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12 **WHITE PAPER:**

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14 **Effect of Methodology on the Life Cycle Analysis of Paper Products**

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26 **Executive Summary:**

27 Paper products are integral to the quality of life currently enjoyed in North America. These products
28 have significant environmental benefits but also have environmental impacts. Life cycle analysis (LCA) is
29 a method in which the potential impact of a product on the environment is evaluated from its cradle
30 (raw material procurement) to grave (end-of-life). Standard methods of performing LCAs exist (ISO
31 14040, 14044); however, within those methods, many choices about the methodologies are made by
32 the practitioner, which tend to be subjective and influenced by personal value judgments.

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

36 Three LCA's of paper were reviewed: a Paper Task Force study (2002), a Heinz study (2006) and a NCASI
37 study (2010). The Paper Task Force study analyzed the LCA of printing and packaging paper materials
38 with two separate systems: (1) virgin paper with disposal and (2) production of recycled paper with
39 recycling, and has recently been revised to better reflect the actual flows of paper through recycling and
40 waste management. The Heinz study performed a partial LCA on *Time* and *InStyle* magazines focusing
41 only on the Carbon Footprint, with a significant amount of primary data but without any environmental
42 burdens inherent in upstream production of input materials like bleaching chemicals or printing inks. It
43 used a "cut off" allocation method for recycling. The NCASI study was a LCA on catalog product (among
44 other printing and writing grades) that included upstream processing of materials as well as a complex
45 open loop recycling allocation method. The Heinz study reported 1.1 ton CO₂e per ton of product
46 whereas the NCASI study reported 3.5 ton CO₂e per ton of product. Several differences in the two
47 studies were identified that could contribute to this.

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

55 Recommendations are the following:

- 56
- 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
57 materials, the choice of available allocation methods can determine whether virgin or recycled
58 material is promoted; uncertainty and sensitivity analyses and external review are important in
59 establishing the reasonableness of the chosen allocation method.
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- 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).

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83

84 **Introduction**

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

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

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

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

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

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

129

130 **Paper Task Force White Paper No. 3 Lifecycle environmental comparison: virgin paper and recycled**
131 **paper based systems. Originally published Dec. 19, 1995 (Paper Task Force, 1995), updated February**
132 **2002 (Paper Task Force, 2002)**

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

137 The main objective of this study was to compare the environmental burdens of recycling versus virgin
138 production and waste management (i.e., landfilling and incineration). This study involved the basic
139 descriptions of activities and environmental impacts of four types of paper: newsprint, corrugated
140 containers, office paper, and paperboard. The only coated grade evaluated was coated unbleached
141 kraft. Environmental indicators considered were solid waste output, energy use, release of air
142 emissions, and waterborne wastes and water use/wastewater quantity. The study included end of life
143 aspects of landfilling, incineration and recycling, but does not include printing operations. Of the
144 material to be disposed, 80 percent was assumed landfilled and the rest incinerated. Net greenhouse
145 gases (GHG) are reported as lbs of CO₂e /ton of product. Net GHG does not include any CO₂ from
146 burning biomass.

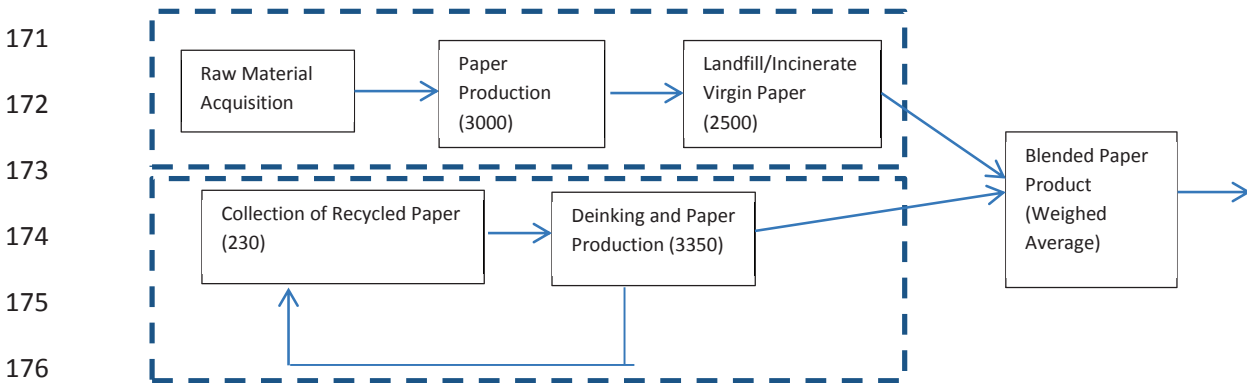
147 **Data.** National industry averages were used (some data from the 1980s but other data from circa 1993-
148 1994). The study states that the life cycle inventory data frequently do not represent actual measured
149 releases but rather regulatory limits, estimates, or surrogate values.

150 **Emission Factors.** Net GHG are reported, which includes fossil fuel usage and methane from the
151 landfills. It is not documented which data are actually from primary sources. Emissions of landfill
152 methane use an estimated emission of 123 lbs of methane per ton of MSW landfilled. Methane is
153 considered to have 21 times the global warming potential of CO₂ (lb/lb) (IPPC, 1996).

154 **System Boundaries.** This study treats the virgin and recycled paper making systems as completely
155 separate, **shown in Figure 1a, which defines the boundaries of the different cases.** Virgin fiber is
156 considered to be produced, used once and disposed. Three disposal scenarios are reported: landfilling,

157 incineration, and waste management, using the assumed disposal splits. Transportation is included in
 158 both cases. The analysis cannot be identified as a cradle to gate or cradle to grave, as the stages of a
 159 paper product life cycle are synthetically separated into two systems. The temporal boundary is
 160 undefined but includes the air emissions from landfilling over the entire lifetime of the landfill. Paper
 161 products that have a blend of virgin and recycled content simply are assigned a weighted average of the
 162 burdens of the virgin and recycled fibers used in the product (a mass weighted average). The blended
 163 product is not described in the White Paper No. 3 but is a feature of the PaperCalculator based on the
 164 findings. Note that fillers and coating materials have no associated environmental burdens; non-fibrous
 165 material simply reduces the total amount of fiber in the product and thus reduce the environmental
 166 impact that the reduced fiber amount introduces per ton of product.

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



177 **Figure 1a.** Modeled Activities for the Paper Task Force White Paper No. 3. The paper industry is
 178 separated into two systems, a virgin paper system and a recycled paper loop. Numbers in parentheses
 179 indicate the net GHG emissions in lbs of CO₂e/ton of product for the office paper operations. A
 180 virgin/recycled paper product has the weighted average GHG of the inputs.

181 It is observed from **Table 1** that the study promotes the use of recycled fibers for office paper, coated
 182 UB Kraft Board and newsprint, with respect to net GHG emissions. This is in part due to the allocation
 183 assumption that all environmental burdens of raw material acquisitions and waste management are
 184 taxed to the virgin paper products. The recycled products are not charged any of these burdens. This
 185 results in 2.9 tons of CO₂e per ton of product for virgin office paper plus waste management versus 1.8
 186 tons of CO₂e per ton of product for recycled office paper. It is clear that this study also promotes
 187 incineration over landfilling; for example, 1.3 and 3.4 CO₂e per ton of product are reported for office
 188 paper incineration and landfilling, respectively.

189 The results indicate also that incineration of the paper has more benefit than landfilling with regards to
 190 net GHG emissions. This is in agreement with a study that indicated virgin kraft paper production,
 191 followed by incinerating the paper with energy recovery, significantly decreased CO₂ emissions relative

192 to several cases, including virgin paper or recycled paper without incineration and energy recovery
 193 (Gilbreath, 1996). Another study analyzing the waste management of newspapers indicated that energy
 194 recovery was superior to landfilling (Dahlbo et al, 2005).

195 **Table 1** Virgin and recycled systems considered and net GHG in lbs of CO₂e /ton of product
 196 (ton CO₂e /ton product) for Office Paper, Coated Unbleached Board and Newsprint (Paper Task Force,
 197 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)

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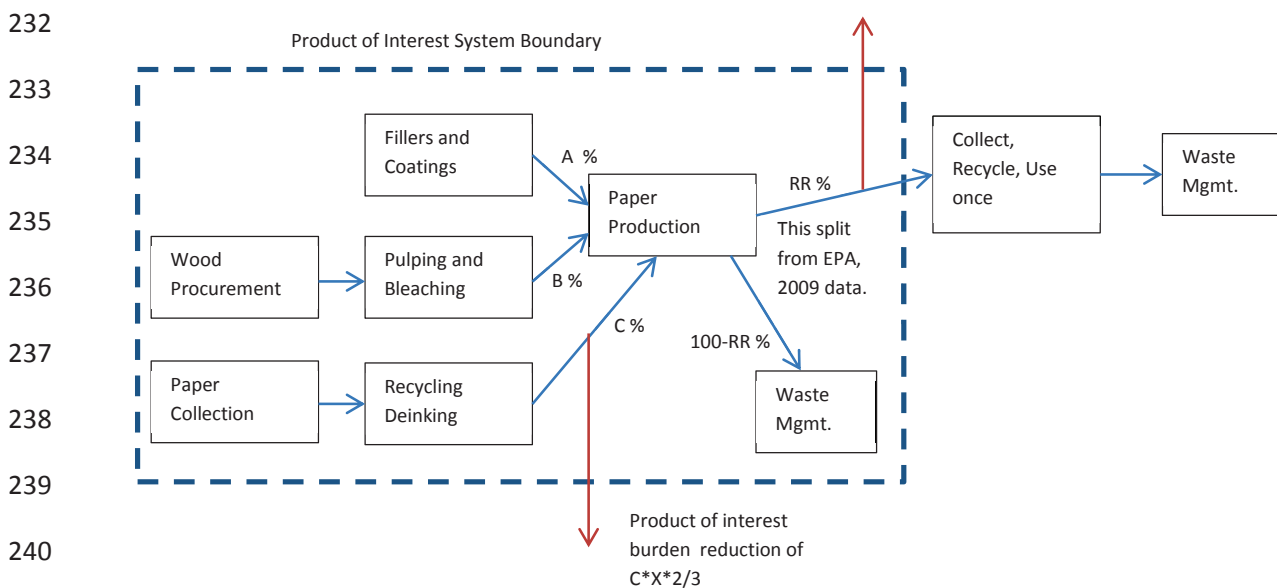
199 The following is reported in the study: *This paper addresses only environmental parameters relevant to*
 200 ***a comparison of paper recycling and waste management options..... This paper does not contain***
 201 *purchasing recommendations* (Paper Task Force, 2002, pg. 132). The main question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

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

216 **Environmental Paper Network (2011) Paper Calculator.**

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

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



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

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

248 model treats all products made from uncoated freesheet as being recycled at the rate of its largest
249 consuming category, office paper.

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

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

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

264 Data for copy paper (uncoated free sheet) before the revisions in 2008-2011 and after the revisions
265 instituted are shown in **Appendix A**. It can be observed in the data before the revision that in 15 of the
266 16 categories recycled fibers outperform virgin fibers, with the only exception being purchased
267 electricity. Data were updated in 2011 to include energy use for harvesting and transport of trees, and
268 reflect annual recycling rates from EPA data. This explains the increase in purchased energy for virgin
269 papers in the 2011 updated Calculator. In the revised data, recycled fibers outperform virgin fibers in all
270 but the chemical oxygen demand category. The main conclusions of the Paper Calculator are relatively
271 unchanged due to the revision for uncoated free sheet.

