inputs.

With these modifications, FEFPro was used to calculate the GHG emissions using both the cut off and the number of subsequent uses method. Example GHG results for the North American average for catalog production are shown in **Table 9,** as calculated with both the FEFPro program and the NCASI data (NCASI, 2010). The results from FEFPro modeling match those produced by NCASI (2010) using SimaPro software. The percent difference in results between the two methods indicates that the FEFPro model produces similar results for the given inputs. This suggests that the FEFPro model has the fidelity and robustness to capture the significant contributors to the GHG emissions in a paper product life cycle, as judged against the NCASI (2010) study.

The major FEFPro results for all of the cases (baseline, recovery rate and utilization rate experiments) used in this report are in **Table C-1.**

Please note, FEFPro is a cradle to grave tool, in some cases emission and storage data appear in the result. These are applicable to cradle to grave calculations but not to cradle to gate. FEFPro does not allow the user to remove some of the cradle to grave calculation results. Thus, this data must remain in the FEFPro spreadsheet and be corrected outside of the program. See the footnotes and calculation methods at the bottom of the attached data table for some of these corrections.

Table C-1. Summary of results of the coated freesheet (catalog) FEFPro model.

Fefpro Results: NA Avg Coated Freesheet	1/4/2012 16:23																			
		Recovery Rate Expts						Utilizaton Rate Expts				Recovery Rate Expts						Utilization Rate Expts		
Product	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free
Cradle to (Gate/Grave)	Gate	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Gate	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave
Allocation Method	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses
Recovery Rate (%)	39	0	10	20	39	60	80	39	39	39	39	0	10	20	39	60	80	39	39	39
Utilization Rate (%)	3	3	3	3	3	3	3	3	10	26	3	3	3	3	3	3	3	3	10	26
Amount of Recyled Fiber Used (kg dry)								19	65	172								19	65	172
Amount of Virgin Fiber Used (kg dry)								633	587	480								633	587	480
Amount of Virgin Market Pulp								73	27	0								73	27	0
Amount of Slurried Market Pulp								80	80	0										
% landfilled (81% not recycled)	50	81	73	65	49	32	16	49	50	50	50	81	73	65	49	32	16	49	50	50
% burned with E recovery (19% not recycled)	11	19	17	15	12	8	4	12	11	11	11	19	17	15	12	8	4	12	11	11
Total emissions, including transport (kg CO2 eq./BoC):	3035	4026	3867	3709	3407	3054	2736	3407	3519	3783	2760	4032	3843	3610	3100	2454	1829	3100	3271	3634
Of which, total transport (includes all transport components):	103.6	166.5	166.5	166.5	166.5	166.5	166.5	166.5	166.5	169	98.34	166.5	166	164.7	161.2	156.2	151	161.2	161.8	164.9
Emissions from fuel used in manufacturing (including transport)	857.6	989.7	989.7	989.7	989.7	989.7	989.7	989.7	989.7	989.7	727.1	989.7	975	939.2	839.2	698.1	550.1	839.2	864.8	903
Emissions from purchased electricity and steam	228	418.2	418.2	418.2	418.2	418.2	418.2	418.2	418.2	418.2	193.4	418.2	414.8	406.5	383.5	351	317	383.5	389.5	398.4
Emissions from wood and fiber production (including transport)	354.8	354.8	354.8	354.8	354.8	354.8	354.8	354.8	467	730.6	312.9	360.9	356.3	344.8	312.9	267.9	220.6	312.9	438.9	734.2
Emissions from other raw materials (including transport)	279.8	351.5	351.5	351.5	351.5	351.5	351.5	351.5	351.5	351.5	237.3	351.5	346.3	333.6	298.1	248	195.5	298.1	307.2	321
Emissions from manufacturing wastes	172.2	172.2	172.2	172.2	172.2	172.2	172.2	172.2	172.2	172.2	146	172.2	169.7	163.4	146	121.5	95.8	146	150.5	157.3
Emissions from product transport	0	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53	0	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53
Emissions from end of life (including transport)	1143	1677	1518	1360	1058	704.9	387.4	1058	1058	1058	1143	1677	1518	1360	1058	704.9	387.4	1058	1058	1058
Carbon Storage:																				
Total carbon storage changes (kg CO2 eq./BoC)	138.3	175.1	165.6	156.2	138.3	117.3	98.38	138.3	138.3	138.3	138.3	175.1	165.6	156.2	138.3	117.3	98.38	138.3	138.3	138.3
Changes in forest carbon (kg CO2 eq./BoC)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon in products in use (kg CO2 eq./BoC)	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4
Carbon in landfills from products at end of life (kg CO2 eq./BoC)	58.76	95.58	86.14	76.7	58.76	37.76	18.88	58.76	58.76	58.76	58.76	95.58	86.14	76.7	58.76	37.76	18.88	58.76	58.76	58.76
Carbon in mill landfills from manufacturing wastes (kg CO2 eq./BoC)	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1
Kg CO2/BOC (BOC = 862 dry kg or 1 short ton with 5% MC)	1850										1575									
(3) Kg CO2/catalog		0.663	0.637	0.611	0.562	0.505	0.454	0.562	0.582	0.627		0.664	0.633	0.594	0.510	0.402	0.298	0.510	0.539	0.601
(2) Kg CO2/bd short ton	1947										1658									
(1) NCASI Value	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	1469	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489
% Difference											13	36	29	22	4	-18	-39	4	10	23

Not reported: NR

Notes: For recycled fiber data, in the Fefpro program, recycled fiber emission factors don't change automatically between cut off or # uses scenarios. Must check this.

Notes: To conduct the RR experiments, the recovery rate, the percent landfilled and the % burned were changed.

Notes: to conduct the utilization rate (UR) experiments, the amount of deinked market pulp, virgin pulp purchased and slurried market pulp purchased was changed.

