

A Comparative Life Cycle Analysis of Selected Resolute Paper Grades with North American Freesheet: Report to Third Parties

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1 INTRODUCTION

Uncoated freesheet (UFS) is a paper grade used for printing and copying whose main ingredients are chemical pulp and calcium carbonate. Resolute manufactures several high brightness papers at its paper mill in Alma, QC, with mechanical pulp and mineral fillers, which are sold as economical and ecological alternatives to UFS. In its Catawba, SC paper mill, Resolute manufactures an economical alternative to coated freesheet (CFS) used for magazines and catalogs, with a mix of mechanical and chemical pulps.

Resolute commissioned a comparative Life Cycle Analysis (LCA) to compare some of its paper grades with the North American freesheet market, because many of their customers are interested in the environmental attributes of Resolute's papers. Mechanical pulps have a high yield from wood, of 90 to 95%, compared to chemical pulps, which have a yield of 45 to 50%, so less wood is needed to make a sheet of mechanical-pulp based paper. Chemical pulp mills use most of the remainder of the wood as a source of energy, while mechanical pulps use more electrical energy than chemical pulps. In order to compare the total environmental footprint of their mechanical-pulp based sheets with chemical-pulp based UFS, Resolute chose to carry out a Life Cycle Analysis, where all the process inputs and outputs are considered, from the forest to final disposal.

A previous LCA study commissioned by Resolute was published in 2009, where Equal Offset paper manufactured in Alma was compared to a typical UFS which was represented by two large mills, one in the USA and one in Canada [Ref 3]. In 2010, a study was carried out by NCASI [Ref. 1] which carried out a LCA on UFS and CFS using an aggregate of several mills representing most of the industry. The present study therefore provides a good opportunity to update the earlier comparison, using a more representative average of North American producers.

This study was carried out under contract by Martin Fairbank, who is a former Resolute employee with a Ph.D. in chemistry and 26 years of experience in the pulp and paper industry. He is familiar with pulp and paper processes and their environmental aspects.

The study was carried out according to the requirements of ISO 14044.

A critical review was carried out by a panel of three experts, and a report of their comments and a response to the comments is included.

2 GOAL

The goal of this study is to compare the life cycle impact of a number of paper grades, made by Resolute at four of its paper mills which use mechanical pulp or mechanical/chemical pulp mixtures, to the life cycle impact of either UFS or CFS paper made in North America principally of chemical pulp. The study intends to support comparative assertions to be disclosed to the public.

3 SCOPE

A ream of paper, consisting of 500 sheets of 8½ x 11 inch paper (or 30.16 m² of paper) was the functional unit chosen for this analysis. The function of all the paper grades analyzed is to provide a paper printing surface. Most UFS paper can be printed by offset, laser or inkjet printing, whereas some of the Resolute grades examined are customized for each printing process, as indicated by their names (Laser, Offset or Inkjet). Customers that print on Resolute "uncoated freesheet substitute" grades report that the sheets can be used interchangeably with UFS and perform at least as well under the same printing conditions. Mechanical pulp is bulkier than chemical pulp, which means that a lower basis weight sheet can be used to provide a sheet of the same thickness. The basis weights chosen in this comparative study match the thickness of the 75 g/m² UFS. When used as office paper for laser or inkjet printing, a 500-sheet ream is the normal unit of sale. Paper for offset printing is usually sold in rolls, but to enable direct LCI comparisons between grades, a 500-sheet ream was chosen in all cases.

Coated freesheet (CFS) is a grade of paper used for high-quality magazines, catalogs, retail flyers, annual reports, and general commercial printing, and is made with no mechanical pulp and a coating made with high brightness pigments. AbiBow Max is an 84 brightness paper grade made in Catawba, SC, containing about 15% mechanical pulp, and is sold as an economical alternative to CFS at 82 and higher brightness for the same applications. Although CFS and AbiBow Max is usually sold in rolls and not 500-sheet reams, the functional unit was again chosen as a 500-sheet ream, to enable easy LCI comparisons with the products from the other paper mills in this study.

In this cradle-to-grave analysis, inputs included wood fibre from the forest, chemicals and additives, fossil and biomass fuels and electricity, as well as all upstream material inputs. Outputs included solid wastes, liquid effluent and air emissions, as well as disposal of product at end of life. Recycling of the product was also taken into account. Transportation was included at each stage of the life cycle.

Product use by the printer and the end user was excluded from the study. Packaging of the ream was not included in either the freesheet models or the Resolute paper (it was originally included in NCASI's UFS study [Ref. 1], but those data were removed for this study). These minor exclusions were made to simplify the analysis and to focus the study only on aspects of the life cycle where there would be a difference, since all the sheets studied would be processed and used identically. In the study, Resolute paper grades were considered to have equivalent loss and recycling rates as the UFS and CFS being compared to, although, due to different fibre contents this would vary slightly. A sensitivity analysis was added (see section 5.3)

Any ingredients making up less than 1% of the total mass (such as minor coating ingredients) were ignored for the purpose of this study, to simplify the analysis (this rule was followed for the UFS as well [Ref. 1]). Any use of fuel onsite for mobile equipment (e.g. forklifts for moving paper in the warehouse or front-end loaders in the woodyard) was ignored, because this was shown to represent less than 1% of overall fuel use, and was not consistently tracked at each of Resolute's paper mills.

3.1 Resolute's Paper Grades

3.1.1 Alma, QC

The six grades of paper made at the Alma, QC mill in this study are manufactured on paper machine #14. They are high brightness sheets made with peroxide-bleached thermomechanical pulp plus mineral fillers and a light coating. Table 1 shows the approximate make-up of each sheet. The Equal Offset and Alternative Offset grades have lower brightness than freesheet but the Ecopaque grades have a brightness that is not visibly different than freesheet. Equal Offset Book paper is similar to Equal Offset, but is made to a specific caliper (thickness) specification for book publishers. There is no electrical generation from steam in Alma.

Table 1: Characteristics of Alma Paper Grades

Functional Unit	Uncoated	Equal	Ecopaque	Ecopaque	Ecopaque	Equal	Alternative
	Freesheet	Offset	Offset	Laser	Jet	Offset Book	Offset
	1 ream (500 sheets 8½ x 11")						
Basis Weight, #	50	42.5	42.5	45	45	45	45
Basis Weight, g/m ²	75	62.9	62.9	66.6	66.6	66.6	66.6
Wood fibre, odmt/admt paper	1.53	0.75	0.75	0.73	0.73	0.78	0.90
Brightness	91	83	90	90	90	83	79
Moisture	5.0%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Kraft pulp	74%	0%	0%	0%	0%	0	0
Deinked pulp	3%	0%	0%	0%	0%	0	0
TMP	0%	69%	70%	68.0%	68.0%	72%	84%
CaCO ₃	13.5%	16.7%	10.3%	9.7%	9.5%	14.4%	6.0%
Clay	0.1%	5.2%	6.2%	5.1%	5.1%	4.9%	4.0%
Synthetic clay	0%	0%	4%	8%	8%	0%	0%
Starch	4%	1.1%	1.0%	1.0%	1.8%	0.8%	0%
Latex	0%	1.1%	1.0%	1.0%	0%	0.8%	0%
Sizing	0.7%	0%	0%	0%	0%	0%	0%

3.1.2 Catawba, SC

AbiBow Max is a paper grade made on machine #2 in Catawba. The base sheet is made from a mixture of southern softwood kraft pulp and peroxide-bleached TMP from southern softwood, and a coating is applied to the surface. Table 2 shows characteristics of this grade, compared to those of the CFS from the NCASI study. The Catawba mill generates 20% of its electricity requirement from biomass cogeneration.