272

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

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

283 **Table 2.** Activities in the net GHG Life Cycle tracked in the Heinz Center Study for the *InStyle* and *Time*
 284 magazines (ton CO₂e/ton product listed)

Forest Management and Harvesting	Transport	Paper Manufacturing	Transport to Printers and Printing and to Distribution Centers	Final Fate: Landfill Recycle Incinerate	<i>InStyle</i> (1.11)
Purchased Power					<i>Time</i> (1.17)

285
 286 For *Time* the net CO₂e was 1.17 ton/ton product and for *InStyle* was 1.11 ton/ton product. The
 287 breakdown for the individual processes is shown in **Table 3** (Approximations taken from bar chart,
 288 Figure 11 in Heinz Study). Mill emissions seem to be the stage where there is a significant difference
 289 between the two magazines. The two major mills which supplied paper to the two magazines had
 290 products with different net GHG emissions, Biron mill with 0.9 t CO₂e/ton paper and Whiting Mill at 0.68
 291 t CO₂e/ton paper. This suggests that *InStyle* received a larger percentage of its paper from the Biron Mill
 292 than did *Time*, which may have received all of its paper from the Whiting Mill. The study indicates that
 293 the ratio of mechanical pulp to chemical pulp was 38:62 for the Biron Mill and 42:58 for the Whiting
 294 Mill, However, no concrete compositional information about the individual magazines is provided,
 295 perhaps a trade secret. The difference in final fate emissions between the two magazines is due to
 296 *InStyle* having a higher recovery rate (35%) than *Time* (22%).

297 **Table 3.** Heinz study net GHG for various stages in the life cycle (CO₂e kg/kg product)

	Management and Harvest	Transp. To Mill	Mill Emissions	Transp. To Printer	Printer Emissions	Transp. To Customer	Final Fate
<i>InStyle</i>	0.02	0.04	0.85	0.01	0.03	0.08	.13
<i>Time</i>	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

298

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

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

318 **Emission Factors.** Carbon dioxide, methane and N₂O were considered with 1, 21 and 310 times the
319 GWP correction factors, respectively (IPPC, 1996). Emission factors were determined for specific states
320 in which the electricity was generated. Printers provided estimates of net GHG emissions based on
321 annual electricity and natural gas use. Pulp and paper mills provided estimates of net GHG emissions.
322 Neither details on the source of emissions reported by the printers or pulp and paper mills nor details on
323 the fuel emissions for transportation were provided. In summary, the study is not presented with
324 available documentation with respect to definitions of emission factors, material flows or product
325 compositions, perhaps to conceal trade secrets.

326 **Recycling Allocation Assumptions.** No recycled content was used in the manufacture of the magazines.
327 The split of landfilling, recycling and incineration was defined for each magazine. For both magazines a
328 17% recovery of sold subscription and 95% recovery of unsold newsstand magazines were estimated.
329 For both of types of unrecovered magazines, 90% were assumed to be landfilled and 10% were
330 assumed to be incinerated (based on PTF study from 1995, in contrast to the revised PTF study in 2002
331 with 80%/20% split). It was assumed that recovered magazine was used once for newsprint with a
332 lifespan of one year. Recycling activities were not defined, but it was suggested that the burden of
333 transportation of the recovered magazine to the recyclers was included within the system boundary.

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

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

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

350

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

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

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

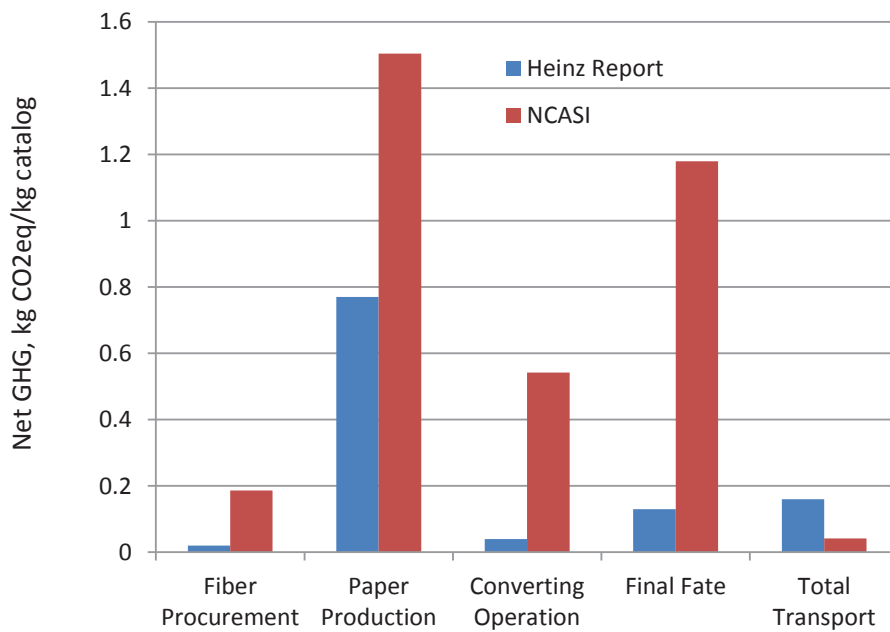
Fiber Procurement	Transp	Paper Production	Transp	Catalog Production	Transp	Use	Transp	End of Life: Recycling, burning, landfill, storage
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365 Co-product allocation methods were used. A sensitivity analysis on the allocation weighting methods
 366 was performed. The software SimaPro and the TRACI impact assessment method were used primarily.
 367 Impact indicator results for global warming, acidification, respiratory effects, eutrophication,
 368 stratospheric ozone depletion, smog and fossil fuel depletion were also tracked. The net ton of CO₂e per
 369 ton of product from cradle to grave was determined to be 1.88 for copy paper (uncoated free sheet),

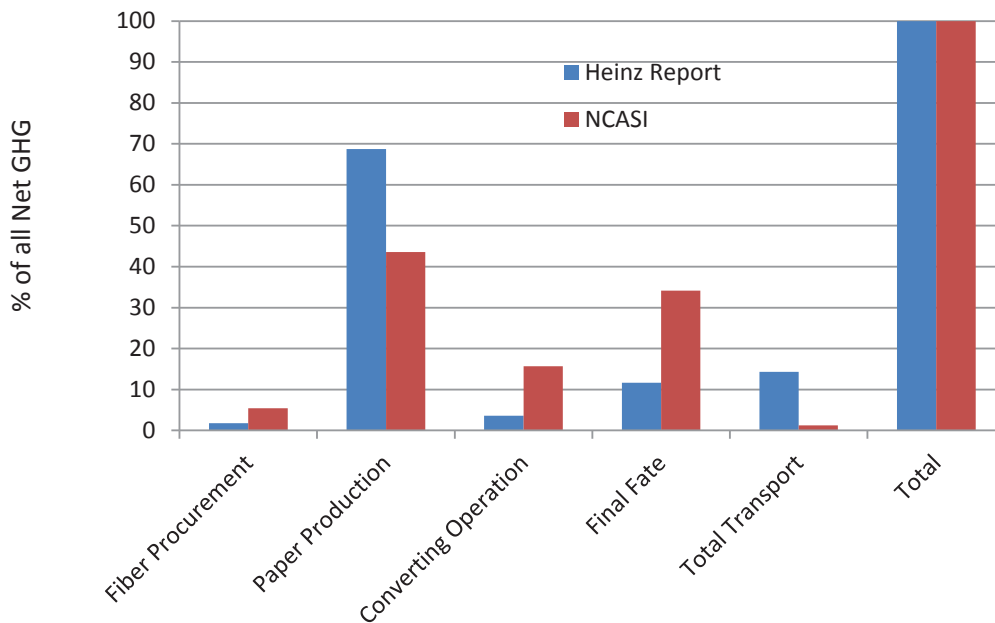
370 3.45 for catalog (coated freesheet), 1.77 for telephone directory (uncoated mechanical sheet) and 2.36
371 for magazines (coated mechanical sheet).

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



377

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



380

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

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

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

394 **Emission Factors.** The main source for emission factors came from the IPCC 2007 report (also see NCASI
 395 2010,pg 30). Carbon dioxide, methane and N₂O were considered with 1, 25 and 298 times the GWP
 396 correction factors, respectively. Other emission factors were taken from the US LCI database
 397 preferentially, and from the EcoInvent database with a modification for the North American electricity
 398 grid.

399 **Recycling Allocation Assumptions.** The number of subsequent uses allocation approach for open loop
 400 recycling was used to partition the shared environmental burdens between the different uses of the
 401 fibers upon virgin and recycled stages. In the NCASI study the number of uses of various paper grades

402 was estimated to be 2.19 for office paper, 1.85 for mixed paper, 2.52 for newsprint, 2.70 for corrugated
403 container, 1.76 for magazines, 1.43 for telephone directory and 1.64 for catalogs. A number of uses of
404 2.19 indicates that for a ton of virgin pulp produced, another 1.19 tons of recovered paper will be
405 produced from it. Note that these data are valid for the year 2006 and will change as the levels of
406 paper recycling change.

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

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

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

418

419

420 **Summary of the Three Studies**

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

427 **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	<i>Time</i> and <i>InStyle</i> 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 <i>Time</i> and <i>InStyle</i> 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

428

429 Both the Paper Task Force/EPN and NCASI studies considered coated freesheet and uncoated
430 mechanical papers. The original PTF study does not compare directly to the NCASI study, as the original
431 PTF study separately analyzed fully recycled or virgin systems. However, comparing uncoated freesheet
432 results for the NCASI study on a cradle to grave basis yields a net GHG emissions value of 1.88 (ton of
433 CO₂e per ton of product), which is between the 1.79 for the recycling loop and the 2.29 for the virgin
434 paper route in the original PTF study. The NCASI study reported a value of 1.77 for uncoated mechanical
435 papers, in between the results for the original PTF study of 1.7 for the recycled loop and 4.7 for the
436 virgin route (tons of CO₂e per ton of product). Due to the significant differences in methodology, the
437 agreement between the studies should not be considered to determine equivalence in the studies, and
438 may be due to chance.

439 The Heinz study considered both mechanically pulped (40%) and chemically pulped and bleached (60%)
440 fibers within a product, with 1.11 and 1.17 tons of CO₂e per ton of product for *InStyle* and *Time*
441 magazine, respectively. In contrast, the NCASI study resulted in significantly higher values of 3.45 and
442 2.36 for the uncoated freesheet and coated mechanical sheet, respectively. The distribution of the
443 relative contributions of the life cycle stages to the overall emissions are also different for the two
444 studies (**Figure 3**). These differences between the two studies are most likely due to differences in data
445 (emission sources, times, mill specific versus continent averaged data), differences in what data was
446 included, different assumptions, different boundary conditions, and different product compositions.
447 Some of the suspected significant differences are discussed below.

448 An example of the differences in assumptions regards black liquor use, a renewable biofuel produced in
449 the wood chemical pulping process. The Heinz study considers black liquor to be carbon neutral whereas
450 the NCASI study considers it as contributing to the GHG emissions through N₂O or CH₄ generation, about
451 6 kg CO₂e per ton of catalog product (only 0.5% of total cradle to gate emissions). In a similar fashion, it
452 is assumed that other biomass fuel sources such as hog fuel are not included in the Heinz study but are
453 considered in the NCASI study (about 1% of total cradle to gate emissions). Without a life cycle
454 inventory clearly documented in the Heinz study, it is not possible to confirm these exclusions .

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

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

464 Another difference between the Heinz and NCASI studies involves the Heinz study reporting CO₂ from
465 landfills as a net GHG emission whereas the NCASI study only includes methane from landfills as

466 contributing to net GHG emissions. The studies also differ in the amount and type of GHG emissions
 467 per unit product landfilled.

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

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

Study:	Followed ISO 14040 methods	3 rd 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.

474

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

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

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- 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.

497

498 Allocation Methods Analysis

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

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

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

511 With respect to allocation of sold electricity or steam as coproducts, it can be assumed that the sold
512 energy coproduct should bear the emissions burden of an equal amount of energy needed to produce it.
513 As an example of an industry average in the NCASI study, sold electricity and steam are equal to about
514 0.1 GJ per machine dry short ton of coated freesheet. Total energy expenditures (renewable and non-
515 renewable) are equal to about 25.1 GJ per machine dry short ton of coated freesheet. Thus, of the
516 emissions that the mill generates from energy sources, only 0.8% are attributed using mass allocations
517 to producing the sold electricity or steam and 99.2% are due to the paper, turpentine and tall oil.
518 Further, when considering all emissions, not just from energy sources, the significance of sold electricity
519 or steam is reduced even more. In this case, the correction due to the allocation factor is below the
520 level of expected uncertainty in the results (and may be chosen to be ignored for this case). However,
521 mill specific data may require consideration of this allocation factor for co-products.