(1) Cradle to gate, NCASI Table 9-2 is 1469 kg CO2/bd short ton

(1) Cradle to grave, NCASI Table 9-1 is 0.489 kg CO2/catalog

(2) Kg CO2/bd short ton for cradle to gate is equal to Total emissions-Emissions from end of life (including transport)-Carbon stored in mill landfill

Note: some numbers appear above (to match Fefpro output) and are not used in the calculation since they are outside of the cradle to gate boundary (eg. Carbon in products in use)

(3) Kg CO2/catalog for cradle to grave is equal to (Total emissions-Total carbon storage changes in kg CO2/BOC)*(BOC/785 kg catalog)*(.135 kg/catalog)

For this calculation one catalog =.135 dry kg and the BOC makes 785 kg of dry catalogs.

Appendix D. The Effect of the use of the Cut-off and the Number of Subsequent Uses Methods for Recycling Allocation: Net GHG Emissions for Magazine Versus Recovery Rate and Utilization Rate

The impact on the net GHG emissions (Carbon Footprint) of using a cut-off or a number of subsequent uses recycling allocation method of a coated mechanically pulped paper product (magazine) is explored with respect to recovery and utilization rates. Comparisons are made with a related product, coated chemically pulped and bleached paper product (catalog). Catalog results correspond to those presented previously in this paper and are shown again for convenient comparison.

Methods

An Excel™-based tool to assist in the calculation of the carbon footprint for paper and paperboard products was utilized, FEFPro V1.3 (FEFPro, 2010). As stated in the user manual, *There is no single official definition for a carbon footprint but it can be seen as a picture of the overall greenhouse gas impact (not just CO_2) of a product over its lifecycle (cradle-to-grave). The accounting begins with emissions associated with extracting or growing raw materials and finishes with the emissions associated with reusing or disposing of the product.* Some carbon footprint analyses do not consider product disposal and use. These studies are referred to as "cradle–to-gate" and can be useful when analyzing different production processes for the same product or for business-to-business communications. Carbon footprints can be performed at different levels (FEFPro, 2010):

- Carbon footprint of a specific product often defined via a functional unit;
- Carbon footprint of a mill;
- Carbon footprint of a company; or
- Carbon footprint of a sector.

The FEFPro model was populated with data from the study published by NCASI (2010), *Life cycle assessment of North American printing and writing paper products*. Average North American data for magazine paper (coated mechanical sheets) was used. The average North American industry magazine product utilized 2% recycled fiber furnish (utilization rate) and had a 44% recovery rate. Two types of cradle-to-grave cases were explored herein

- Varied recovery rate with the utilization rate constant
- Varied utilization rate with recovery rate constant

Assumptions and estimations for the model follow:

- A magazine consisted of 0.176 OD kg of coated mechanical sheets and 0.009 OD kg of coated free sheet (cover). Since the objective of this study was to evaluate the carbon footprint of coated mechanical paper with regards to recycling, only the 0.176 OD kg of coated mechanical sheets were evaluated.
- It is assumed that 9% of the coated mechanical sheets are lost at the printing operation and that all of this material is recycled. The post-consumer recovery rate of magazine is 38.6% (NCASI, 2010, Table 4-5). This combined with the 100% recovery rate of the printer's waste resulted in an overall recovery rate of 44% for the magazine material.

- Of the magazine that is not recovered, 81% is landfilled and 19% is burned for energy recovery.
- Due to the structure of the industrial data collected in the NCASI 2010 survey, it was only possible to explore a limited range of utilization rates (<20%). Utilization rate experiments were performed by exchanging purchased bleached kraft hardwood pulp and purchased TMP pulp with market deinked pulp. At the 10% utilization rate, only a portion of purchased bleached kraft hardwood pulp was replaced by market deinked pulp. At the 17% utilization rate, all of the purchased bleached kraft hardwood pulp and purchased TMP pulp was replaced with the market deinked pulp
- The type of market deinked pulp that would be probably used to replace virgin in a coated mechanical sheet is deinked newsprint and the like. FEFPro does not have data for deinked newsprint. Thus, the emission factor for market deinked pulp originating from the typical process in which wastepaper that is mainly lignin free (chemically pulped and bleached) is deinked to produce high brightness, lignin free pulp suitable for incorporation into copy paper and the like, was used for deinked newsprint. This assumption was checked using data publically available (Paper Task Force, 2002, Table C-3). In this report, market deinked pulp for copy paper has a GHG emission of 3582 and for deinked newsprint of 3498 lb CO_2e /ton product. Since the difference between the two numbers is only 2% and the uncertainty of the emissions factor is expected to be larger than 2%, the use of the FEFPro emission factor for conventional market deinked pulp was deemed reasonable.

Results

The model was used to calculate the GHG emissions using both the cut off and the number of subsequent uses recycling allocation methods. The base case GHG results for the North American average for magazine production (coated mechanical sheets only) are shown in **Table D-1** as calculated with the FEFPro program. Also shown are the NCASI data (NCASI, 2010). The results from FEFPro modeling adequately match those produced by NCASI (2010) using SimaPro software. This suggests that the FEFPro model has the fidelity and robustness to capture the significant contributors to the GHG emissions in a paper product life cycle, as judged against the NCASI (2010) study.

The net GHG for the magazine system for cradle-to-gate and cradle-to-grave scenarios using the cut off method are greater than for the number of subsequent uses allocation methods, by 20% and 19%, respectively, **Table D-1**. These decreases are due to the fact that the number of subsequent uses allocation method exports more virgin burdens out of the system of study due to the product's high recovery rate (44%) than it imports into the system of study due to a low percentage of recycled fiber used in the product (2%). These types of results are case-specific and depend on the particular values of the recovery rate and utilization rate. The effect of the utilization and recovery rates on the GHG results with the two allocation methods are further explored later. For comparison, **Table D-2** presents the parallel data for catalog production (coated freesheet). It is observed that the carbon footprint is greater for catalog than for magazine for all results, including FEFPro results determined herein and NCASI (2010) results.

Table D-1. FEFPro Modeling Results of industry average for coated mechanical sheet (***magazine***) for two recycling allocation methods. The values of the net GHG emissions depend on the allocation method, utilization rate, and recovery rate. In this case the utilization rate is 2% and the recovery rate of the product is 44%. Numbers in parentheses are the % difference between the number of uses and cut off allocation methods. One magazine contains 0.176 OD kg of coated mechanical sheet.