Table 2: Characteristics of Catawba Paper

Functional Unit	Coated	AbiBow
	Freesheet	Max
	ream (500 sheets 8½ x 11)	
Basis Weight, #	50	45
Basis Weight, g/m ²	75	66.6
Wood fibre, odmt/admt paper	1.50	1.42
Moisture	5.0%	4.3%
Softwood Kraft pulp	25%	50%
Hardwood Kraft pulp	33%	0%
Deinked pulp	4%	0%
TMP	0%	15%
CaCO ₃	16%	0%
Clay	12%	25%
Starch	2%	0.4%
Latex	3%	2%

3.2 Uncoated Freesheet

A Life Cycle Assessment of common North American paper grades was recently completed by NCASI [Ref 1] and shared with its members. Included in this study was UFS paper based on an aggregate of 31 paper mills that represent 75% of the industry. This paper is typically made with a mixture of softwood and hardwood chemical pulp, precipitated calcium carbonate filler and a surface treatment applied in a size press. The composite sample includes northern and southern hardwood and softwood, but the exact

amount of each pulp is not provided by NCASI (only the amounts of raw material, i.e. logs, chips or sawdust). There is more hardwood than softwood kraft. The average amount of deinked, recycled pulp in this aggregated UFS is 3% by weight of the sheet, or about 4% of the pulp fibre. The impacts of purchased electricity were based on published state and province electrical sources. The data from this study were shared with Resolute in order to perform the present study.

3.3 Coated Freesheet

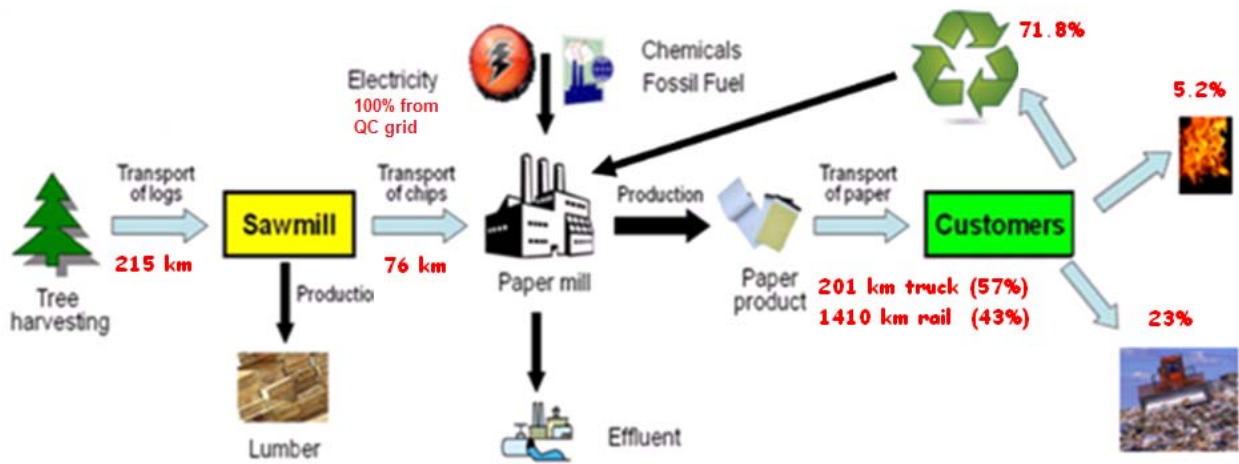
The NCASI study also looked at coated freesheet paper (CFS) used for catalogs. The Life Cycle Inventory was based on 15 mills representing 80% of the industry. This aggregated CFS contains 28% mineral fillers and 62% pulp fibre, including hardwood and softwood kraft pulp and 4% of deinked, recycled pulp.

3.4 Methodology – Life Cycle Inventory

Data for the Resolute paper grades were collected from personnel at each paper mill, representing the paper produced in the calendar year 2010, and the author validated the data using process knowledge and other data sources provided by the corporate offices of Resolute. A cradle-to-grave approach was used. Among the data included were data for wood supply, chemical use, energy use, environmental discharges to air, water and soil, and transportation distances and modes for the ingredients. By usingecoinvent data for each type of wood, fuel and chemical input, the background process contributions to impact score are included.

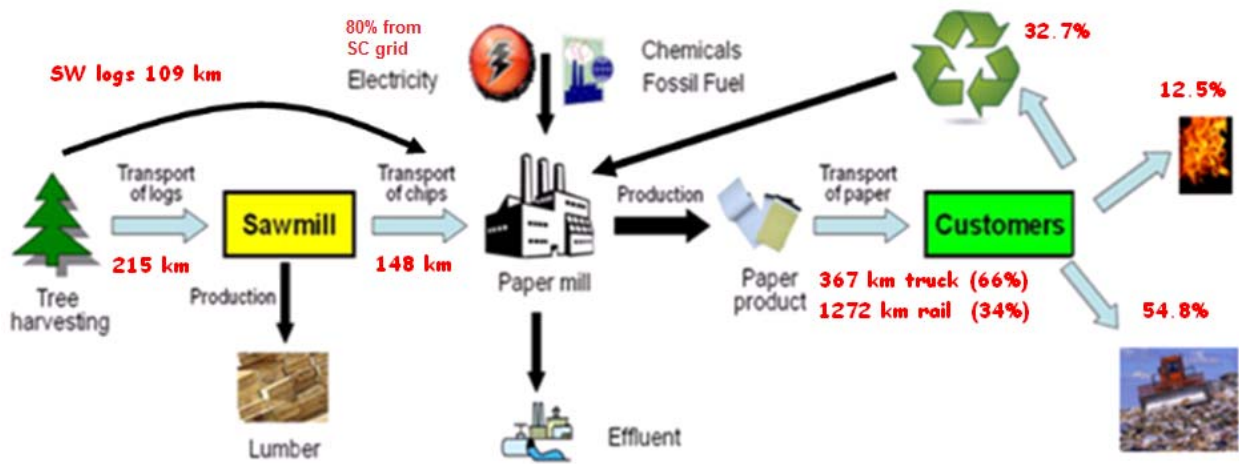
Figure 1 shows the processes included in the life cycle of paper, including some of the differences in transportation distance at each paper mill. For chemical or thermomechanical pulp, wood is either delivered to the paper mill as logs, debarked and chipped, or delivered as chips, generally from sawmills. After manufacture of paper from pulp, mineral fillers, internal additives and, in some cases, coating or a surface treatment, the paper is transported to customers. After printing and delivery to end users, the paper is either recycled, incinerated or landfilled.