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

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

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

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

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

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

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

564

565 **Table 7.** Net GHG of office paper from various life cycle stages from the Paper Task Force (2002, p. 132),
 566 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 ₂ e lb/ton product	300	3000	230	3350	230	3350	2500
CO ₂ e ton/ton product	0.15	1.50	0.12	1.68	0.12	1.68	1.25

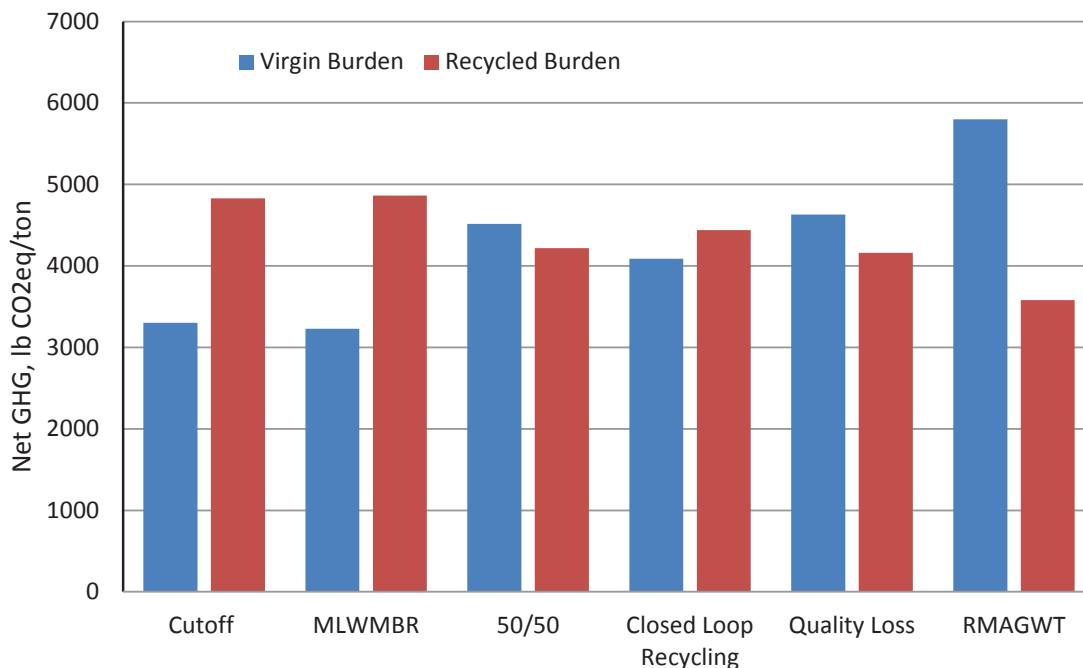
567

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

571 **Table 8.** Allocation methods for recycling: based on data for copy paper from the Paper Task Force
 572 (2002) lb CO₂e/ton of product. Calculations as defined by Baumann and Tillman (2004) for closed loop
 573 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 1 st 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

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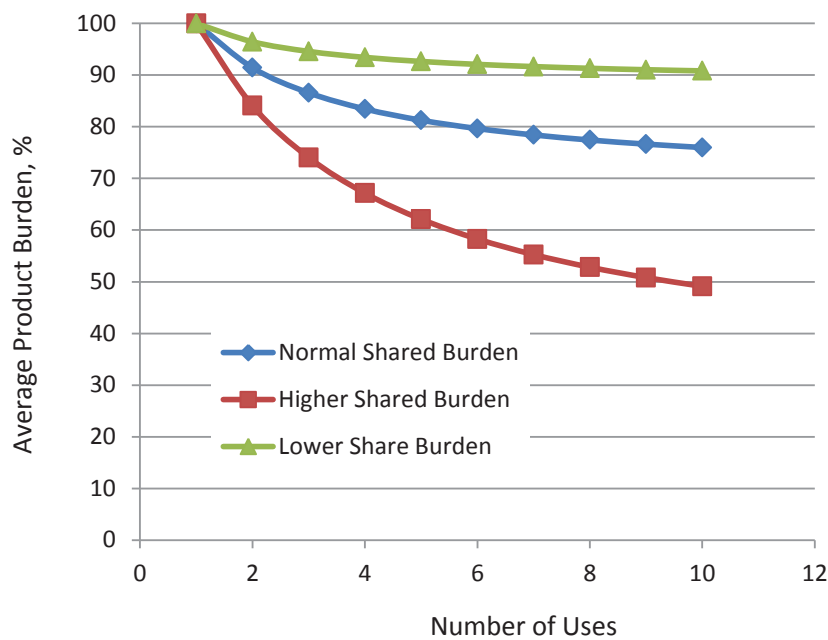


575
 576 **Figure 4.** The net GHG emissions attributed to virgin and recycled paper products based on the
 577 allocation method used (see **Table 8** for nomenclature and **Appendix B** for allocation methods and
 578 calculations).

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

588 It is very clear that if a product has significant environmental burdens in raw material acquisition or end-
 589 of-life scenarios (termed *shared burdens*), and the recycling manufacturing step has an environmental
 590 burden similar to or less than the primary manufacturing step, an increased recycling rate (or number
 591 of uses) makes the overall system more efficient. For instance, taking the environmental burdens as
 592 listed in **Table 7** for office paper but varying the number of times recycled results in a decreased average
 593 environmental burden per use as shown in **Figure 5** for the actual shared burden. Again, this discussion
 594 assumes that the system is a closed recycling loop. The most significant benefit from recycling is
 595 realized by the first recycle; thereafter each recycle step has a decreasing amount of benefit. It is
 596 instructive to compare the actual case (**Table 7**) to a case in which the shared burden is twice
 597 (designated as higher) or half (designated as lower) the actual shared burden. The higher the shared

598 burden, the more benefit is realized by recycling and the significant benefit of recycling persists for a
 599 greater number of uses. With zero shared burden, there is little benefit claimed for recycling. This
 600 simplified analysis demonstrates that there is significant potential environmental benefit to recycle
 601 paper products multiple times under the conditions and assumptions used for net GHG emissions (**Table**
 602 **7**).



603
 604 **Figure 5.** Average product environmental burden (net GHG) as a percent of the product burden for the
 605 case with no recycling versus number of uses (data from **Table 7**). The normal shared burden is equal to
 606 2800 lb CO₂e/ton product, the higher shared burden is set at twice that value and the lower shared
 607 burden is set as half that value. The simplified system is modeled as a closed loop.

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

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

629

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

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

636 **Methods**

637 An Excel™-based tool to assist in the calculation of the carbon footprint for paper and paperboard
638 products was utilized, FEFPro V1.3 (FEFPro, 2010). As stated in the user manual, *There is no single*
639 *official definition for a carbon footprint but it can be seen as a picture of the overall greenhouse gas*
640 *impact (not just CO₂) of a product over its lifecycle (cradle-to-grave). The accounting begins with*
641 *emissions associated with extracting or growing raw materials and finishes with the emissions*
642 *associated with reusing or disposing of the product. Some carbon footprint analyses do not consider*
643 *product disposal and use. These studies are referred to as “cradle-to-gate” and can be useful when*
644 *analyzing different production processes for the same product or for business-to-business*
645 *communications. Carbon footprints can be performed at different levels (FEFPro, 2010):*

- 646 • Carbon footprint of a specific product often defined via a functional unit;
- 647 • Carbon footprint of a mill;
- 648 • Carbon footprint of a company; or
- 649 • Carbon footprint of a sector.

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

- 655 • Varied recovery rate with the utilization rate constant
- 656 • Varied utilization rate with recovery rate constant

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

658 **Results**

659 The model was used to calculate the GHG emissions using both the cut off and the number of
660 subsequent uses recycling allocation methods. The base case GHG results for the North American
661 average for catalog production are shown in **Table 9** as calculated with the FEFPro program. Also shown
662 are the NCASI data (NCASI, 2010). The results from FEFPro modeling adequately match those produced
663 by NCASI (2010) using SimaPro software. This suggests that the FEFPro model has the fidelity and

664 robustness to capture the significant contributors to the GHG emissions in a paper product life cycle, as
 665 judged against the NCASI (2010) study.

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

Case	FEFPro	NCASI, SimaPro	% Difference
	kg CO ₂ e/bdst catalog	kg CO ₂ e/bdst catalog	
Cradle-to-Gate, # Uses	1658	1469 *	13
Cradle-to-Gate, cut off	1947 (17% increase)	(not reported)	Not applicable.
	kg CO ₂ e/ catalog	kg CO ₂ e/ catalog	
Cradle-to-Grave, # Uses	0.51	0.49 **	4
Cradle-to-Grave, cut off	0.56 (10% increase)	(not reported)	Not applicable.

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

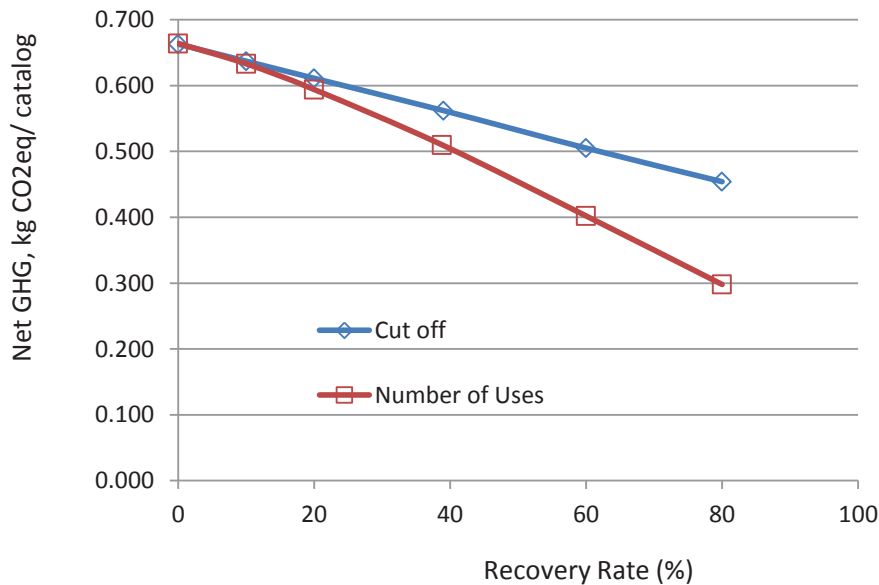
672 The net GHG for the studied system for cradle-to-gate and cradle-to-grave scenarios using the cut off
 673 method are greater than for the number of subsequent uses allocation methods, by 17% and 10%,
 674 respectively, **Table 9**. These decreases are due to the fact that the number of subsequent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

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

681 ***Effect of the Recovery Rate on net GHG emissions***

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

692 recovery rate increases, more of the environmental burdens from the virgin fiber production are
693 exported out of the system to the subsequent uses (in addition to the reduction of landfilling and
694 incineration).

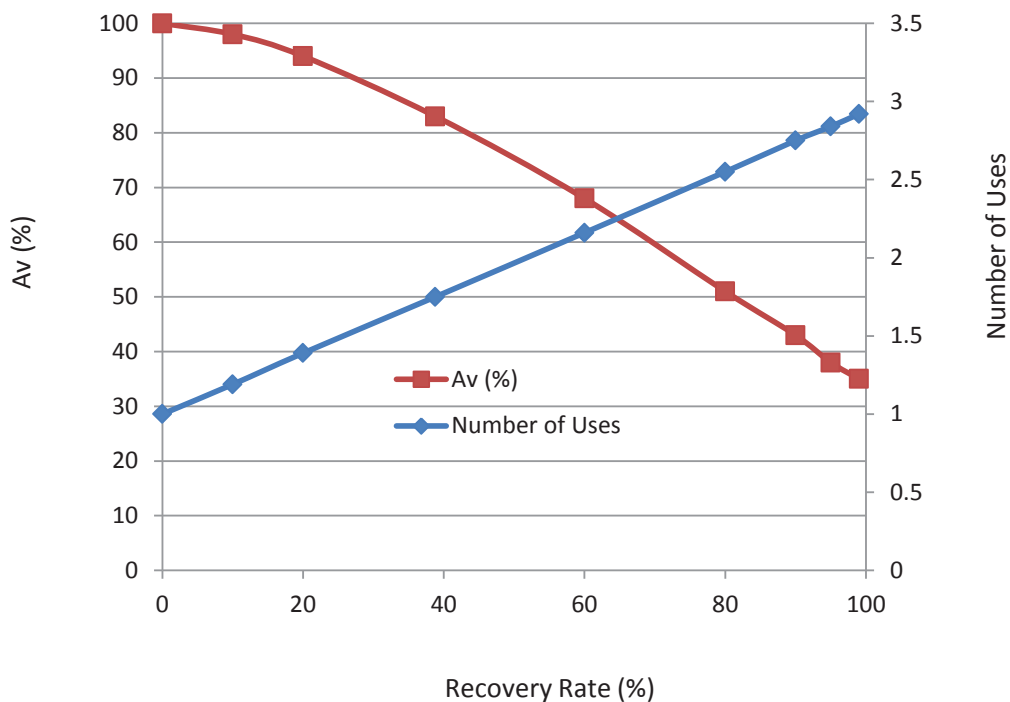


695
696 **Figure 6.** The net GHG emissions per catalog versus recovery rate using the cut-off and the number of
697 uses recycling allocation method for cradle-to-grave.