Case	FEFPro	NCASI, SimaPro	% Difference
	kg CO_2e/bdst coated mechanical	kg CO_2e/bdst coated mechanical	
Cradle-to-Gate, # Uses	1379	1393 *	-1
Cradle-to-Gate, cut off	1655 (20% increase)	(not reported)	Not applicable.
	kg CO_2e/ catalog	kg CO_2e/ catalog	
Cradle-to-Grave, # Uses	0.36	0.43 **	-19
Cradle-to-Grave, cut off	0.43 (19% increase)	(not reported)	Not applicable.

* from Table 11-2, NCASI (2010) study. ** from Table 11-1, NCASI (2010) study, adjusted such that the covers of the magazine are not considered (93% of the published value of 0.46 for a magazine with 0.176 kg coated mechanical and 0.0093 kg coated free sheets).

Table D-2. FEFPro Modeling Results of industry average for ***catalog*** (coated free sheet) for two recycling allocation methods. The values of the net GHG emissions depend on the allocation method, utilization rate, and recovery rate. In this case the utilization rate is 2% and the recovery rate of the product is 38.8%. Numbers in parentheses are the % difference between number of uses and cut off allocation methods. One catalog is 0.135 OD kg.

Case	FEFPro	NCASI, SimaPro	% Difference
	kg CO_2e/bdst catalog	kg CO_2e/bdst catalog	
Cradle-to-Gate, # Uses	1658	1469 *	13
Cradle-to-Gate, cut off	1947 (17% increase)	(not reported)	Not applicable.
	kg CO_2e/ catalog	kg CO_2e/ catalog	
Cradle-to-Grave, # Uses	0.51	0.49 **	4
Cradle-to-Grave, cut off	0.56 (10% increase)	(not reported)	Not applicable.

* from Table 9-2, NCASI (2010) study. ** from Table 9-1, NCASI (2010) study.

An inspection of **Table D-3 and Table D-4** reveal the major factors that in these models cause the carbon footprint of coated mechanical sheets to be smaller than coated freesheet. The results are plotted for the cradle-to-grave system with cut-off allocation method in **Figure D-1** and for the cradle-to-gate system with cut off allocation method in **Figure D-2**. Some important points (cradle-to-grave) are summarized in the following:

- The mechanical pulping process has a significantly higher yield (circa 90%) than does the chemical pulping process and bleaching (circa 50%) so that wood and fiber requirements are lower.
- The mechanical pulping process uses more (about twice) electricity since this drives the mechanical pulping. However, it is known that mechanical pulping facilities coincide with areas with large percentage of renewable electricity so this is not as significant as it might be. The NCASI results are a North American average over existing mills and thus reflect the high portion of renewable electricity used.
- Emissions from fuel are higher for the free sheet than the mechanical sheet, about 35% higher because of the increased dependence on steam and utilities for chemical pulping and bleaching.
- Mechanical sheets are assumed to decompose significantly less in landfills due to the increased lignin content. This makes emissions from end of life about 4 times smaller for mechanical sheets than free sheets. Thus, the carbon storage in landfills is much higher for the mechanical containing sheets. Emissions from manufacturing wastes are also lower for similar reason.
- Transport in total is only 3% of the total carbon footprint and is not considered to be a reasonable operating parameter to effectively reduce the carbon footprint.

Similar to the cradle to grave analysis, the coated mechanical sheets have a smaller carbon footprint than the coated freesheet, **Figure D-2.** However, there is less difference between cradle to gate results than cradle to grave results for coated mechanical sheets and coated freesheet, simply due to the exclusion of the emissions from end-of-life in the cradle to gate system boundary**.**

Table D-3. Summary of results of the coated mechanical sheets (magazine) FEFPro model.