Figure 1: Processes involved in the life cycle of paper



Alma, QC

“CRADLE TO GRAVE” ANALYSIS



Catawba, SC

“CRADLE TO GRAVE” ANALYSIS

3.4.1 Software tools

The LCI and LCIA calculations were done using SimaPro™ 7.1 software. Potential environmental impacts were characterized using the IMPACT 2002+ impact assessment method, version 2.10 [Ref. 5], which is an internationally recognized method for LCIA. The database used for the environmental impact of components was Ecoinvent, which is a model based on European inputs, but it was adjusted for the North American electrical grid by NCASI, using data from the International Energy Agency database to model the Canadian, Mexican, and U.S. production mix in 2005. A component was also added to calculate the carbon storage component from paper in landfill at end of life (see section 3.4.7) as well as the proportion of paper considered to be permanently stored due to product in use (assumed to be 2.79% after 100 years for all paper grades in the study). The database used for the original NCASI study was U.S. LCI, which does not consider land use impacts. Since the LCA carried out in 2009 for Resolute showed that land use impact differences can be significant when comparing mechanical and chemical pulps [Ref. 3], it was decided to use the Ecoinvent database (version 2.2, 2010) for all paper grades in the present study. At the same time, it should be stated that the land use data in the Ecoinvent database are from Europe, because there are no North American data available.

3.4.2 Transportation

For transportation of the product to customers, the same modes and distances as in the NCASI study [Ref. 1] were used (56.8% by truck a distance of 201 km and 43.2% by rail a distance of 1410 km), so as to eliminate this as a factor in comparing the life cycle impact of Resolute paper to the UFS paper. These distances and modes come from U.S. Census and EPA data. An exhaustive analysis was not done to determine the real distances to actual customers in 2010. A sensitivity analysis was added in section 5.4 to determine the effect of product transportation difference on the results.

For the CFS and AbiBow Max paper, the same approach was used. In this case, the figures are 66.2% by truck a distance of 367 km and 33.8% by rail a distance of 1272 km.

3.4.3 Emissions and Wastes

For the Alma mill, data reported for 2009 to the NPRI (National Pollutant Release Inventory) of Environment Canada were used for emissions to air, water and soil. For the Catawba mill, data reported for 2009 to the TRI (Toxics Release Inventory) program of the EPA were used, but as only data for soil are included there, generic data from Ecoinvent were used for air and water, except where specific data were available from the mill.

3.4.4 Energy Usage

An internal analysis was carried out by Resolute in 2010 to calculate the allocation of steam and electricity to various paper grades at the mills in this study. These figures were used to allocate purchased steam fuels and purchased electricity to each paper grade. Tables 5-8 list the sources of energy for each grade, including the reference grades UFS and CFS from the NCASI study. NCASI's estimates were derived from a database provided by Fisher International. The numbers for Resolute are likely of higher accuracy than the UFS and CFS numbers. Alma uses much less energy than UFS because there is no chemical pulp. Catawba uses about the same amount of renewable energy as CFS, but less fossil energy and less purchased electricity than CFS. Higher heating values (HHV) of fuels were used.

Table 3: Energy Usage in Alma paper grades vs. UFS

	Uncoated Freesheet	Equal Offset	Ecopaque Offset	Ecopaque Laser	Ecopaque Jet	Equal Offset Book	Alternative Offset
Oil, GJ/ADMT	1.47	0.12	0.12	0.12	0.12	0.12	0.12
Coal, GJ/ADMT	3.77	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas, GJ/ADMT	4.08	2.87	2.87	2.87	2.87	2.87	2.87
Tire-derived fuel, GJ/ADMT	0.24	0.00	0.00	0.00	0.00	0.00	0.00
Hog fuel, GJ/ADMT	5.39	1.35	1.35	1.35	1.35	1.35	1.35
Black liquor solids, GJ/ADMT	15.44	0.00	0.00	0.00	0.00	0.00	0.00
Total fuel energy, GJ/ADMT	30.38	4.34	4.34	4.34	4.34	4.34	4.34
Purchased electricity, GJ/ADMT	6.59	9.02	9.11	8.91	8.91	9.30	10.36
Total GJ energy/ADMT	37.0	13.4	13.5	13.2	13.2	13.6	14.7

Table 4: Energy Usage in Catawba’s AbiBow Max grade vs. CFS

	Coated Freesheet	AbiBow Max
Oil, GJ/ADMT	1.86	0.00
Coal, GJ/ADMT	6.13	0.00
Natural Gas, GJ/ADMT	2.39	1.85
Tire-derived fuel, GJ/ADMT	0.22	0.34
Hog fuel, GJ/ADMT	6.19	4.49
Black liquor solids, GJ/ADMT	10.0	12.03
Total fuel energy, GJ/ADMT	26.8	18.7
Purchased electricity, GJ/ADMT	4.09	4.58
Total GJ energy/ADMT	30.9	23.3

3.4.5 Sources of electrical energy

Several of the impact categories are affected by the types of electrical energy on the local grid. For instance, coal-fired electricity has the highest global warming impact score of the five sources listed in Table 5, and nuclear energy affects ionizing radiation as well as non-renewable energy. Quebec (where the Alma mill is located) has 94% hydro-based power, which is considered renewable, whereas South Carolina has mostly non-renewable power.

Table 5: Sources of Electrical Energy, in %

Power Source	QC	SC	UFS	CFS
Hydro	94.1	0.2	15.5	5.1
Natural Gas	2.6	6.1	14.4	11.2
Nuclear	2.5	51.3	23.0	15.8
Coal	0.0	39.8	43.3	62.4
Biomass	0.0	1.8	2.2	4.0

3.4.6 Allocation

For the question of recycling of the product after it is used, and how this affects the allocation of life cycle impact values, the method called “Subsequent Uses” was adopted. This allocates impacts between the first use of fibers and any subsequent uses as it is recycled. This is the same method used in the NCASI study, but a sensitivity analysis for allocation method was also performed and reported on in Section 5.2. The allocation of wood from the forest into lumber, chips and woodwaste was treated the same way as in the NCASI study, which is an economic allocation (91% of economic value goes to lumber, 6% to chips

and 3% to woodwaste). A sensitivity study was added in section 5.6 to determine the differences if a mass allocation is used.

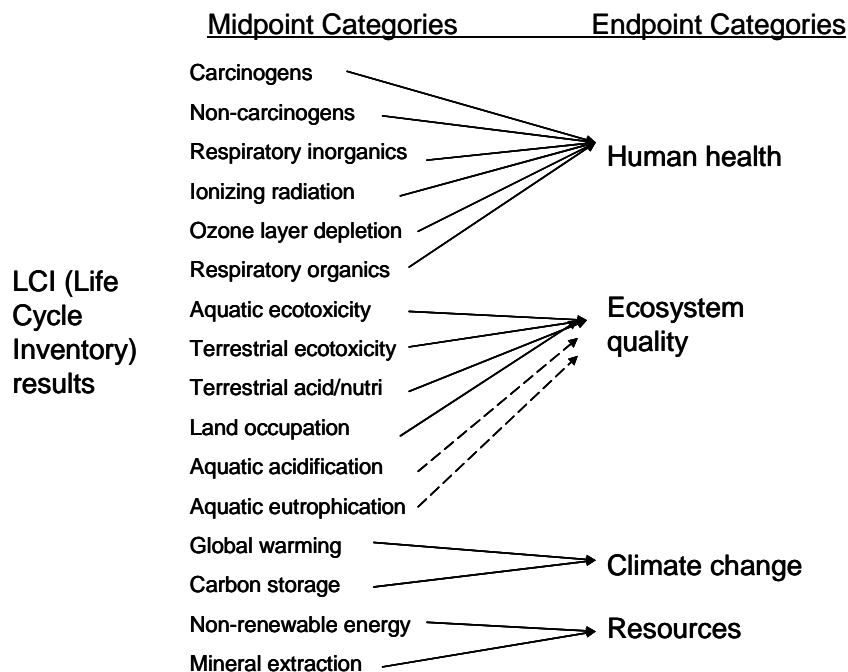
3.4.7 End of life treatment

As in the NCASI study, it was considered that 71.8% of UFS is recycled, 23% goes to landfill and 5.2% is incinerated at end of life. For CFS converted into catalogs, it was considered that 32.7% is recycled, 54.8% goes to landfill and 12.5% incinerated at end of life. According to studies done by the University of North Carolina and interpreted by the US EPA [Ref. 2], about 88% of uncoated freesheet paper disposed of in a landfill decomposes to a mixture of methane and carbon dioxide while 12% remains there permanently as stored carbon. The same study shows that only 15% of mechanical pulp-based papers decompose in a landfill and 85% remains as stored carbon. Methane emission to air and carbon stored in the landfill were calculated by the same method as in the NCASI study. Biomass carbon content was calculated for each grade, and the amount decomposed was calculated based on the mechanical and chemical pulp content of the sheets and whether it was coated or not. Details are given in Appendix 1.