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

701 These trends are in agreement with a recent study conducted in Finland on a magazine product (Pikhola,
702 et. al., 2010). The product was made entirely from virgin materials and an 85% recovery rate for the
703 magazine was assumed. The cradle-to-grave carbon footprint was calculated to be 1.6 kg CO₂e/OD kg
704 catalog with a cut-off method and 1.0 kg CO₂e/OD kg catalog with a number of uses allocation method,
705 a percent difference of 60%, of the same order as the percent difference shown in **Figure 6**. In that
706 study, the number of uses allocation method was considered to be more relevant than the cut off
707 method, since the production of a recyclable product has environmental benefit in other, sometimes not
708 fully known, uses.

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



713

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

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

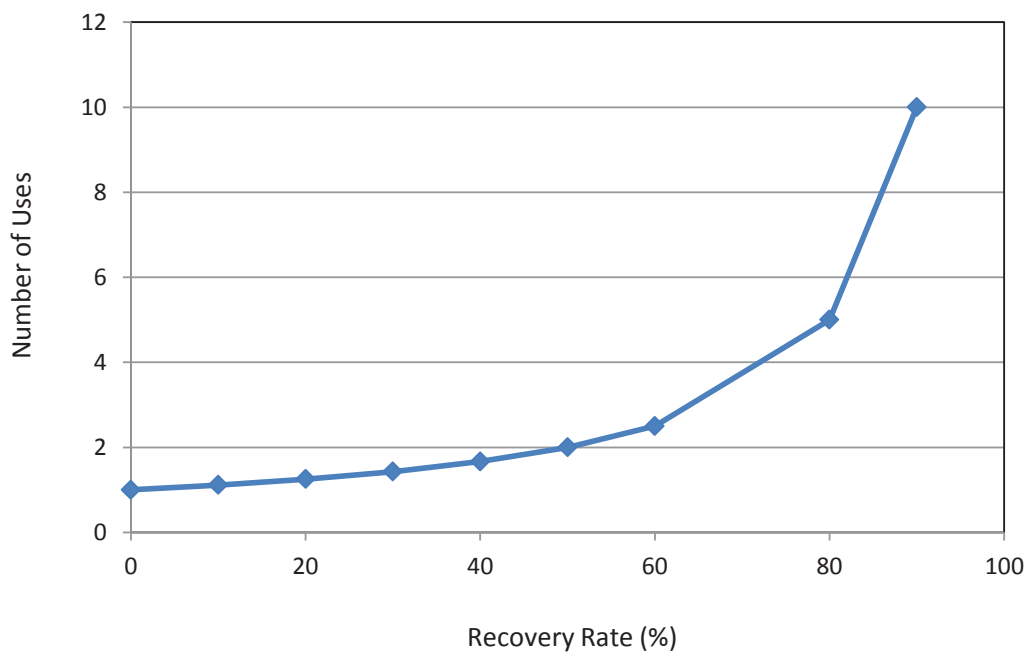
722 It is instructive to consider an ideal case of closed loop recycling and the effect of the recovery rate on
 723 the number of uses. It is known that if the paper was in a closed loop recycling system (with no yield
 724 losses on recycling) that the number of uses would equal $N=100/(100-RR\%)$,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

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

730 The downside to the open loop recycling assumption (versus the cut-off method) is that it is difficult to
 731 determine (1) all of the flows between a specific product of interest and the percentage of uses in all of

732 the various recycled products and (2) yield information concerning the recycling of all the recycled
733 products. This data needs to be updated as trends in recycling change in the industry. Communicating
734 the math/methodology to those not experts in LCA methods is also difficult.

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



741
742 **Figure 8.** The theoretical number of uses versus recovery rate for a strictly closed recycling system.

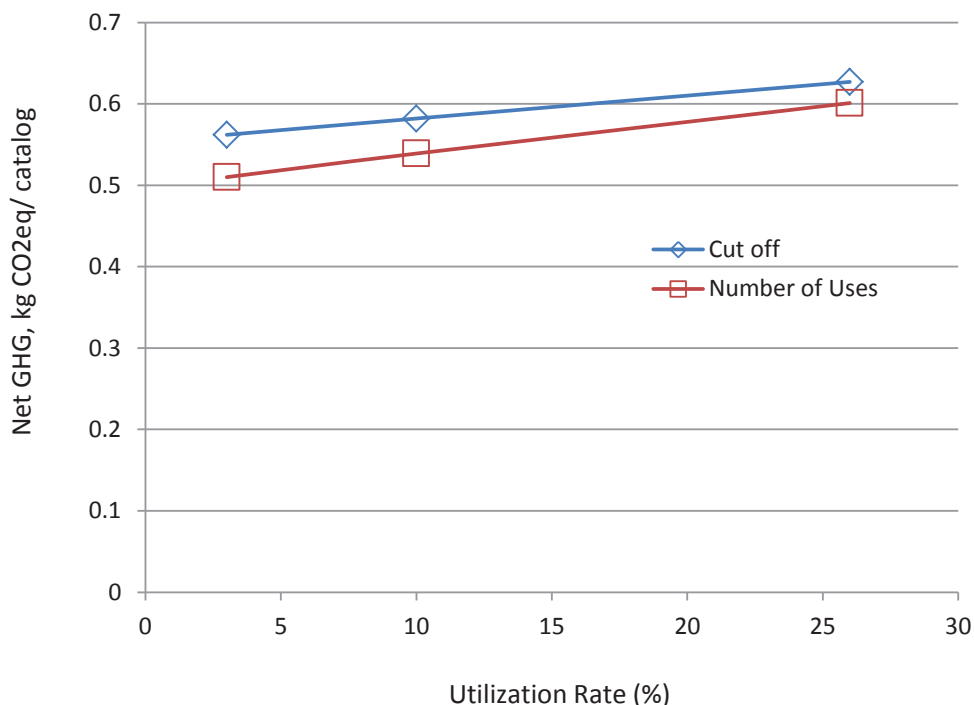
743 To summarize, it has been shown that the choice of recycling allocation method is important to the
744 assignment of environmental burdens between the product of interest and subsequent products that
745 utilize recovered material from the product of interest. It can be observed in **Figure 6** that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

750

751 **Effect of the Utilization Rate on net GHG emissions**

752 It is also of interest to understand how the recycling allocation method impacts the emissions as a
753 function of the utilization rate of recycled paper in the product of interest. For the base case, the
754 utilization rate was 3% and the recovery rate of the catalogs was 38.8%. It is not straightforward in
755 FEFPro to simply change the utilization rate into the system based on the North American industry
756 average data. For instance, when the utilization rate is increased, then all mill operations must be
757 adjusted. These include virgin fiber sources, fuels used in manufacturing, pulping and bleaching
758 chemicals used, electricity and purchased steam, manufacturing wastes, lime kiln CO₂ capture and other
759 variables. FEFPro is not able to make these changes automatically. The user must have some mill
760 knowledge to predict these changes, which is not an easy task. To explore the effect of different
761 utilization rates using FEFPro and the North American industry average data, purchased virgin market
762 pulp was substituted by purchased deinked pulp in the model. By simply switching one purchased pulp
763 by another, then all of the information about the average mill operations would still be valid and would
764 not need to be adjusted.

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



770

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

773

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

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

784 Although the results in **Figure 9** are just an example, it is expected that the results roughly approximate
785 the current state of the North American catalog production, in which recycled fiber is sparingly used, a
786 3% utilization rate, but the product is significantly recycled, 38.8% recovery rate. Based on these
787 findings, in considering the overall GHG life cycle analysis of a typical catalog, the results are expected to
788 be more significantly related to the recovery rate than the utilization rate when considering recycling
789 allocation methods. This might not be true for other types of paper or board, for example recycled
790 paperboard products have very high utilization rates and relatively lower recovery rates.

791

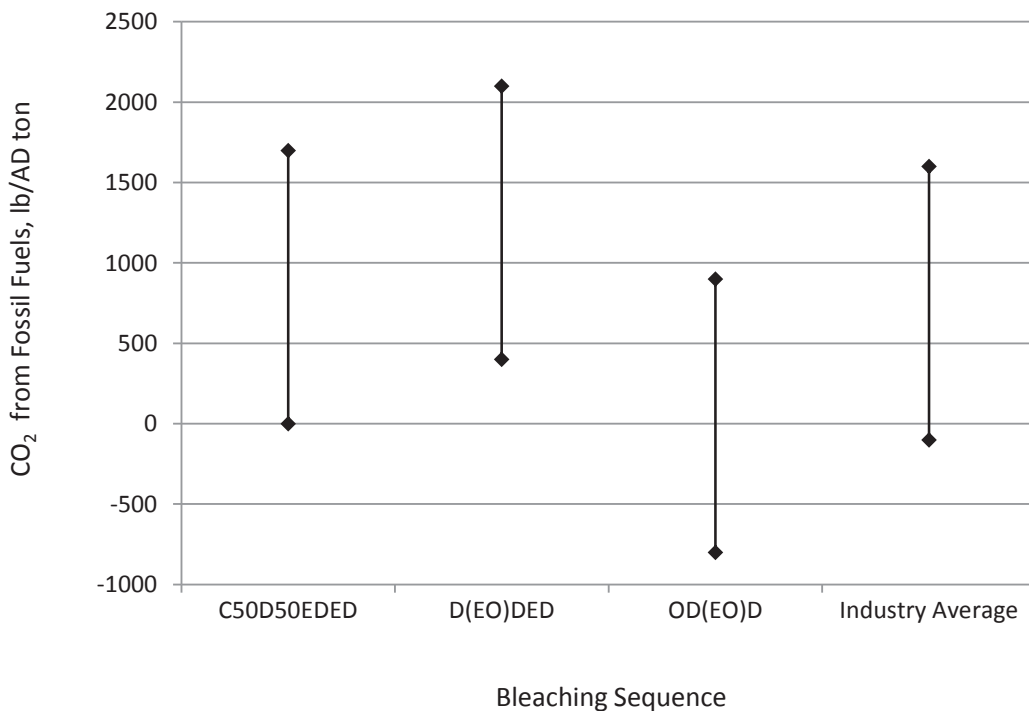
792 ***Coated Mechanical Sheets Used in Magazine: Effect of Recycling Allocation Method***

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

798 **The Use of Industry-wide Averages to Describe Individual Products**

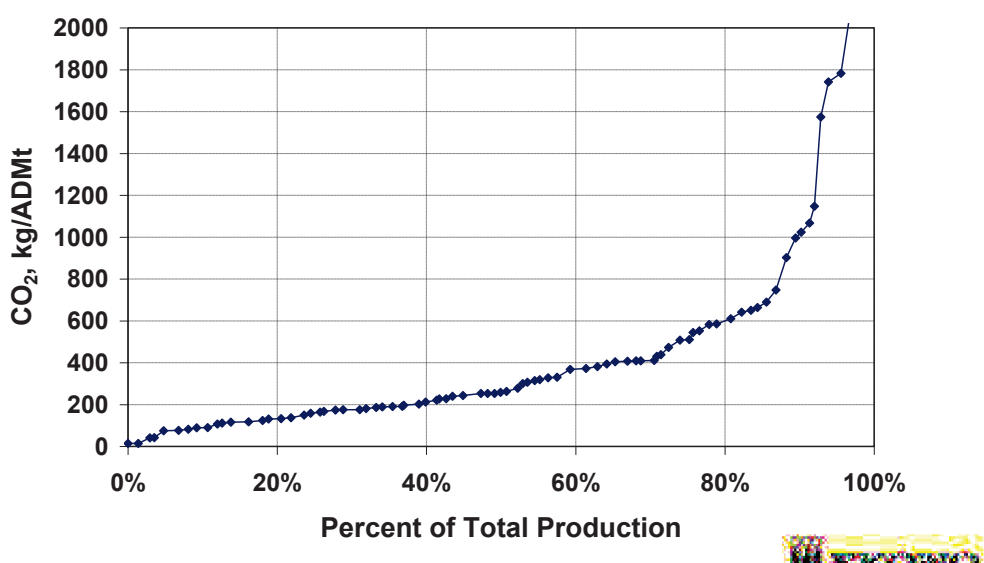
799 Both the NCASI (2010) and the Paper Task Force study (2002)/Environmental Paper Network Paper
 800 Calculator (2011) are based on industry average information. These types of studies have value in
 801 benchmarking the industry and for comparing a product with an alternate product, such as a paper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

810 The same type of paper or pulp can be manufactured in many different ways. For instance, types of
 811 bleaching processes, methods of mechanical refining, and methods of pressing and drying, among other
 812 examples, can have a significant effect on the overall energy consumption or emissions from a process.
 813 As an example, the range of total CO₂ emissions from fossil fuels to produce bleached kraft pulp for
 814 different bleaching sequences is shown in **Figure 10** (Paper Task Force, 1995, pg. 1).