Fefpro Results: NA Avg Coated Mechanical		1/4/2012 17:12																		
		Recovery Rate Expts						Utilizaton Rate Expts				Recovery Rate Expts						Utilization Rate Expts		
Product	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech	Ctd Mech
Cradle to (Gate/Grave)	Gate	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Gate	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave
Allocation Method	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses
Recovery Rate (%)	44	0	10	20	44	60	80	44	44	44	44	0	10	20	44	60	80	44	44	44
Utilization Rate (%)	2	2	2	2	2	2	2	2	10	17	2	2	2	2	2	2	2	2	10	17
Amount of Recyled Fiber Used (kg dry)								17	84	142								17	84	142
Amount of Virgin Fiber Used (kg dry)								825	758	700								825	758	700
Amount of ONP used (kg dry)								17	17	17								17	17	17
Amound of Purch Bl Kraft HW used (kg dry)								109	42	0								109	42	0
Amount of Purch TMP (kg dry)								16	16	0								16	16	0
Amount of Purch DI Mkt Pulp (kg dry)								0	67	125								0	67	125
% landfilled (81% not recycled)	46	81	73	65	46	32	16	46	46	46	46	81	73	65	46	32	16	46	46	46
% burned with E recovery (19% not recycled)	10	19	17	15	10	8	4	10	10	10	10	19	17	15	10	8	4	10	10	10
Total emissions, including transport (kg CO2 eq./BoC):	1842	2484	2457	2429	2362	2316	2261	2362	2526	2657	1580	2493	2440	2351	2054	1821	1511	2054	2303	2510
Of which, total transport (includes all transport components):	98.71	161.7	161.7	161.7	161.7	161.7	161.7	161.7	161.7	161.7	93.03	161.7	161.3	160.2	156	152.6	147.9	156	156.6	157.2
Emissions from fuel used in manufacturing (including transport)	572.1	730.1	730.1	730.1	730.1	730.1	730.1	730.1	730.1	730.1	458.7	730.1	718.5	690.3	585.3	500.2	383.6	585.3	619.3	648.5
Emissions from purchased electricity and steam	547.3	774.9	774.9	774.9	774.9	774.9	774.9	774.9	774.9	774.9	489	774.9	770.2	758.9	716.6	682.3	635.2	716.6	730.4	742.4
Emissions from wood and fiber production (including transport)	242.2	242.2	242.2	242.2	242.2	242.2	242.2	242.2	405.7	536.7	201.6	250.7	246.8	237.2	201.6	172.8	133.2	201.6	387.5	540
Emissions from other raw materials (including transport)	222.8	294.5	294.5	294.5	294.5	294.5	294.5	294.5	294.5	294.5	178.7	294.5	289.9	278.5	236.1	201.8	154.8	236.1	250	262
Emissions from manufacturing wastes	31.43	31.43	31.43	31.43	31.43	31.43	31.43	31.43	31.43	31.43	25.2	31.43	30.93	29.72	25.2	21.54	16.52	25.2	26.68	27.96
Emissions from product transport	0	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53	0	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53
Emissions from end of life (including transport)	226.4	348.5	321	293.5	226.4	180	125	226.4	226.4	226.4	226.4	348.5	321	293.5	226.4	180	125	226.4	226.4	226.4
Carbon Storage:																				
Total carbon storage changes (kg CO2 eq./BoC)	466.4	766.8	699.1	631.4	466.4	352.2	216.8	466.4	466.4	466.4	466.4	766.8	699.1	631.4	466.4	352.2	216.8	466.4	466.4	466.4
Changes in forest carbon (kg CO2 eq./BoC)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon in products in use (kg CO2 eq./BoC)	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87	37.87
Carbon in landfills from products at end of life (kg CO2 eq./BoC)	385	685.4	617.7	550	385	270.8	135.4	385	385	385	385	685.4	617.7	550	385	270.8	135.4	385	385	385
Carbon in mill landfills from manufacturing wastes (kg CO2 eq./BoC)	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54
Kg CO2/BOC (BOC = 862 dry kg or 1 short ton with 5% MC)	1572										1310									
(3) Kg CO2/mag		0.385	0.394	0.403	0.425	0.441	0.459	0.425	0.462	0.491		0.387	0.391	0.386	0.356	0.329	0.290	0.356	0.412	0.458
(2) Kg CO2/bd short ton	1655										1379									
(1) NCASI Value	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	1393	0.427	0.427	0.427	0.427	0.427	0.427	0.427	0.427	0.427
% Difference											-1	-9	-9	-10	-17	-23	-32	-17	-4	7

Not reported: NR.

Notes: must use cut off file or # uses file since default recycling ef don't change automatically.

Notes: RR experiments, must change RR, %LF, %burned

Notes: UR experiments, must change purch DI mkt pulp, purchased TMP, purchased bl Kr Hw

(1) Cradle to gate, NCASI Table 11-2 is 1393 kg CO2/bd short ton

(1) Cradle to grave, NCASI Table 11-1 is 0.459 kg CO2/magazine, adjusted so covers of magazine not considered (93% for a magazine with 0.176 kg coated mechanical and 0.0093 kg coated free sheets).

(2) Kg CO2/bd short ton for cradle to gate is equal to Total emissions-Emissions from end of life (including transport)-Carbon stored in mill landfill

Note: some numbers appear above (to match Fefpro output) and are not used in the calculation since they are outside of the cradle to gate boundary (eg. Carbon in products in use)

(3) Kg CO2/catalog for cradle to grave is equal to (Total emissions-Total carbon storage changes in kg CO2/BOC)*(BOC/785 kg catalog)*(.176 kg/catalog)

For this calculation one catalog =.176 dry kg and the BOC makes 785 kg of dry catalogs (91% yield at printer, pg 62 NCASI study), ignore cover of magazine .009 dry kg ctd free sheet.

Table D-4. Summary of results of the coated freesheet (catalog) FEFPro model.

Fefpro Results: NA Avg Coated Freesheet — 1/4/2012 16:23

		Recovery Rate Expts						Utilizaton Rate Expts				Recovery Rate Expts						Utilization Rate Expts		
Product	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free	Ctd Free
Cradle to (Gate/Grave)	Gate	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Gate	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave	Grave
Allocation Method	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	Cut Off	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses	# Uses
Recovery Rate (%)	39	0	10	20	39	60	80	39	39	39	39	0	10	20	39	60	80	39	39	39
Utilization Rate (%)	3	3	3	3	3	3	3	3	10	26	3	3	3	3	3	3	3	3	10	26
Amount of Recyled Fiber Used (kg dry)								19	65	172								19	65	172
Amount of Virgin Fiber Used (kg dry)								633	587	480								633	587	480
Amount of Virgin Market Pulp								73	27	0								73	27	0
Amount of Slurried Market Pulp								80	80	0										
% landfilled (81% not recycled)	50	81	73	65	49	32	16	49	50	50	50	81	73	65	49	32	16	49	50	50
% burned with E recovery (19% not recycled)	11	19	17	15	12	8	4	12	11	11	11	19	17	15	12	8	4	12	11	11
Total emissions, including transport (kg CO2 eq./BoC):	3035	4026	3867	3709	3407	3054	2736	3407	3519	3783	2760	4032	3843	3610	3100	2454	1829	3100	3271	3634
Of which, total transport (includes all transport components):	103.6	166.5	166.5	166.5	166.5	166.5	166.5	166.5	166.5	169	98.34	166.5	166	164.7	161.2	156.2	151	161.2	161.8	164.9
Emissions from fuel used in manufacturing (including transport)	857.6	989.7	989.7	989.7	989.7	989.7	989.7	989.7	989.7	989.7	727.1	989.7	975	939.2	839.2	698.1	550.1	839.2	864.8	903
Emissions from purchased electricity and steam	228	418.2	418.2	418.2	418.2	418.2	418.2	418.2	418.2	418.2	193.4	418.2	414.8	406.5	383.5	351	317	383.5	389.5	398.4
Emissions from wood and fiber production (including transport)	354.8	354.8	354.8	354.8	354.8	354.8	354.8	354.8	467	730.6	312.9	360.9	356.3	344.8	312.9	267.9	220.6	312.9	438.9	734.2
Emissions from other raw materials (including transport)	279.8	351.5	351.5	351.5	351.5	351.5	351.5	351.5	351.5	351.5	237.3	351.5	346.3	333.6	298.1	248	195.5	298.1	307.2	321
Emissions from manufacturing wastes	172.2	172.2	172.2	172.2	172.2	172.2	172.2	172.2	172.2	172.2	146	172.2	169.7	163.4	146	121.5	95.8	146	150.5	157.3
Emissions from product transport	0	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53	0	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53	62.53
Emissions from end of life (including transport)	1143	1677	1518	1360	1058	704.9	387.4	1058	1058	1058	1143	1677	1518	1360	1058	704.9	387.4	1058	1058	1058
Carbon Storage:																				
Total carbon storage changes (kg CO2 eq./BoC)	138.3	175.1	165.6	156.2	138.3	117.3	98.38	138.3	138.3	138.3	138.3	175.1	165.6	156.2	138.3	117.3	98.38	138.3	138.3	138.3
Changes in forest carbon (kg CO2 eq./BoC)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon in products in use (kg CO2 eq./BoC)	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4
Carbon in landfills from products at end of life (kg CO2 eq./BoC)	58.76	95.58	86.14	76.7	58.76	37.76	18.88	58.76	58.76	58.76	58.76	95.58	86.14	76.7	58.76	37.76	18.88	58.76	58.76	58.76
Carbon in mill landfills from manufacturing wastes (kg CO2 eq./BoC)	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1
Kg CO2/BOC (BOC = 862 dry kg or 1 short ton with 5% MC)	1850										1575									
(3) Kg CO2/catalog		0.663	0.637	0.611	0.562	0.505	0.454	0.562	0.582	0.627		0.664	0.633	0.594	0.510	0.402	0.298	0.510	0.539	0.601
(2) Kg CO2/bd short ton	1947										1658									
(1) NCASI Value	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	1469	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489
% Difference											13	36	29	22	4	-18	-39	4	10	23