3.4.8 Impact Categories

The IMPACT 2002+ method [Ref. 5] provides potential environmental impact scores for 15 midpoint or “problem” categories. In this study, we added a sixteenth midpoint category called carbon storage which is really a sub-category of global warming. This was done so that its individual contribution to global warming could be tracked easily, particularly since it is a negative impact (it reduces atmospheric carbon and therefore prevents global warming). Figure 2 shows the impact categories used by this method of calculation. The IMPACT 2002+ method also provides results for 4 endpoint or “damage” categories (human health, ecosystem quality, climate change and resources) by applying a different weight to the midpoint categories contributing to each endpoint category (Figure 2). This allows the evaluation of how important each of the midpoint categories are, relative to these four endpoints. However, no weighting factors were as yet provided for the aquatic acidification and eutrophication categories.

Figure 2: IMPACT Categories of Environmental Impact

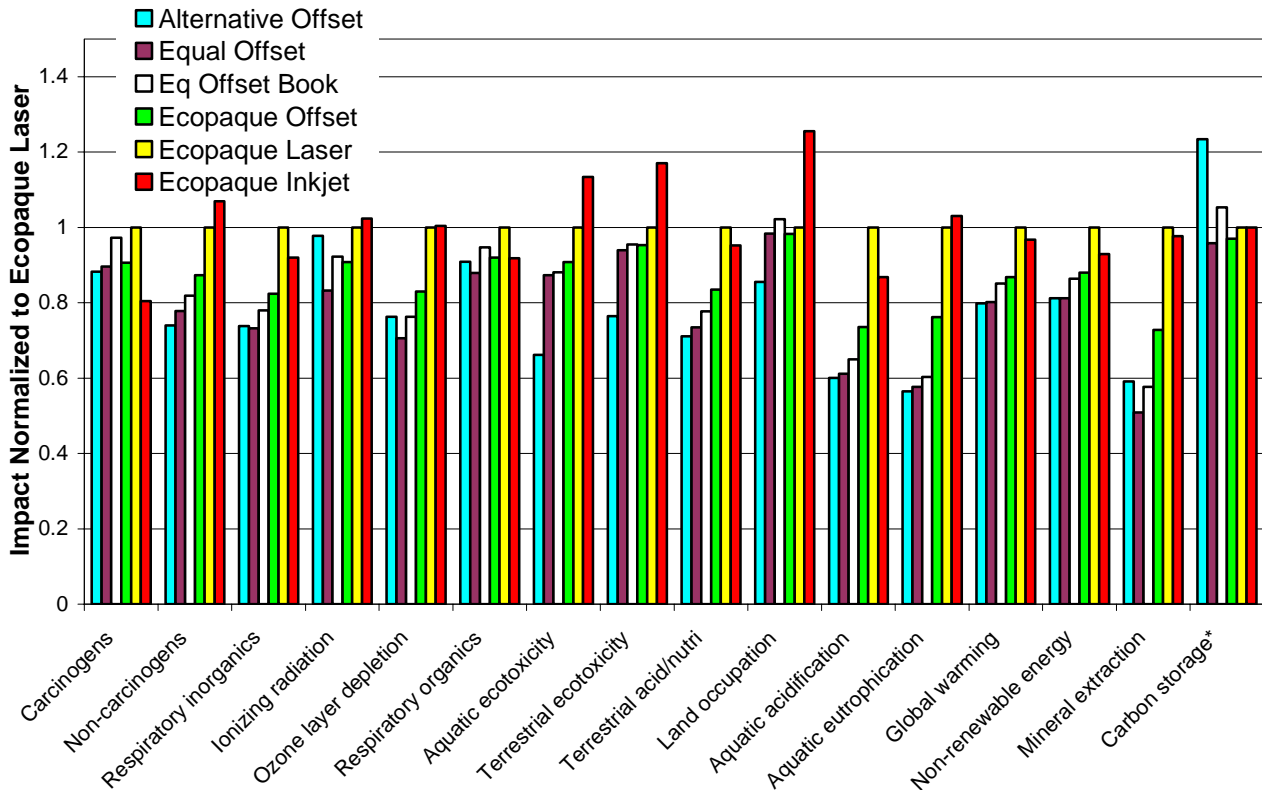


4 IMPACT ASSESSMENT

4.1 Comparison between Alma paper grades

Life Cycle Impact scores were calculated for each of the six Resolute paper grades studied. The scores are tabulated in Appendix 2, along with those for UFS. Shown in Figure 3 are the relative midpoint values normalized to the Ecopaque Laser impact value for each category. Note that Carbon storage is actually a negative impact.

Figure 3: Relative impacts of six Resolute Alma paper grades



*Carbon storage is a negative score

The differences between the impact scores of these six grades can be explained principally by differences in basis weight, type and quantity of filler and coating binder formulations (see Table 1 for details).

- Basis weight:** The Equal and Ecopaque Offset grades are a slightly lower basis weight.
- Fillers:** Equal Offset contains a higher amount of calcium carbonate filler and a small amount of clay. The three Ecopaque grades use a synthetic filler. Clay and calcium carbonate are mined with little processing, while manufacturing the synthetic filler requires more energy and chemical processing than a mined filler.
- Coating binder:** The Inkjet grade uses more starch as a binder in the coating, whereas the other three coated grades use about equal quantities of starch and latex as a binder. This is the only significant difference between the grades in the case of Land Occupation, because more farmland is required to grow corn to provide the starch. Alternative Offset is the only uncoated grade, so it has the lowest levels of calcium carbonate and clay and contains no starch or latex, thus it has the lowest impact score in many categories. And the Inkjet grade has the most starch, which increases its impact score in a number of categories.