815 **Figure 10.** The range of total CO₂ emissions from fossil fuels to produce bleached kraft pulp for different
 816 bleaching sequences. (Paper Task Force, 1995)
 817

818 The industry average is estimated to be 850 lbs CO₂/air dry ton of product (unweighted results since mill
 819 emissions data were available but did not contain the associated production rate for each mill), but the
 820 range of the overall results are from -800 to 2,100 lbs CO₂/air dry ton of product. Negative results
 821 indicate the use of non-petroleum fuel sources that displace petroleum fuel sources. The range of the
 822 results is 340% of the average. It is clear that for all manufacturers of bleached kraft pulp to claim the
 823 industry average as representing their product would be grossly misleading, with some manufacturers
 824 underestimating environmental claims and others exaggerating claims. More recent data from 85 North
 825 American integrated bleached kraft pulp and paper mills confirm that there is an equally large spread
 826 reported for CO₂ emissions from fossil fuels about 15 years after the Paper Task Force report in 1995
 827 (Mannisto, 2011).



828

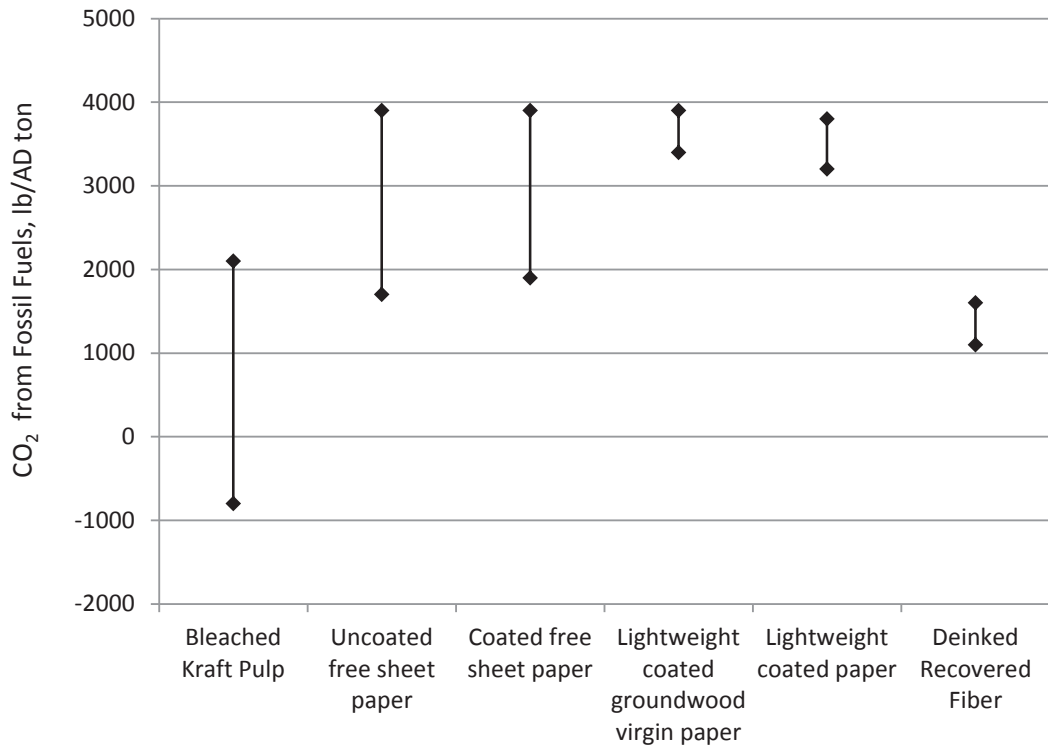
829 **Figure 11.** Distribution of CO₂ emissions from fossil fuel use in 85 integrated bleached kraft pulp and
 830 paper mills worldwide. Emissions do not include those from the purchase of electricity or any other
 831 upstream emission. Total production represented by the data is 48 million metric tonnes/year. Data
 832 from 2008 (Mannisto, 2011).

833 In the Paper Task Force study (1995), the average and ranges of CO₂ emissions from fossil fuels were
 834 reported for other types of pulp and paper manufacturing processes, **Figure 12.** It is clear that the
 835 range of results is large, further evidence that the use of industry averages by a manufacturer of pulp or
 836 paper products can be misleading.

837 As another example, printing/converting/delivery pathways for the carbon footprint of *Time* magazine
 838 production were determined via five actual specific pathways (Heinz, 2006). The kg CO₂e/kg magazine
 839 ranged from 1.01 to 1.25 for the different pathways, a difference of 25% for the entire cradle-to-grave
 840 life cycle for the exact same product within one consistent LCA.

841

842



843

844 **Figure 12.** The range of total pounds of CO₂ emissions from fossil fuels to produce an air dry ton of
845 different pulp and paper products. (Paper Task Force, 1995)

846 **Recommendations**

- 847 • Developing meaningful comparisons of different LCA studies can be extremely difficult. Issues
848 arise when studies use different boundaries, LCA calculation methods, type and quality of data,
849 and assumptions. Further, a lack of adequate documentation, mainly arising from not
850 presenting a well-documented life cycle inventory further complicates interpretations of the
851 meaning, limitations and results of different studies. The use of standard methods (ISO
852 2006a,b) is necessary to produce LCAs of clarity and value.
- 853 • When considering two related products in the same life cycle such as virgin or recycled
854 materials, the choice of available allocation methods can determine whether virgin or recycled
855 material is promoted. LCA methods (ISO 2006a, b) do not dictate which allocation method to
856 use; it is up to the LCA practitioner to choose a method, explain the rationale of the choice, and
857 evaluate the sensitivity of the result to the allocation method.
- 858 • In choosing allocation methods, an understanding of the industry, its processes, and the
859 relationships between players in the industry, should be used; practitioners of LCA should be
860 sensitive to biases rising from self-promotion. A sensitivity analysis should be presented for
861 allocation methods. External review of the LCA is also very useful in establishing the
862 reasonableness of the chosen allocation method.
- 863 • The number of uses method is an appropriate model for the life cycle assessment of paper
864 products, which is most reasonably modeled as an open loop recycling process. This method of
865 allocation reasonably allows a sharing of environmental burdens with respect to virgin and
866 recycled life stages of the fibers. This method rewards the production of virgin materials that
867 are made to be recyclable. However, the allocation method is very complex and more difficult
868 to communicate than the cut-off method. Only sophisticated LCA practitioners are able to
869 utilize and discuss with understanding the number of uses method, reducing the utility of the
870 method.
- 871 • For the paper products studied herein, the number of uses method results in a carbon footprint
872 of about 10-20% lower than the cut off method for the same product. The ease of use and
873 ability to communicate the cut-off method are two of its strengths. More research needs to be
874 performed to understand if the decrease between the two methods is significant or if it is within
875 the uncertainty of the calculations.
- 876 • As based on data in this paper, the recovery of used paper for manufacture of new materials or
877 use in incineration to create energy is in general more desirable than landfilling. Recovery of
878 used paper should be encouraged; the ceiling on the limit of how much can be recovered is an
879 economic/technical one. Based only on GHG emissions, it is generally considered that
880 incineration with energy recovery is the preferred end of life scenario.
- 881 • With respect to the utilization of recovered paper in specific products, the data in this paper
882 demonstrate that a blanket statement that all paper products should maximize the use of
883 recovered paper for environmental advantage is not substantiated. In the simplified case for
884 coated paper, there is not a significant carbon footprint advantage for increased utilization of
885 recovered paper, assuming that recovered paper has more effective and economical uses than

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

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

905

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

912

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

975 Paper Calculator Data for Uncoated Freesheet Before the 2008-2011 Updates (Data accessed from a pre-
 976 2008 version of the Paper Calculator). Basis of 1000 tons of paper.

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

977

978

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 (NO_x)	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

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

982 **Table 7.** Net GHG of office paper from various life cycle stages from the Paper Task Force(2002, pg. 132),
 983 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
CO ₂ _e lb/ton product	300	3000	230	3350	230	3350	2500
CO ₂ _e ton/ton product	0.15	1.50	0.12	1.68	0.12	1.68	1.25

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

986 Product 1=V1+P1=3300

987 Product 2=R1+P2=3580

988 Product 3=R2+P3+W3=6080

989 Avg Product 2+3=4830

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

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

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

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

996 Avg Product 2+3=4440

997

998 Quality Loss Method (quality loss: $Q_1=1$, $Q_2=0.5$, $Q_3=0.5$). Therefore, recycled paper production is
999 promoted due to higher attributed shared burdens to virgin since the value/quality of virgin is assumed
1000 to be higher.

1001 Product 1= $\frac{1}{2}(V_1+R_1+R_2+W_3)+P_1=4630$

1002 Product 2= $\frac{1}{4}(V_1+R_1+R_2+W_3)+P_2=4160$

1003 Product 3= $\frac{1}{4}(V_1+R_1+R_2+W_3)+P_3=4160$

1004 Avg Product 2+3=4160. Raw Material Acquisition Generates Waste Treatment. Therefore, recycled
1005 paper production is promoted, as recycling is a way to “delay” waste disposal.

1006 Product 1= $V_1+P_1+W_3=5800$

1007 Product 2= $R_2+P_2=3580$

1008 Product 3= $R_3+P_3=3580$

1009 Avg Product 2+3=3580.

1010 Material Lost as Waste Must be Replaced. Therefore, virgin paper production is promoted, as the raw
1011 material procurement and waste management burden is placed on the last product.

1012 Product 1= $P_1+R_1=3230$

1013 Product 2= $P_2+R_2=3580$

1014 Product 3= $P_3+V_1+W_3=6150$

1015 Avg Product 2+3=4865.

1016 50/50 Method: Raw Material Procurement and Waste management to 1st and Last Product and
1017 Recycling to upstream and downstream Product (50/50 splits). Therefore, recycled paper production is
1018 promoted, but there is not much difference as raw materials and waste management are spread over
1019 two recycled products.

1020 Product 1= $\frac{1}{2}(V_1+W_3)+\frac{1}{2}R_1+P_1=4515$

1021 Product 2= $\frac{1}{2}R_1+\frac{1}{2}R_2+P_2=3580$

1022 Product 3= $\frac{1}{2}(V_1+W_3)+\frac{1}{2}R_2+P_3=4865$

1023 Avg Product 2+3=4220

1024

1025

1026 **Appendix C. FEFPro modeling of a North American Average Catalog Product: Supporting Information**

1027 In order to set up a calculator to evaluate allocation assumptions and for Sappi's use to evaluate paper
1028 products, FEFPro V1.3 was utilized. FEFPro is an Excel™-based tool to assist in the calculation of the
1029 carbon footprint for paper and paperboard products (FEFPro, 2010). As appearing in the user manual,
1030 *There is no single official definition for a carbon footprint but it can be seen as a picture of the overall*
1031 *greenhouse gas impact (not just CO₂) of a product over its lifecycle (cradle-to-grave). The accounting*
1032 *begins with emissions associated with extracting or growing raw materials and finishes with the*
1033 *emissions associated with reusing or disposing of the product.* Some carbon footprint analyses do not
1034 consider product disposal and use. These studies are referred to as "cradle-to-gate" and can be useful
1035 when analyzing different production processes for the same product or for business-to-business
1036 communications. Carbon footprints can be performed at different levels:

- 1037 • Carbon footprint of a specific product often defined via a functional unit;
- 1038 • Carbon footprint of a mill;
- 1039 • Carbon footprint of a company; or
- 1040 • Carbon footprint of a sector.