Not reported: NR

Notes: For recycled fiber data, in the Fefpro program, recycled fiber emission factors don't change automatically between cut off or # uses scenarios. Must check this.

Notes: To conduct the RR experiments, the recovery rate, the percent landfilled and the % burned were changed.

Notes: to conduct the utilization rate (UR) experiments, the amount of deinked market pulp, virgin pulp purchased and slurried market pulp purchased was changed.

(1) Cradle to gate, NCASI Table 9-2 is 1469 kg CO2/bd short ton

(1) Cradle to grave, NCASI Table 9-1 is 0.489 kg CO2/catalog

(2) Kg CO2/bd short ton for cradle to gate is equal to Total emissions-Emissions from end of life (including transport)-Carbon stored in mill landfill

Note: some numbers appear above (to match Fefpro output) and are not used in the calculation since they are outside of the cradle to gate boundary (eg. Carbon in products in use)

(3) Kg CO2/catalog for cradle to grave is equal to (Total emissions-Total carbon storage changes in kg CO2/BOC)*(BOC/785 kg catalog)*(.135 kg/catalog)

For this calculation one catalog =.135 dry kg and the BOC makes 785 kg of dry catalogs.

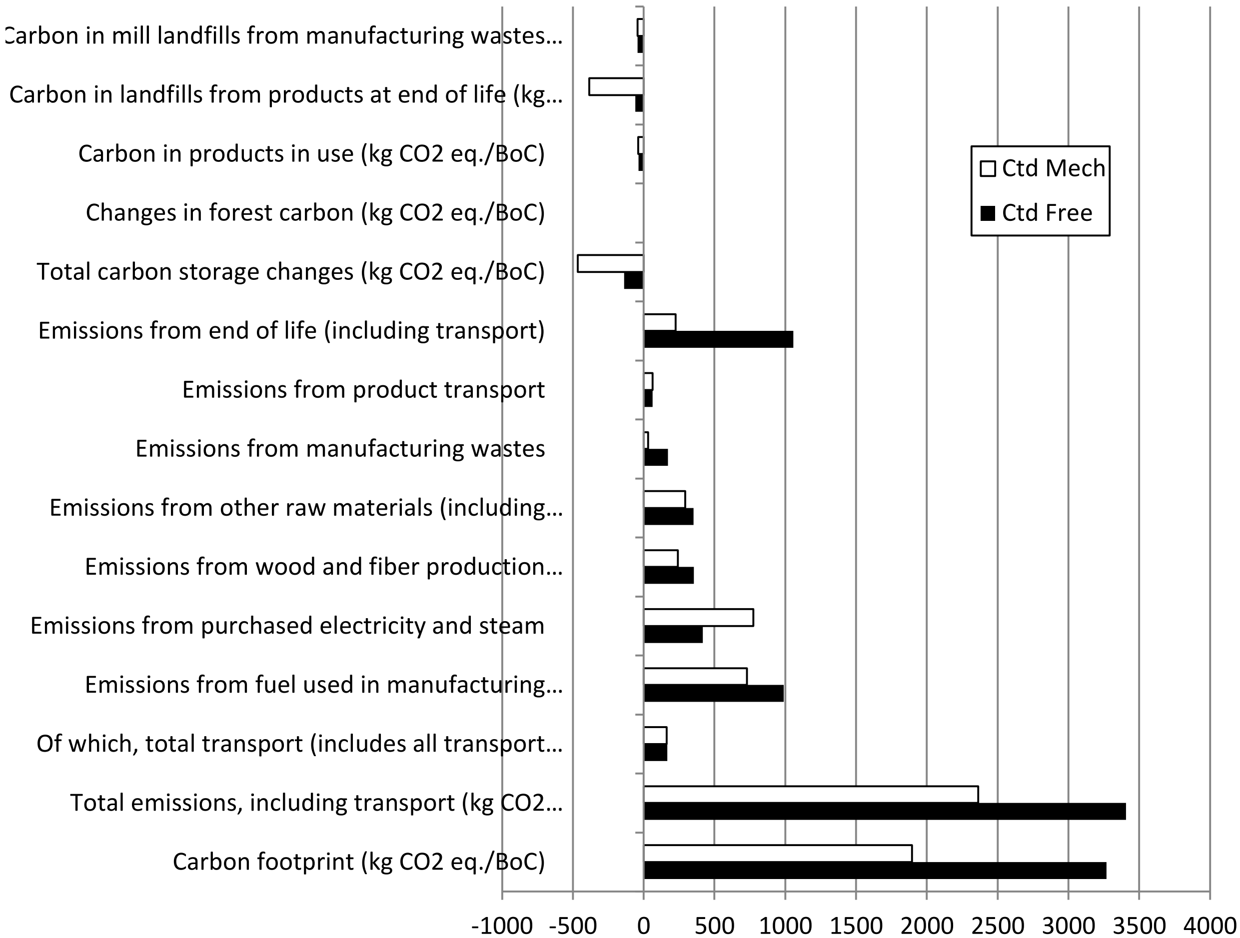

Figure D-1. Life cycle stages contribution to the carbon footprint for the cradle-to-grave system with cut-off allocation method. Basis of calculation (BoC) was one short ton with 5% MC. Units are kg CO2 eq./BoC. Carbon footprint is the sum of all emissions minus the sum of all carbon storage.

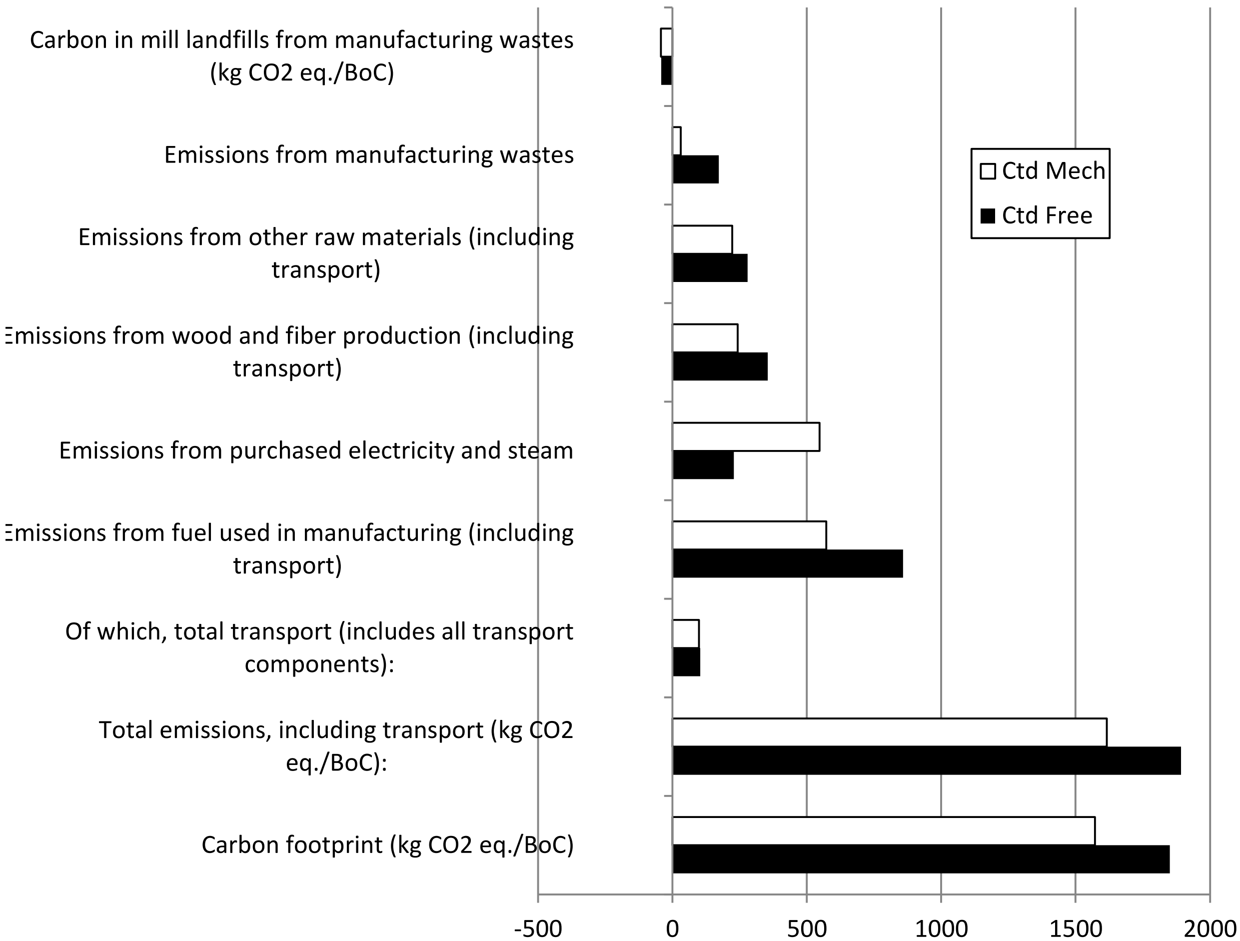