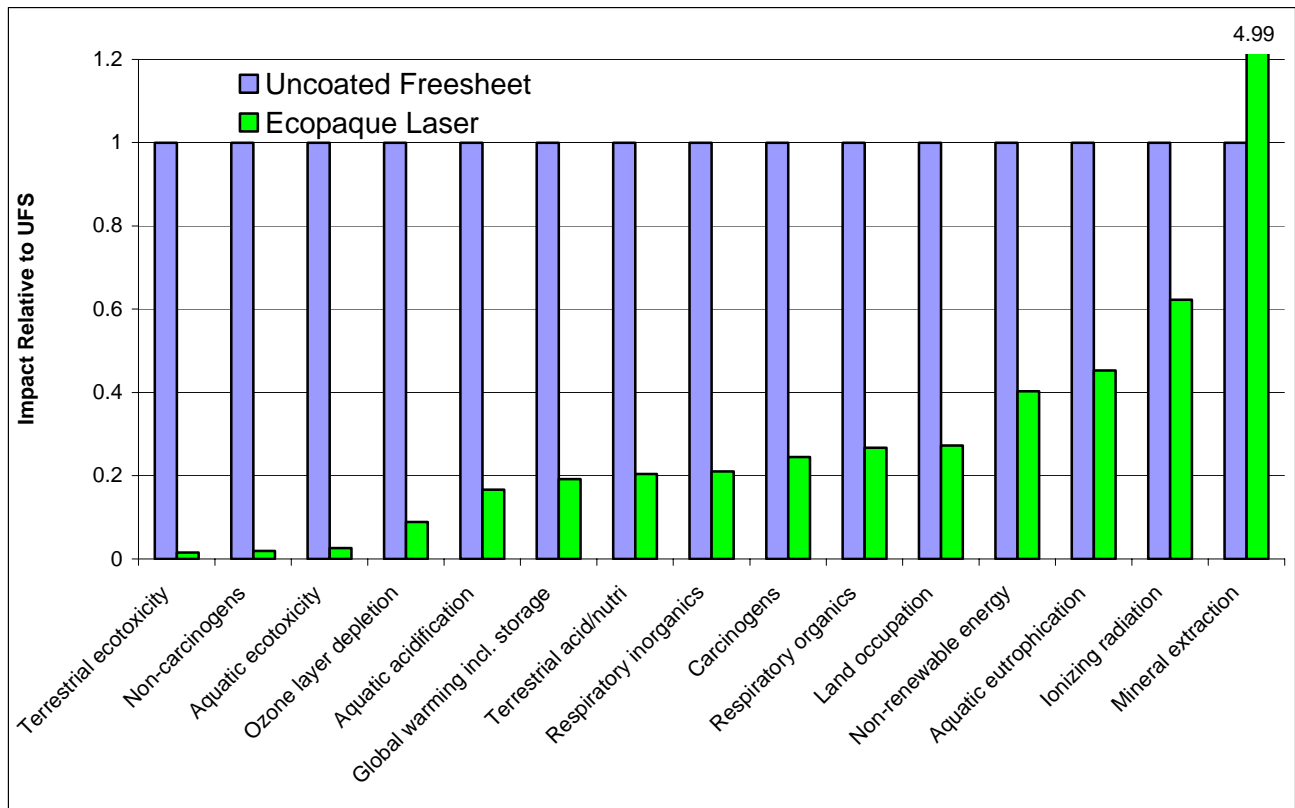
4.2 Comparison of Alma paper grades to Uncoated Freesheet paper

4.2.1 Midpoint Categories

Figure 4 shows the midpoint impact score of Ecopaque Laser relative to that of the uncoated freesheet paper described earlier. For every category but mineral extraction, the impact score is much lower for the Ecopaque Laser. In this graph, the carbon storage impact score was subtracted from the global warming impact score to create an overall global warming impact score.

For the other Alma grades' impact ratio to UFS, the impact ratio can be calculated by multiplying the ratio here by the ratio to Ecopaque Laser in Figure 3.

Figure 4: Relative impact of Ecopaque Laser to Uncoated Freesheet



. The principal reasons for the difference in impact scores between Ecopaque Laser and UFS can be summarized as follows:

- Basis weight:** the EP Laser grade is 11% lower in basis weight.
- Thermal Energy:** the kraft process requires much more steam to drive the process than the mechanical pulping process. Although about half of this energy comes from the wood itself, the amount of fossil fuel and hog fuel used are also much higher (see Table 5). There are also life cycle impacts from the boiler emissions to air and to soil.
- Electrical Energy:** Mechanical pulp uses more electricity than kraft pulp, but some of the electrical energy is used to generate steam in the process, which offsets the purchase of other steam fuels. The electricity grid in Quebec is about 95% from hydro-electric power, which has a very low carbon footprint, compared to the average power grid for the UFS in this study, which uses more fossil fuels such as coal.
- Filler type:** Uncoated freesheet in North America uses calcium carbonate as a filler, whereas Ecopaque laser uses a mixture of calcium carbonate, clay and synthetic clay (see Table 1).

One of the reasons why the mineral extraction impact score is lower for UFS because limestone extracted for calcium carbonate used in UFS is an abundant material, whereas the raw materials for synthetic clay and clay are relatively less abundant on the earth's surface. The units of this impact category are MJ of surplus energy for future extraction, so when a material is less available, it takes more energy to extract it.

- e. **Pulp yield:** Kraft pulp has a yield of 45-50% from wood, compared to 93% for the mechanical pulp in Alma. This means about twice as much wood needs to be harvested and transported per ream of UFS paper (see Table 1).
- f. **Chemicals used:** Kraft pulping and bleaching requires chemicals that are not used in mechanical pulping, such as sulphuric acid, sodium chlorate and oxygen. It also uses higher quantities of starch. Another key difference is the amount of hydrogen peroxide used – around 4 times more is used in the Alma grades than in UFS. This contributes toward the difference in Mineral extraction scores due to the use of aluminum chloride as a reagent in the manufacture of this chemical.
- g. **Decomposition in landfills:** Mechanical pulp results in less methane emission and more carbon storage in the landfill. See section 3.4.7.

4.2.2 Endpoint Categories

The concept of endpoint categories, or “damage” categories, is used to determine the relative importance of each midpoint category to an overall environmental issue [Ref 4]. Figure 2 shows which of four endpoint categories each midpoint is assigned to. In Figure 5, we see the contribution of each of the midpoint impact scores to the endpoint impact scores. It can be seen that for Human Health (5a), only respiratory inorganics and toxic (carcinogenic or non-carcinogenic) emissions are important. While Simapro calculated figures for the other three midpoints noted here, the amounts can be considered negligible in comparison. For example, although in Figure 4 the EP Laser grade has an Ionizing Radiation impact score that is 62% of that for UFS, the main reason for this is the presence of more nuclear energy in the power grid for the aggregated UFS paper. Figure 5c, however, shows that the impact on human health of the presence of nuclear energy in the power grid is negligible.