1041 To evaluate FEFPro V1.1, data from the study published by NCASI (2010), *Life cycle assessment of North*
1042 *American printing and writing paper products* was inputted into FEFPro and the results compared to
1043 the results in the study. In doing so, several complications occurred. There were problems with
1044 FEFPro V1.1 in that some of the calculations in the program (allocations, final fate) were in need of
1045 updating, and were revised. It was then recognized that data from the original NCASI LCA study
1046 needed to be adjusted and a revised LCA study was provided. Dr. Caroline Gaudreault, Senior
1047 Scientist at NCASI was integral to these efforts.

1048 The data from the NCASI LCA study was inputted into the updated FEFPro V1.3. The concept was to
1049 input the average North American data for catalog paper as reported in the NCASI LCA study and to
1050 compare with the FEFPro output to the NCASI LCA study, which were calculated in the SimaPro
1051 software program. Several significant issues had to be addressed in the development of the FEFPro
1052 V1.3 model:

- 1053 • FEFPro requires co-product allocation to be performed outside of the program. A mass
1054 allocation was determined to allocate emissions to turpentine, tall oil fatty acid, and to the
1055 coated paper product. A percentage of 97.64% of the paper manufacturing emissions were
1056 allocated to the paper product
- 1057 • FEFPro requires co-product allocation to be performed outside of the program. Sold electricity
1058 can be considered a co product of the paper manufacturing process. The emissions from all
1059 fuel sources was allocated to the sold electricity co-product by taking a ratio of the sold
1060 electricity energy to the total energy produced by fuels in the paper manufacturing process. The
1061 result allocated 99.2% of the fuel emissions to the paper product.
- 1062 • FEFPro does not have emission factors for most printing chemicals/supplies. To incorporate the
1063 printing process emissions to the cradle to grave analysis Dr. Gaudreault provided SimaPro
1064 results of the printing process not present in the supplied NCASI LCA study (NCASI, 2010).
1065 Essentially, the emissions that are present with the printing chemicals/supplies were known
1066 to be 7% and the electricity use emissions were known to be 41.8% of the total emissions of

1067 the converting process. This information was combined with the LCA study result of total
1068 emissions from 187 kg CO₂e/1 machine dry short ton of catalog paper at 5% consistency
1069 converted to electricity. The emissions from all printing chemicals/supplies were determined
1070 to be 72 kg CO₂e/1 machine dry short ton of catalog paper at 5% consistency (not adjusted
1071 for recycling allocations).

- 1072 • The overall recovery rate, including both pre-consumer scrap from converting and post-
1073 consumer recovered material was calculated to be 38.8%. This number is based on a 9%
1074 loss of material during converting. All converting losses are recycled. A value of 32.7%
1075 recovery rate of catalogs, as reported in the NCASI LCA study was used.
- 1076 • Printing/Converting Notes: The final manufacturing operation input cells in FEFPro were
1077 reserved for the printing/converting operations. Data in the fuel final manufacturing input
1078 section of the model reflect printing/converting. Other material input sections of FEFPro
1079 include a single lumped/estimated grouping for the printing/converting materials. Data in
1080 the electricity/steam final manufacturing input area reflect printing/converting.
- 1081 • Electricity/steam. FEFPro did not have enough entry places in primary manufacturing in the
1082 electricity and steam sections of the model to accommodate the North American averages,
1083 so both the primary and secondary manufacturing categories were used for the pulp/paper
1084 manufacturing process to input electricity/steam inputs.

1085

1086 With these modifications, FEFPro was used to calculate the GHG emissions using both the cut off and
1087 the number of subsequent uses method. Example GHG results for the North American average for
1088 catalog production are shown in **Table 9**, as calculated with both the FEFPro program and the NCASI
1089 data (NCASI, 2010). The results from FEFPro modeling match those produced by NCASI (2010) using
1090 SimaPro software. The percent difference in results between the two methods indicates that the
1091 FEFPro model produces similar results for the given inputs. This suggests that the FEFPro model has the
1092 fidelity and robustness to capture the significant contributors to the GHG emissions in a paper product
1093 life cycle, as judged against the NCASI (2010) study.

1094 The major FEFPro results for all of the cases (baseline, recovery rate and utilization rate experiments)
1095 used in this report are in **Table C-1**.

1096 *Please note, FEFPro is a cradle to grave tool, in some cases emission and storage data appear in the*
1097 *result. These are applicable to cradle to grave calculations but not to cradle to gate. FEFPro does not*
1098 *allow the user to remove some of the cradle to grave calculation results. Thus, this data must remain in*
1099 *the FEFPro spreadsheet and be corrected outside of the program. See the footnotes and calculation*
1100 *methods at the bottom of the attached data table for some of these corrections.*

1101

1102

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1104

1107 **Appendix D. The Effect of the use of the Cut-off and the Number of Subsequent Uses Methods for**
1108 **Recycling Allocation: Net GHG Emissions for Magazine Versus Recovery Rate and Utilization Rate**

1109 The impact on the net GHG emissions (Carbon Footprint) of using a cut-off or a number of subsequent
1110 uses recycling allocation method of a coated mechanically pulped paper product (magazine) is explored
1111 with respect to recovery and utilization rates. Comparisons are made with a related product, coated
1112 chemically pulped and bleached paper product (catalog). Catalog results correspond to those presented
1113 previously in this paper and are shown again for convenient comparison.

1114 **Methods**

1115 An Excel™-based tool to assist in the calculation of the carbon footprint for paper and paperboard
1116 products was utilized, FEFPro V1.3 (FEFPro, 2010). As stated in the user manual, *There is no single*
1117 *official definition for a carbon footprint but it can be seen as a picture of the overall greenhouse gas*
1118 *impact (not just CO₂) of a product over its lifecycle (cradle-to-grave). The accounting begins with*
1119 *emissions associated with extracting or growing raw materials and finishes with the emissions*
1120 *associated with reusing or disposing of the product.* Some carbon footprint analyses do not consider
1121 product disposal and use. These studies are referred to as “cradle-to-gate” and can be useful when
1122 analyzing different production processes for the same product or for business-to-business
1123 communications. Carbon footprints can be performed at different levels (FEFPro, 2010):

- 1124 • Carbon footprint of a specific product often defined via a functional unit;
1125 • Carbon footprint of a mill;
1126 • Carbon footprint of a company; or
1127 • Carbon footprint of a sector.

1128 The FEFPro model was populated with data from the study published by NCASI (2010), *Life cycle*
1129 *assessment of North American printing and writing paper products.* Average North American data
1130 for magazine paper (coated mechanical sheets) was used. The average North American industry
1131 magazine product utilized 2% recycled fiber furnish (utilization rate) and had a 44% recovery rate. Two
1132 types of cradle-to-grave cases were explored herein

- 1133 • Varied recovery rate with the utilization rate constant
1134 • Varied utilization rate with recovery rate constant

1135 Assumptions and estimations for the model follow:

- 1136 • A magazine consisted of 0.176 OD kg of coated mechanical sheets and 0.009 OD kg of
1137 coated free sheet (cover). Since the objective of this study was to evaluate the carbon
1138 footprint of coated mechanical paper with regards to recycling, only the 0.176 OD kg of
1139 coated mechanical sheets were evaluated.
1140 • It is assumed that 9% of the coated mechanical sheets are lost at the printing operation and
1141 that all of this material is recycled. The post-consumer recovery rate of magazine is 38.6%
1142 (NCASI, 2010, Table 4-5). This combined with the 100% recovery rate of the printer’s waste
1143 resulted in an overall recovery rate of 44% for the magazine material.

- 1144 • Of the magazine that is not recovered, 81% is landfilled and 19% is burned for energy
1145 recovery.
- 1146 • Due to the structure of the industrial data collected in the NCASI 2010 survey, it was only
1147 possible to explore a limited range of utilization rates (<20%). Utilization rate experiments
1148 were performed by exchanging purchased bleached kraft hardwood pulp and purchased
1149 TMP pulp with market deinked pulp. At the 10% utilization rate, only a portion of
1150 purchased bleached kraft hardwood pulp was replaced by market deinked pulp. At the 17%
1151 utilization rate, all of the purchased bleached kraft hardwood pulp and purchased TMP pulp
1152 was replaced with the market deinked pulp
- 1153 • The type of market deinked pulp that would be probably used to replace virgin in a coated
1154 mechanical sheet is deinked newsprint and the like. FEFPro does not have data for deinked
1155 newsprint. Thus, the emission factor for market deinked pulp originating from the typical
1156 process in which wastepaper that is mainly lignin free (chemically pulped and bleached) is
1157 deinked to produce high brightness, lignin free pulp suitable for incorporation into copy
1158 paper and the like, was used for deinked newsprint. This assumption was checked using
1159 data publically available (Paper Task Force, 2002, Table C-3). In this report, market deinked
1160 pulp for copy paper has a GHG emission of 3582 and for deinked newsprint of 3498 lb CO₂e
1161 /ton product. Since the difference between the two numbers is only 2% and the uncertainty of
1162 the emissions factor is expected to be larger than 2%, the use of the FEFPro emission factor for
1163 conventional market deinked pulp was deemed reasonable.

1164 Results

1165 The model was used to calculate the GHG emissions using both the cut off and the number of
1166 subsequent uses recycling allocation methods. The base case GHG results for the North American
1167 average for magazine production (coated mechanical sheets only) are shown in **Table D-1** as calculated
1168 with the FEFPro program. Also shown are the NCASI data (NCASI, 2010). The results from FEFPro
1169 modeling adequately match those produced by NCASI (2010) using SimaPro software. This suggests
1170 that the FEFPro model has the fidelity and robustness to capture the significant contributors to the GHG
1171 emissions in a paper product life cycle, as judged against the NCASI (2010) study.

1172 The net GHG for the magazine system for cradle-to-gate and cradle-to-grave scenarios using the cut off
1173 method are greater than for the number of subsequent uses allocation methods, by 20% and 19%,
1174 respectively, **Table D-1**. These decreases are due to the fact that the number of subsequent uses
1175 allocation method exports more virgin burdens out of the system of study due to the product's high
1176 recovery rate (44%) than it imports into the system of study due to a low percentage of recycled fiber
1177 used in the product (2%). These types of results are case-specific and depend on the particular values of
1178 the recovery rate and utilization rate. The effect of the utilization and recovery rates on the GHG results
1179 with the two allocation methods are further explored later. For comparison, **Table D-2** presents the
1180 parallel data for catalog production (coated freesheet). It is observed that the carbon footprint is
1181 greater for catalog than for magazine for all results, including FEFPro results determined herein and
1182 NCASI (2010) results.

1183

1184 **Table D-1.** FEFPro Modeling Results of industry average for coated mechanical sheet (**magazine**) for
 1185 two recycling allocation methods. The values of the net GHG emissions depend on the allocation
 1186 method, utilization rate, and recovery rate. In this case the utilization rate is 2% and the recovery rate
 1187 of the product is 44%. Numbers in parentheses are the % difference between the number of uses and
 1188 cut off allocation methods. One magazine contains 0.176 OD kg of coated mechanical sheet.

Case	FEFPro	NCASI, SimaPro	% Difference
	kg CO ₂ e/bdst coated mechanical	kg CO ₂ e/bdst coated mechanical	
Cradle-to-Gate, # Uses	1379	1393 *	-1
Cradle-to-Gate, cut off	1655 (20% increase)	(not reported)	Not applicable.
	kg CO ₂ e/ catalog	kg CO ₂ e/ catalog	
Cradle-to-Grave, # Uses	0.36	0.43 **	-19
Cradle-to-Grave, cut off	0.43 (19% increase)	(not reported)	Not applicable.