Figure D-2. Life cycle stages contribution to the carbon footprint for the cradle-to-gate system with cut-off allocation method. Basis of calculation (BoC) was one short ton with 5% MC. Units are kg CO_2 eq./BoC. Carbon footprint is the sum of all emissions minus the sum of all carbon storage.

Effect of the Recovery Rate on net GHG emissions

For the base case, 44% of the catalogs were recovered (the utilization rate was 2%). This considers both pre- and post-consumer recovery; 81% is landfilled and 19% is incinerated for energy of the unrecovered magazines. The net GHG emissions per magazine (only the uncoated mechanical sheets) are calculated versus recovery rate using the cut-off and the number of uses recycling allocation method, **Figure D-2.** With a recovery rate of zero the two allocation methods result in a similar value, as expected. For the cut-off allocation method, the GHG emissions per magazine increase approximately linearly. This is because the carbon storage of landfilled mechanical pulped papers is large. Increases in recovery rate decrease the carbon storage in landfills. For the number of uses method, the GHG emissions per magazine is constant from 0 to 20% recovery rate and then decreases at higher recovery rates. Two competing factors are at play, (1) increased recovery rate decreases carbon storage in landfills, and (2) increased recovery rate causes more of the environmental burdens from the virgin fiber production to be exported out of the system with the number of uses allocation method. Below 20% recovery rate effects (1) and (2) balance one another. Above a 20% recovery rate, effect (2) dominates over effect (1) and a decrease in GHG emissions is produced.