Figure 5a: Human Health Relative Impacts

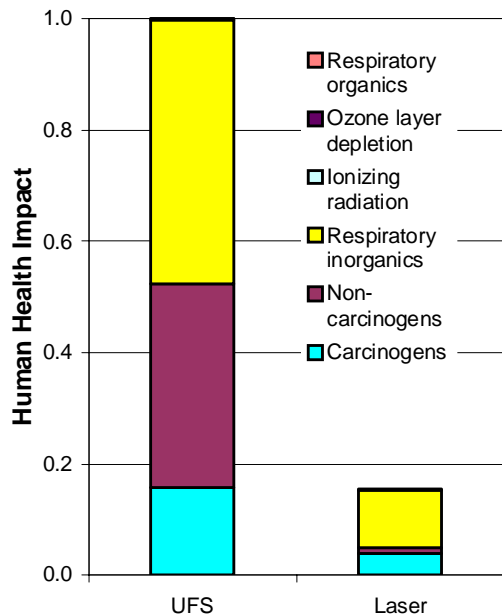
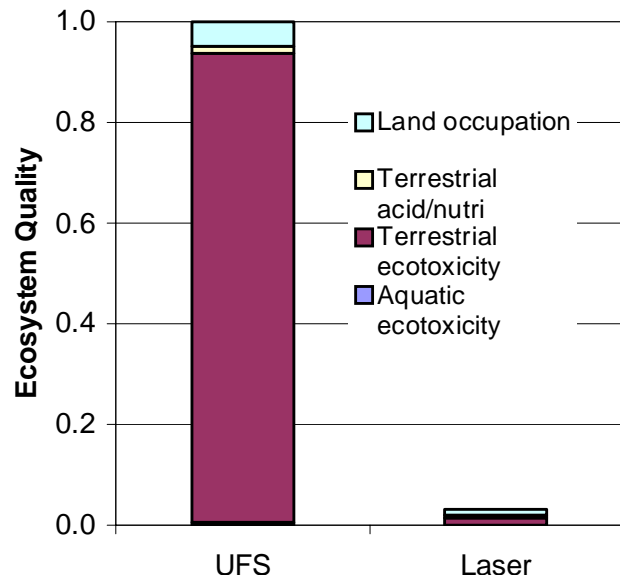


Figure 5b: Ecosystem Quality Relative Impacts



Similarly, in terms of Ecosystem Quality (5b), only terrestrial ecotoxicity and land occupation are significant. For the Resources endpoint (5c), mineral extraction's contribution is negligible; only non-renewable energy is of importance to this endpoint..

Figure 5c: Resources

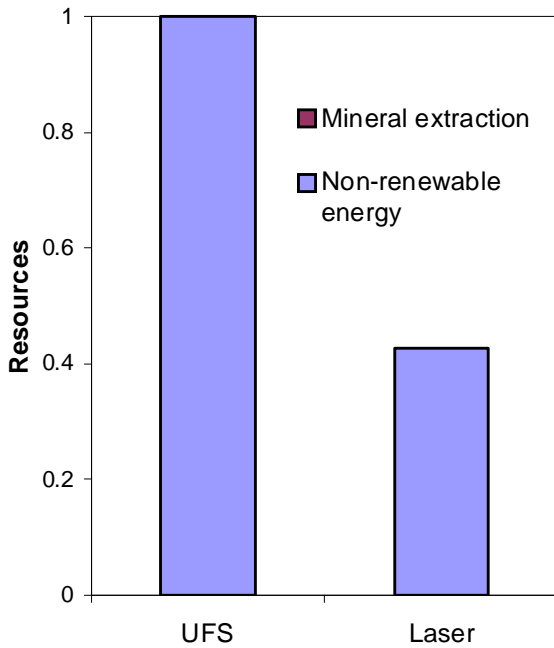
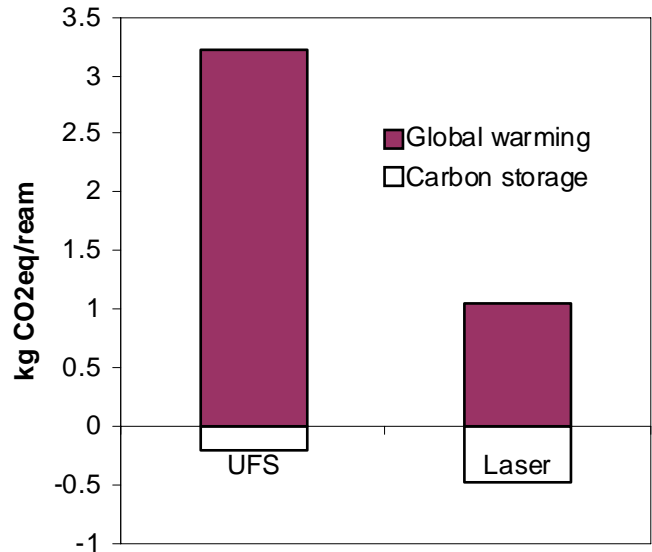


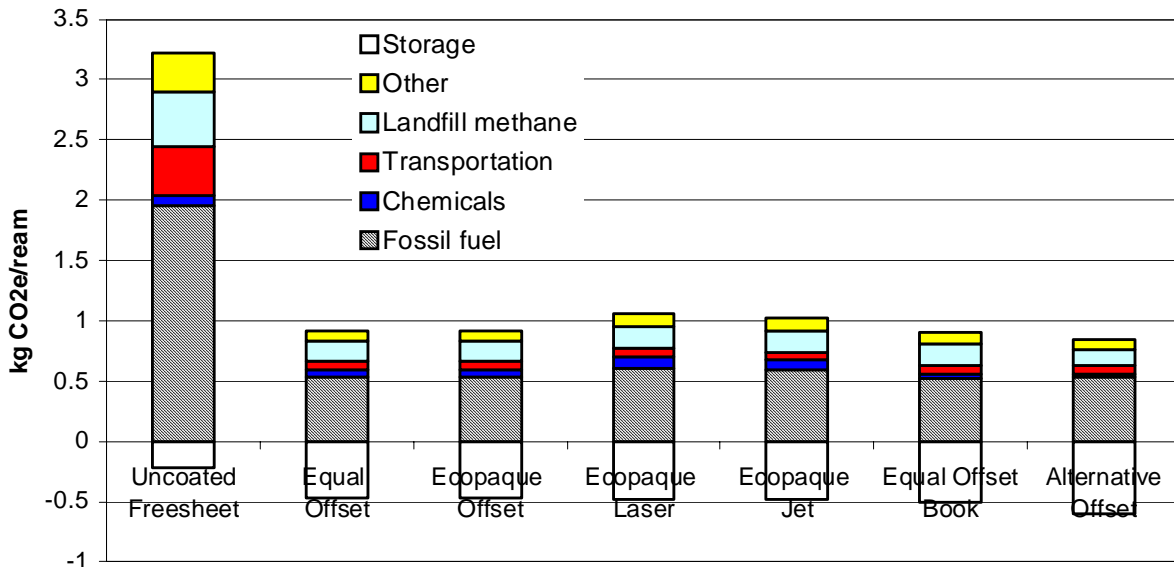
Figure 5d: Climate Change



4.2.3 Detailed Analysis of Climate Change

Climate change is of particular interest to paper customers, and the concept of “carbon footprint” of products likely has more public awareness than the other three endpoints discussed here. The impact data were analyzed further to determine what individual processes in the life cycle contribute to the carbon balance shown in Figure 5d. The results of this analysis are shown in Figure 6. There are significant differences in carbon footprint from several processes in the life cycle, including carbon storage and methane production in the landfill, transportation (of wood as well as chemicals), and use of fossil fuel (for steam or electrical energy). The overall carbon footprint for UFS (emissions minus storage) is 3.0 kg CO₂ eq for UFS and between 0.12 kg for Equal Offset Book and 0.58 kg for Ecopaque Laser.