1189 * from Table 11-2, NCASI (2010) study. ** from Table 11-1, NCASI (2010) study, adjusted such that the
 1190 covers of the magazine are not considered (93% of the published value of 0.46 for a magazine with
 1191 0.176 kg coated mechanical and 0.0093 kg coated free sheets).

1192 **Table D-2.** FEFPro Modeling Results of industry average for **catalog** (coated free sheet) for two recycling
 1193 allocation methods. The values of the net GHG emissions depend on the allocation method, utilization
 1194 rate, and recovery rate. In this case the utilization rate is 2% and the recovery rate of the product is
 1195 38.8%. Numbers in parentheses are the % difference between number of uses and cut off allocation
 1196 methods. One catalog is 0.135 OD kg.

Case	FEFPro	NCASI, SimaPro	% Difference
	kg CO ₂ e/bdst catalog	kg CO ₂ e/bdst catalog	
Cradle-to-Gate, # Uses	1658	1469 *	13
Cradle-to-Gate, cut off	1947 (17% increase)	(not reported)	Not applicable.
	kg CO ₂ e/ catalog	kg CO ₂ e/ catalog	
Cradle-to-Grave, # Uses	0.51	0.49 **	4
Cradle-to-Grave, cut off	0.56 (10% increase)	(not reported)	Not applicable.

1197 * from Table 9-2, NCASI (2010) study. ** from Table 9-1, NCASI (2010) study.

1198

1199

1200

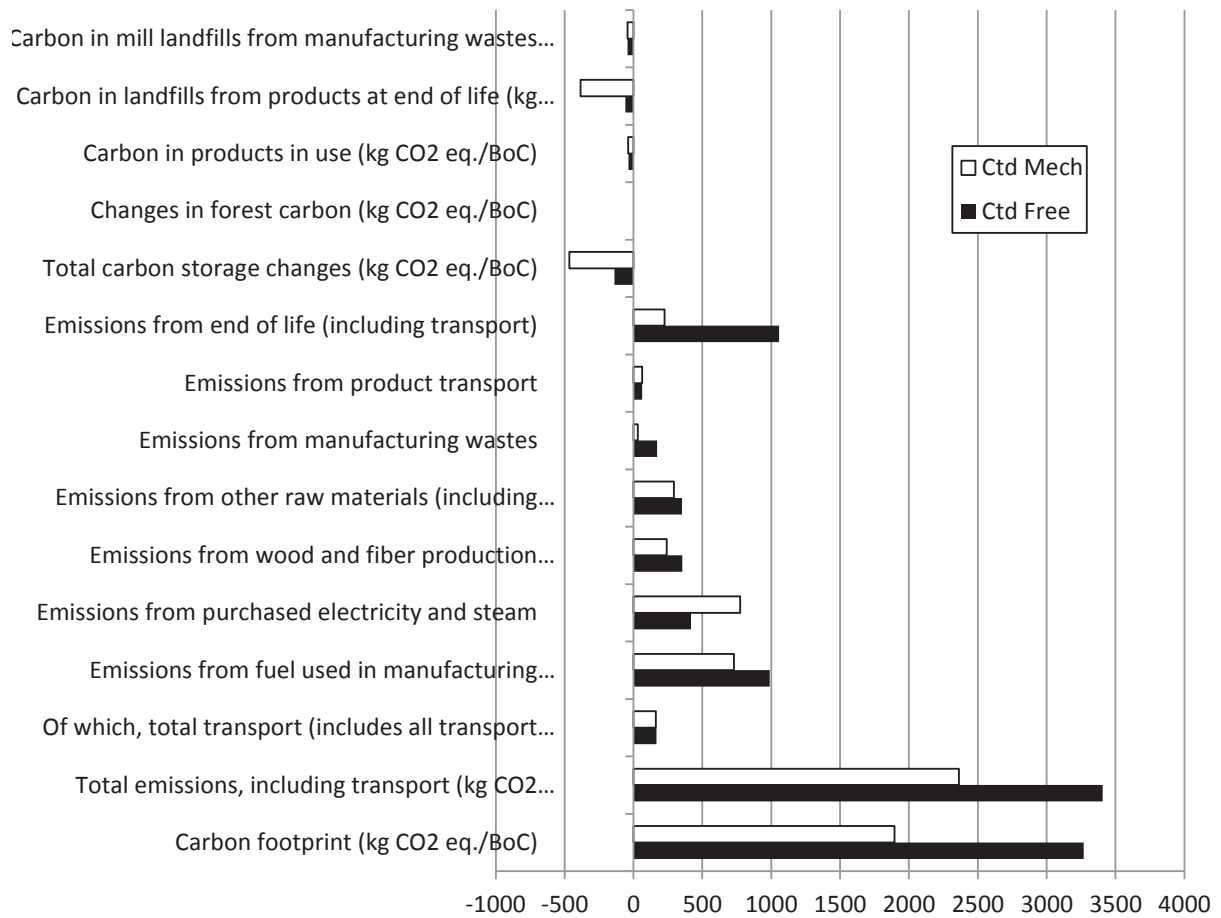
1201 An inspection of **Table D-3 and Table D-4** reveal the major factors that in these models cause the carbon
1202 footprint of coated mechanical sheets to be smaller than coated freesheet. The results are plotted for
1203 the cradle-to-grave system with cut-off allocation method in **Figure D-1** and for the cradle-to-gate
1204 system with cut off allocation method in **Figure D-2**. Some important points (cradle-to-grave) are
1205 summarized in the following:

- 1206 • The mechanical pulping process has a significantly higher yield (circa 90%) than does the
1207 chemical pulping process and bleaching (circa 50%) so that wood and fiber requirements are
1208 lower.
- 1209 • The mechanical pulping process uses more (about twice) electricity since this drives the
1210 mechanical pulping. However, it is known that mechanical pulping facilities coincide with areas
1211 with large percentage of renewable electricity so this is not as significant as it might be. The
1212 NCASI results are a North American average over existing mills and thus reflect the high portion
1213 of renewable electricity used.
- 1214 • Emissions from fuel are higher for the free sheet than the mechanical sheet, about 35% higher
1215 because of the increased dependence on steam and utilities for chemical pulping and bleaching.
- 1216 • Mechanical sheets are assumed to decompose significantly less in landfills due to the increased
1217 lignin content. This makes emissions from end of life about 4 times smaller for mechanical
1218 sheets than free sheets. Thus, the carbon storage in landfills is much higher for the mechanical
1219 containing sheets. Emissions from manufacturing wastes are also lower for similar reason.
- 1220 • Transport in total is only 3% of the total carbon footprint and is not considered to be a
1221 reasonable operating parameter to effectively reduce the carbon footprint.

1222 Similar to the cradle to grave analysis, the coated mechanical sheets have a smaller carbon footprint
1223 than the coated freesheet, **Figure D-2**. However, there is less difference between cradle to gate results
1224 than cradle to grave results for coated mechanical sheets and coated freesheet, simply due to the
1225 exclusion of the emissions from end-of-life in the cradle to gate system boundary.

1226

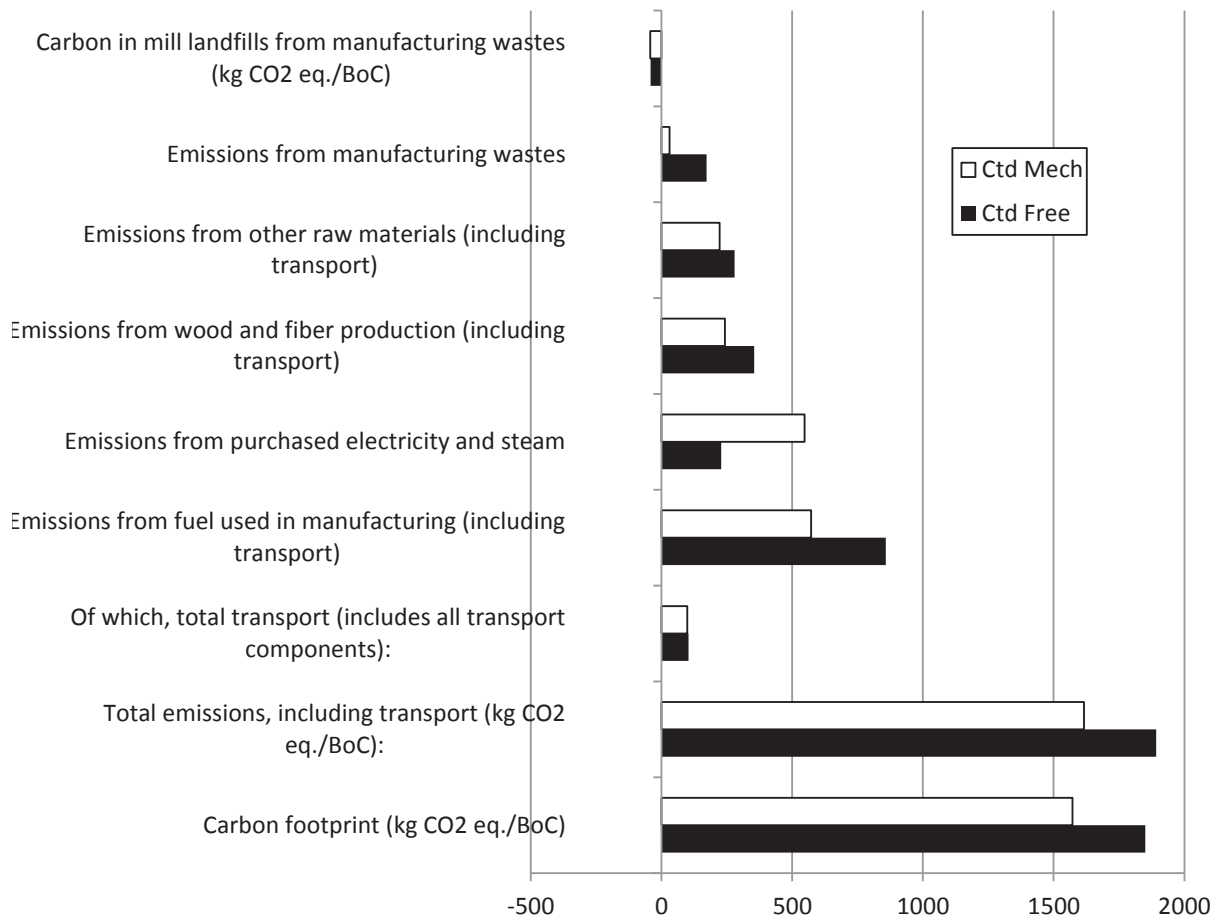
1227



1232

1233 **Figure D-1.** Life cycle stages contribution to the carbon footprint for the cradle-to-grave system with
 1234 cut-off allocation method. Basis of calculation (BoC) was one short ton with 5% MC. Units are kg CO2
 1235 eq./BoC. Carbon footprint is the sum of all emissions minus the sum of all carbon storage.

1236



1237

1238 **Figure D-2.** Life cycle stages contribution to the carbon footprint for the cradle-to-gate system with cut-
 1239 off allocation method. Basis of calculation (BoC) was one short ton with 5% MC. Units are kg CO2
 1240 eq./BoC. Carbon footprint is the sum of all emissions minus the sum of all carbon storage.