In contrast, for coated freesheet, **Figure D-3**, decay in landfills is more prominent than for mechanical pulps and effect (1) is not present. Thus, for both allocation methods a decline in GHG emissions is predicted for increased recovery rates. The decline is more dramatic for the number of uses method.

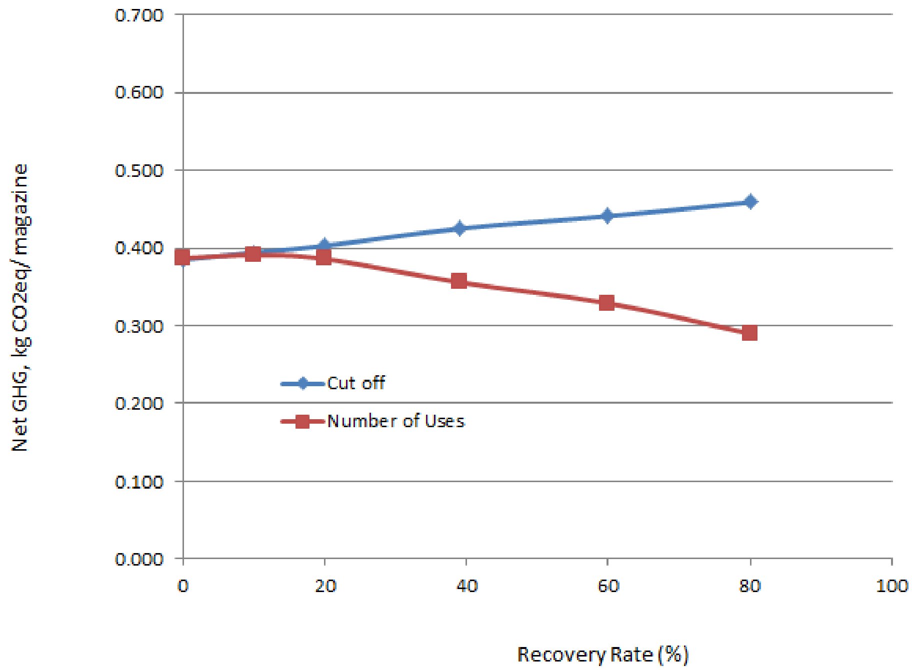

Figure D-2. The net GHG emissions per ***magazine*** versus recovery rate using the cut-off and the number of uses recycling allocation method for cradle-to-grave.

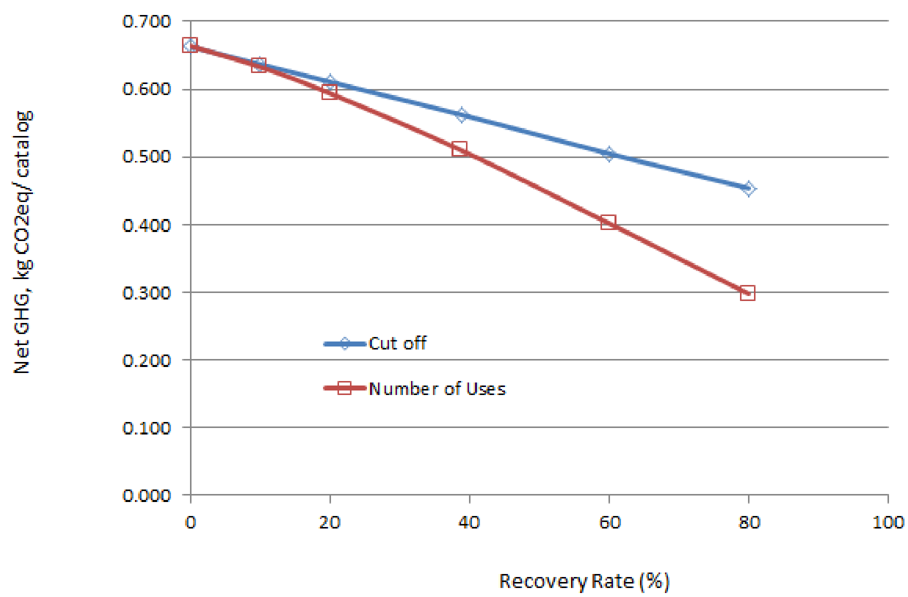

Figure D-3. The net GHG emissions per ***catalog*** versus recovery rate using the cut-off and the number of uses recycling allocation method for cradle-to-grave.

Effect of the Utilization Rate on net GHG emissions

It is also of interest to understand how the recycling allocation method impacts the emissions as a function of the utilization rate of recycled paper in the product of interest. For the base case, the utilization rate was 2% and the recovery rate of the magazines was 44%. It is not straightforward in FEFPro to simply change the utilization rate when using a model based on the North American industry average data. For instance, when the utilization rate is increased, then all mill operations must be adjusted. These include virgin fiber sources, fuels used in manufacturing, pulping and bleaching chemicals used, electricity and purchased steam, manufacturing wastes, lime kiln CO_2 capture and other variables. FEFPro is not able to make these changes automatically. The user must have some mill knowledge to predict these changes, which is not an easy task. To explore the effect of different utilization rates using FEFPro and the North American industry average data, purchased virgin pulps were substituted by purchased deinked pulp in the model, see **Table D-3**. By simply switching one purchased pulp by another, then all of the information about the average mill operations would still be valid and would not need to be adjusted.