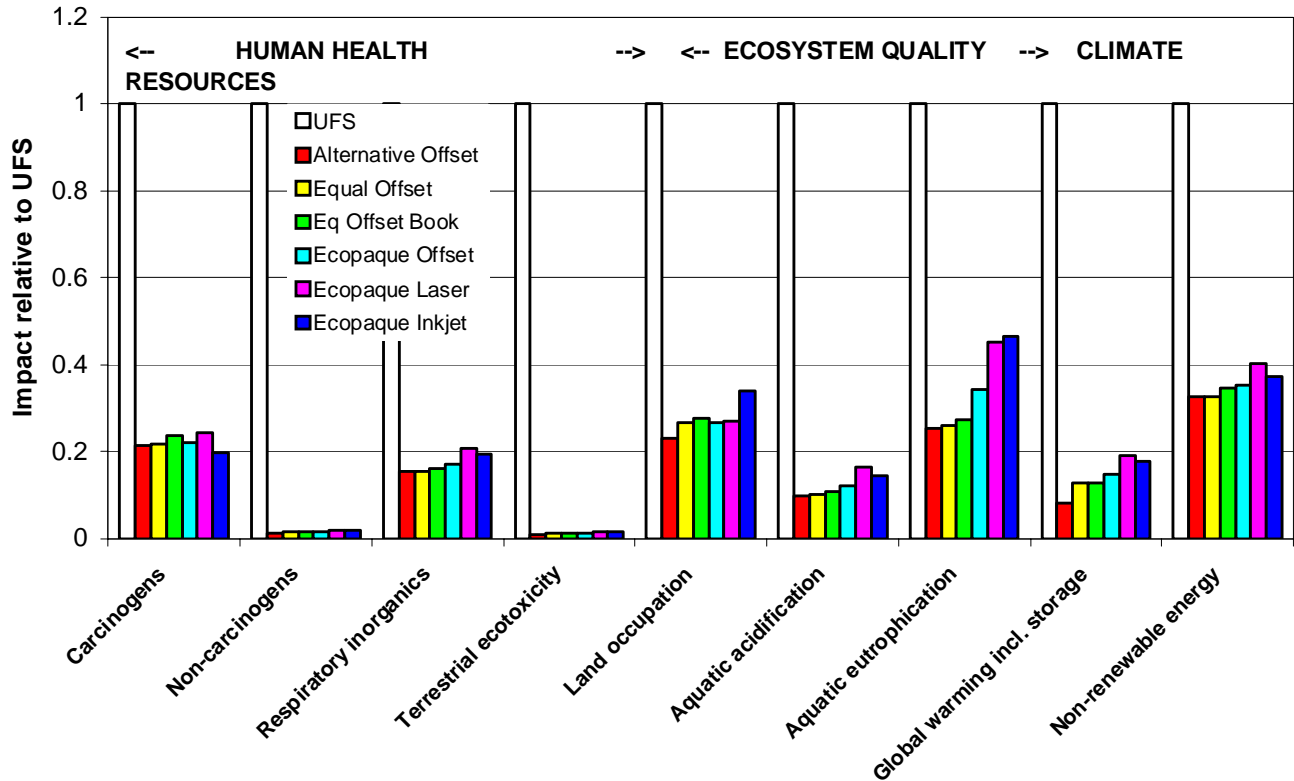
Figure 6: Detailed carbon footprint of UFS and Alma grades



4.2.4 Comparison of Life Cycle Impact after Endpoint Analysis

It may help now to re-analyze the comparison made in Figure 4 in light of what the damage assessment revealed. We learned that there are several categories whose impact is negligible when compared to other midpoints assigned to the same endpoint. Figure 7 shows the relative impact differences for all the remaining categories after removing those with less than 3% contribution to their endpoint in all grades being compared. Aquatic eutrophication and aquatic acidification were not removed, because the damage assessment method does not assign a weighting to these two midpoints; they may or may not be important to ecosystem quality.

Figure 7: Comparison of LCI after Removal of Negligible Midpoints - Alma



4.2.5 Difference analysis of impact categories:

To understand in detail each of the midpoint impact categories, the impact scores in Figure 4 were analyzed to locate the main reasons for these impact differences. The results are shown in Table 6 for the categories shown in Figure 7. The percentages referred to in this Table are calculated from the following equation:

$$100\% \times \frac{[\text{Absolute Impact of source (UFS)} - \text{Absolute impact of source (Resolute grade)}]}{[\text{Total category impact (UFS)} - \text{Total category impact (Resolute grade)}]}$$

where “category” is the impact category in the left-hand column, and “source” is the item listed in the right-hand columns. Where the percentage values do not add up to 100%, no single remaining sources are considered significant.

Most of the factors in Table 6 can be explained by the factors described in section 4.2.1, The reason that transportation shows up as a factor in Table 6 is because kraft pulp needs about twice as much wood as mechanical pulp to produce the same weight of pulp.

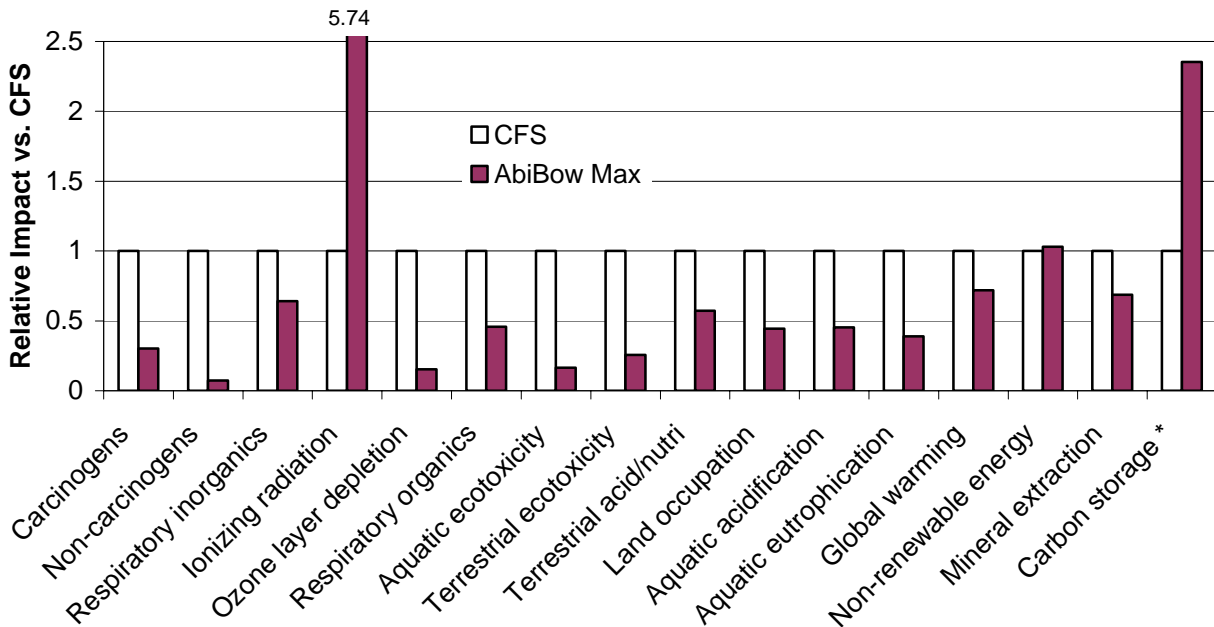
Table 6: Analysis of the difference between impact of Ecopaque Laser and UFS

Carcinogens	Fossil fuel (natural gas production) 100%		
Non-carcinogens	Kraft mill landfill 71%	Deink mill landfill 24%	
Respiratory inorganics	Boiler emissions 36%	Transportation 22%	Fossil fuel 20%
Terrestrial Ecotoxicity	Boiler ash 74%	Deink mill sludge 17%	
Land occupancy	Wood production 51%	Starch production 30%	
Aquatic acidification	Kraft pulp effluent 44%	Fossil fuel 29%	Transportation 12%
Aquatic eutrophication	Fertilizer for corn (starch) 100%		
Global warming	Fossil fuel 42% (coal, gas, grid)	Transportation 10%	Landfill methane 9%
Non-renewable energy	Coal 42%	Oil 39%	Gas 18%