1241

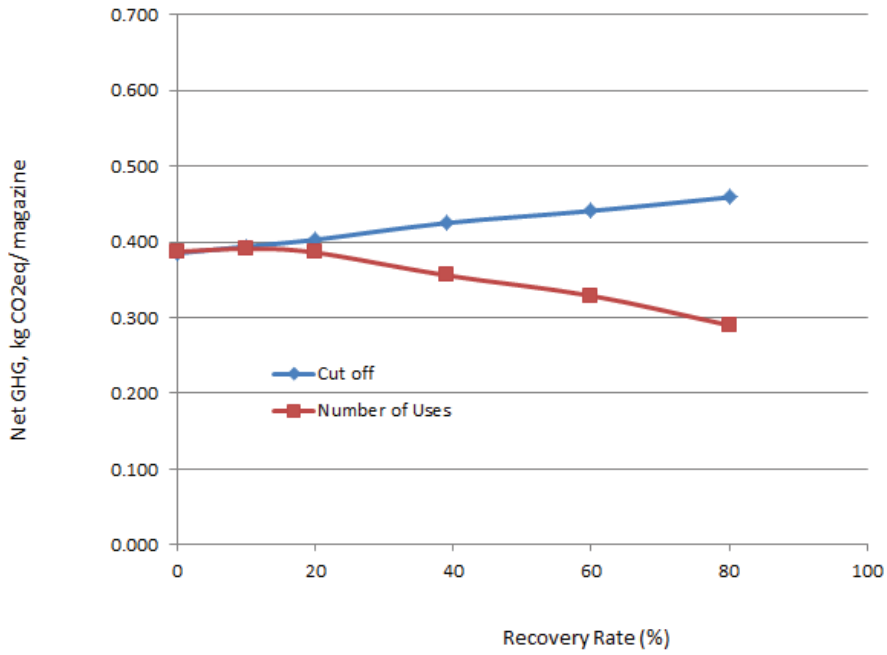
1242 ***Effect of the Recovery Rate on net GHG emissions***

1243 For the base case, 44% of the catalogs were recovered (the utilization rate was 2%). This considers both
1244 pre- and post-consumer recovery; 81% is landfilled and 19% is incinerated for energy of the unrecovered
1245 magazines. The net GHG emissions per magazine (only the uncoated mechanical sheets) are calculated
1246 versus recovery rate using the cut-off and the number of uses recycling allocation method, **Figure D-2**.
1247 With a recovery rate of zero the two allocation methods result in a similar value, as expected. For the
1248 cut-off allocation method, the GHG emissions per magazine increase approximately linearly. This is
1249 because the carbon storage of landfilled mechanical pulped papers is large. Increases in recovery rate
1250 decrease the carbon storage in landfills. For the number of uses method, the GHG emissions per
1251 magazine is constant from 0 to 20% recovery rate and then decreases at higher recovery rates. Two
1252 competing factors are at play, (1) increased recovery rate decreases carbon storage in landfills, and (2)
1253 increased recovery rate causes more of the environmental burdens from the virgin fiber production to
1254 be exported out of the system with the number of uses allocation method. Below 20% recovery rate
1255 effects (1) and (2) balance one another. Above a 20% recovery rate, effect (2) dominates over effect (1)
1256 and a decrease in GHG emissions is produced.

1257 In contrast, for coated freesheet, **Figure D-3**, decay in landfills is more prominent than for mechanical
1258 pulps and effect (1) is not present. Thus, for both allocation methods a decline in GHG emissions is
1259 predicted for increased recovery rates. The decline is more dramatic for the number of uses method.

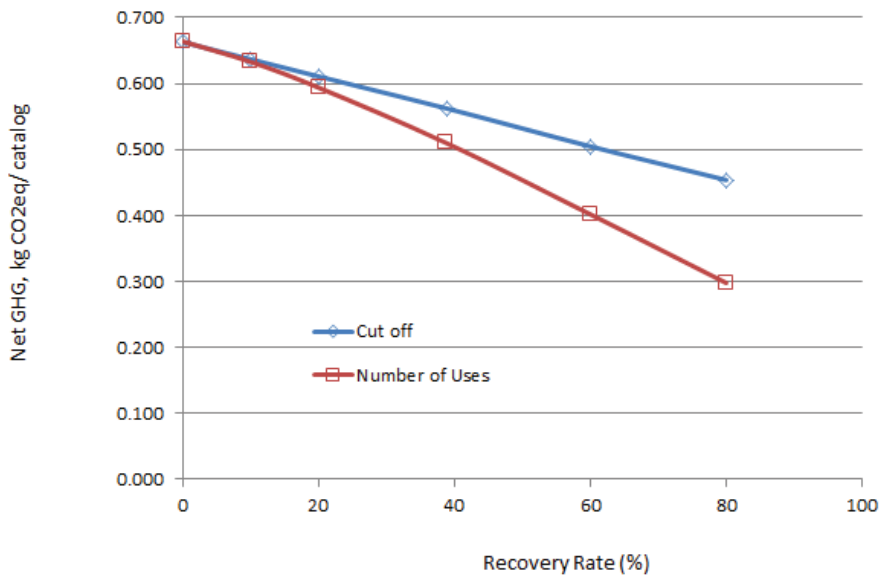
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1262

1263 **Figure D-2.** The net GHG emissions per *magazine* versus recovery rate using the cut-off and the number
1264 of uses recycling allocation method for cradle-to-grave.



1265

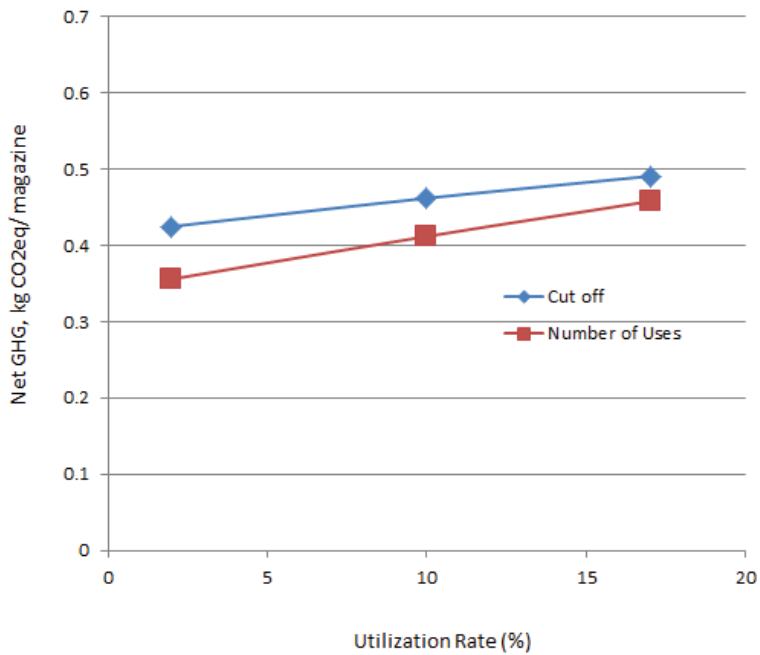
1266 **Figure D-3.** The net GHG emissions per *catalog* versus recovery rate using the cut-off and the number
1267 of uses recycling allocation method for cradle-to-grave.

1268 ***Effect of the Utilization Rate on net GHG emissions***

1269 It is also of interest to understand how the recycling allocation method impacts the emissions as a
1270 function of the utilization rate of recycled paper in the product of interest. For the base case, the
1271 utilization rate was 2% and the recovery rate of the magazines was 44%. It is not straightforward in
1272 FEFPro to simply change the utilization rate when using a model based on the North American industry
1273 average data. For instance, when the utilization rate is increased, then all mill operations must be
1274 adjusted. These include virgin fiber sources, fuels used in manufacturing, pulping and bleaching
1275 chemicals used, electricity and purchased steam, manufacturing wastes, lime kiln CO₂ capture and other
1276 variables. FEFPro is not able to make these changes automatically. The user must have some mill
1277 knowledge to predict these changes, which is not an easy task. To explore the effect of different
1278 utilization rates using FEFPro and the North American industry average data, purchased virgin pulps
1279 were substituted by purchased deinked pulp in the model, see **Table D-3**. By simply switching one
1280 purchased pulp by another, then all of the information about the average mill operations would still be
1281 valid and would not need to be adjusted.

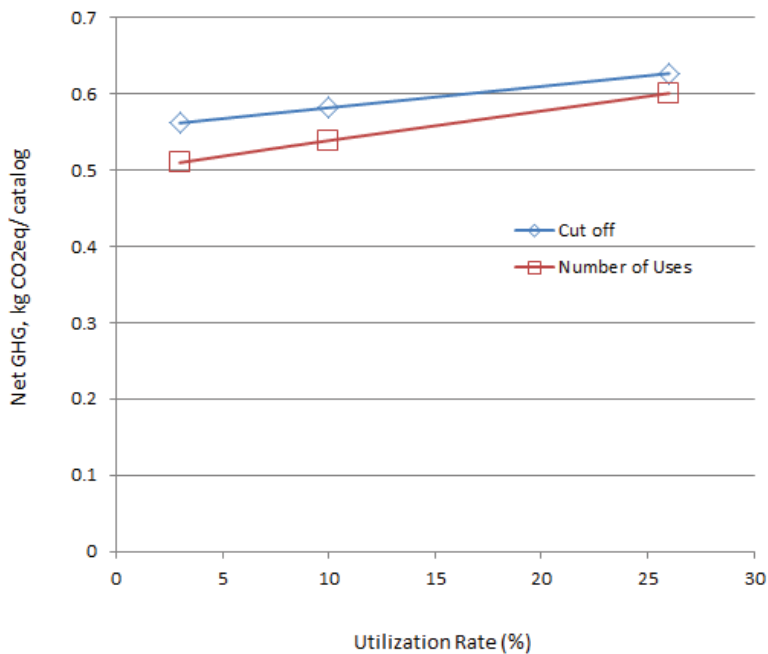
1282 The net GHG emissions per magazine (cradle to grave) have been calculated versus utilization rate at the
1283 constant recovery rate of 44% using the cut-off and the number of uses recycling allocation method,
1284 **Figure D-4**. Note that for both allocation methods the GHG emissions increase approximately linearly
1285 with increased utilization rate (this is mentioned with caution, only 3 points were used). This is because
1286 the emission factor for recycled deinked pulp (3.43 kg CO₂e/OD kg pulp) is greater than both
1287 purchased bleached kraft hardwood pulp (1.00 kg CO₂e/OD kg pulp) and purchased TMP pulp (1.65
1288 kg CO₂e/OD kg pulp). The linear increases are similar to those for catalog, uncoated freesheet,
1289 **Figure D-5**, for the same reasons. Both magazine and catalog have lower GHG emissions using the
1290 number of uses allocation method relative to the cut-off method, due to the export of
1291 environmental burdens from the virgin product to subsequent uses.

1292



1293

1294 **Figure D-4.** The net GHG emissions per *magazine* (coated mechanical) versus utilization rate using the
 1295 cut-off and the number of uses recycling allocation method (recovery rate equal to 44%) for cradle to
 1296 grave.



1297

1298 **Figure D-5.** The net GHG emissions per *catalog* (coated freesheet) versus utilization rate using the cut-
 1299 off and the number of uses recycling allocation method (recovery rate equal to 39%) for cradle to grave.

1300 **Conclusions**

- 1301 • The carbon footprint of coated mechanical sheets is less than for coated free sheets. This is due
1302 mainly to lower emissions from decay in landfills. Also, different pulping yields, different total
1303 energy requirements, and different levels of use of renewable electricity affect the carbon
1304 footprint differences.
- 1305 • Transportation contributions to the carbon footprint are not significant.
- 1306 • The number of uses method is an appropriate model for the life cycle assessment of paper
1307 products, which is most reasonably modeled as an open loop recycling process. This method of
1308 allocation reasonably allows a sharing of environmental burdens with respect to virgin and
1309 recycled life stages of the fibers. This method rewards the production of virgin materials that
1310 are made to be recyclable. However, the allocation method is very complex and more difficult
1311 to communicate than the cut-off method. Only sophisticated LCA practitioners are able to
1312 utilize and discuss with understanding the number of uses method, reducing the utility of the
1313 method.
- 1314 • For the paper products studied herein, the number of uses method results in a carbon footprint
1315 of about 10-20% lower than the cut off method for the same product. The ease of use and
1316 ability to communicate the cut-off method are two of its strengths. More research needs to be
1317 performed to understand if the decrease between the two methods is significant or if it is within
1318 the uncertainty of the calculations.
- 1319 • Increased recovery rate increases the carbon footprint for coated mechanical sheet since
1320 increased recycling reduces carbon storage in landfill. This is not the case for the number of
1321 uses allocation method for coated mechanical sheet in which the export of burdens from the
1322 system causes the carbon footprint at higher recovery rates to decrease despite the effect of
1323 reduced carbon storage in the landfill.
- 1324 • Increased utilization rate causes an increase in carbon footprint due to the emission factor for
1325 deinked pulp being greater than those from virgin chemical pulped and bleached fiber and virgin
1326 mechanically pulped fiber.