The net GHG emissions per magazine (cradle to grave) have been calculated versus utilization rate at the constant recovery rate of 44% using the cut-off and the number of uses recycling allocation method, **Figure D-4**. Note that for both allocation methods the GHG emissions increase approximately linearly with increased utilization rate (this is mentioned with caution, only 3 points were used). This is because the emission factor for recycled deinked pulp (3.43 kg CO2e/OD kg pulp) is greater than both purchased bleached kraft hardwood pulp (1.00 kg CO2e/OD kg pulp) and purchased TMP pulp (1.65 kg CO2e/OD kg pulp). The linear increases are similar to those for catalog, uncoated freesheet, **Figure D-5**, for the same reasons. Both magazine and catalog have lower GHG emissions using the number of uses allocation method relative to the cut-off method, due to the export of environmental burdens from the virgin product to subsequent uses.

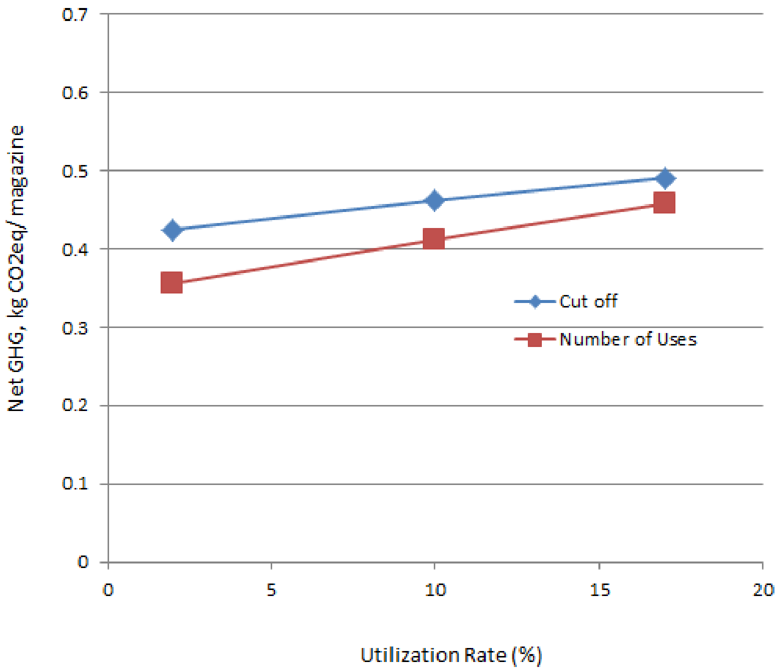

Figure D-4. The net GHG emissions per ***magazine*** (coated mechanical) versus utilization rate using the cut-off and the number of uses recycling allocation method (recovery rate equal to 44%) for cradle to grave.

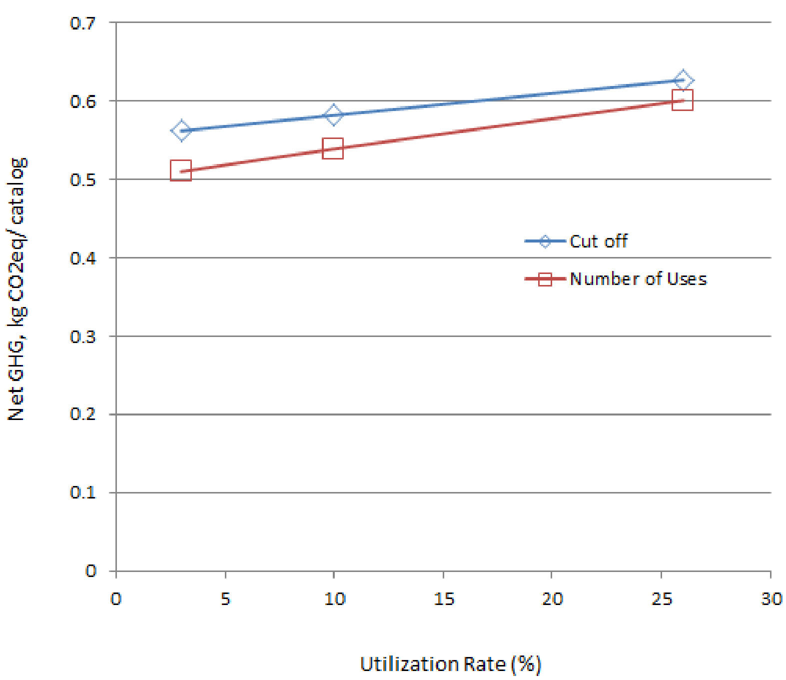

Figure D-5. The net GHG emissions per ***catalog*** (coated freesheet) versus utilization rate using the cut-off and the number of uses recycling allocation method (recovery rate equal to 39%) for cradle to grave.

Conclusions

- The carbon footprint of coated mechanical sheets is less than for coated free sheets. This is due mainly to lower emissions from decay in landfills. Also, different pulping yields, different total energy requirements, and different levels of use of renewable electricity affect the carbon footprint differences.
- Transportation contributions to the carbon footprint are not significant.
- The number of uses method is an appropriate model for the life cycle assessment of paper products, which is most reasonably modeled as an open loop recycling process. This method of allocation reasonably allows a sharing of environmental burdens with respect to virgin and recycled life stages of the fibers. This method rewards the production of virgin materials that are made to be recyclable. However, the allocation method is very complex and more difficult to communicate than the cut-off method. Only sophisticated LCA practitioners are able to utilize and discuss with understanding the number of uses method, reducing the utility of the method.
- For the paper products studied herein, the number of uses method results in a carbon footprint of about 10-20% lower than the cut off method for the same product. The ease of use and ability to communicate the cut-off method are two of its strengths. More research needs to be performed to understand if the decrease between the two methods is significant or if it is within the uncertainty of the calculations.
- Increased recovery rate increases the carbon footprint for coated mechanical sheet since increased recycling reduces carbon storage in landfill. This is not the case for the number of uses allocation method for coated mechanical sheet in which the export of burdens from the system causes the carbon footprint at higher recovery rates to decrease despite the effect of reduced carbon storage in the landfill.
- Increased utilization rate causes an increase in carbon footprint due to the emission factor for deinked pulp being greater than those from virgin chemical pulped and bleached fiber and virgin mechanically pulped fiber.