4.3 Comparison of Catawba grades to Coated Freesheet

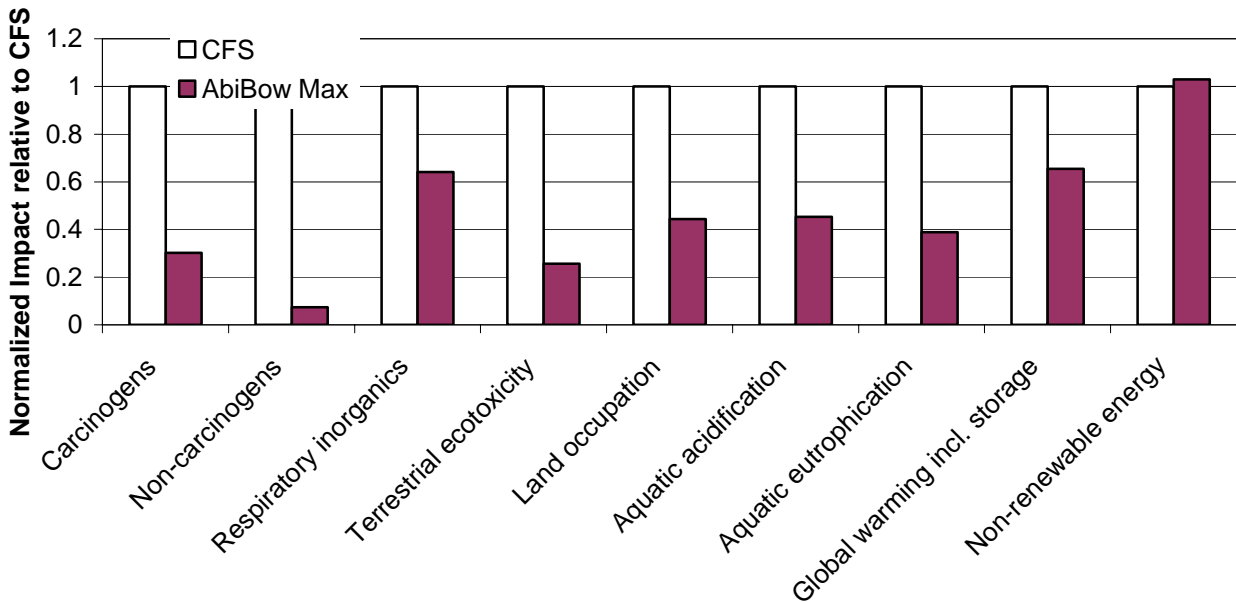
In Figure 8, the midpoint impact scores are seen for Catawba's AbiBow Max sheet, compared to CFS. Damage assessment analysis showed the same categories as before could be ignored, and Figure 9 shows the impact score comparison after removal of negligible categories. Carbon storage is a negative impact, and in Figure 9 it is subtracted from the Global Warming impact score.

Figure 8: Relative Impact of Catawba paper grades compared to CFS



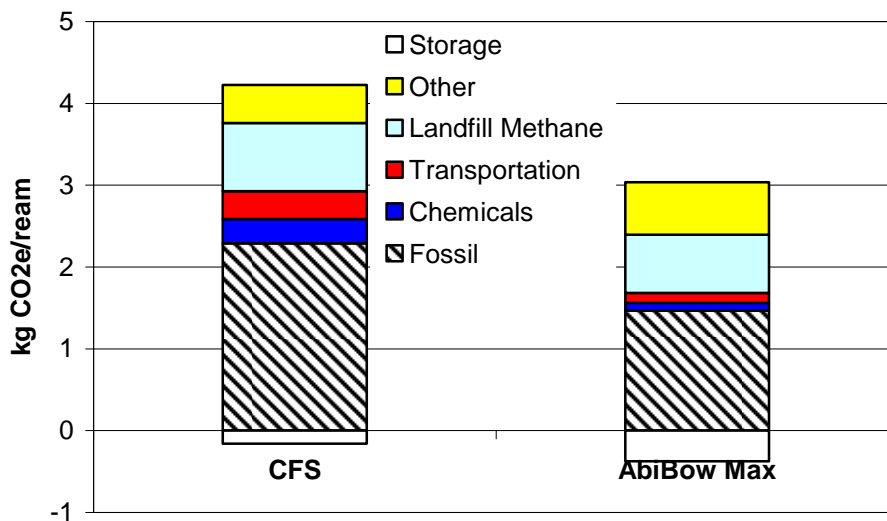
*Carbon storage is a negative score

Figure 9: Comparison of LCI after Removal of Negligible Midpoints – Catawba



It can be seen that when Catawba's AbiBow Max sheet is compared to North American coated freesheet, all of the impact categories show a lower value for the Catawba sheet, except for Non-renewable Energy. This is because the Catawba electrical grid (South Carolina) has 51% nuclear energy, compared to only 16% for the mixture of mills used in the CFS study (see Table 5). This is also the reason for the high Ionizing Radiation impact score in Figure 8, however this was determined to have a negligible contribution to the Human Health endpoint. The detailed carbon footprint for AbiBow Max is shown in Figure 10. Contributions from Fossil fuels, transportation and chemicals are all lower than CFS.

Figure 10: Detailed Carbon footprint of AbiBow Max vs. CFS



5 DISCUSSION

5.1 Difference from Resolute's LCA of 2009

As mentioned previously, Resolute published a Life Cycle Analysis on its website [Ref 3] in 2009 which compared Equal Offset to UFS. In that study the impact scores for Equal Offset were found to range between 30 and 100% of the UFS impact scores, whereas in this study the ratio ranges from 1% to 52%, except for Mineral extraction, which is 2.5 times higher than that for UFS. There are several reasons why the results of that study are different from this one. Here is a list of the principal reasons:

- 1 The Equal Offset paper in the previous study was based on production data from 2006 and 2007, while in this case it came from 2010. The filler content was changed from 5% clay in 2007 to 8% GCC and 2% clay in 2010 due to product optimization. Fuel usage was lower in 2010 due to energy reduction efforts,
- 2 The UFS in the 2009 study was based on data from two large mills, one in Quebec, Canada and one in the Southeast US. The UFS in this study is based on 31 mills in the US and Canada which represent 75% of the industry and thus represent the average much better. Due to the low carbon footprint of Quebec electricity (94% hydro-electric), impact differences attributable to electricity type were not as marked in the 2009 study as in the present study.
- 3 The method of allocating impacts from the lumber and chips portion of the wood in 2009 was based on mass allocation. In the present study, we adjusted our results to an economic allocation where the economic value of the lumber and the chips was used to allocate these impacts. This was done because it is the method used in the Ecoinvent database used in this study. See Section 5.6 for a sensitivity analysis on this parameter.
- 4 The 2009 study was done using only the Extraction Load method of allocation. Results for both this method and the Subsequent Uses method were computed in the present study (section 5.2). The absolute impact scores are different, but in comparing two papers using the same method, the results will be similar for all categories except carbon storage. Using the Extraction Load method gives more credit to carbon storage for mechanical pulp-based grades of paper.

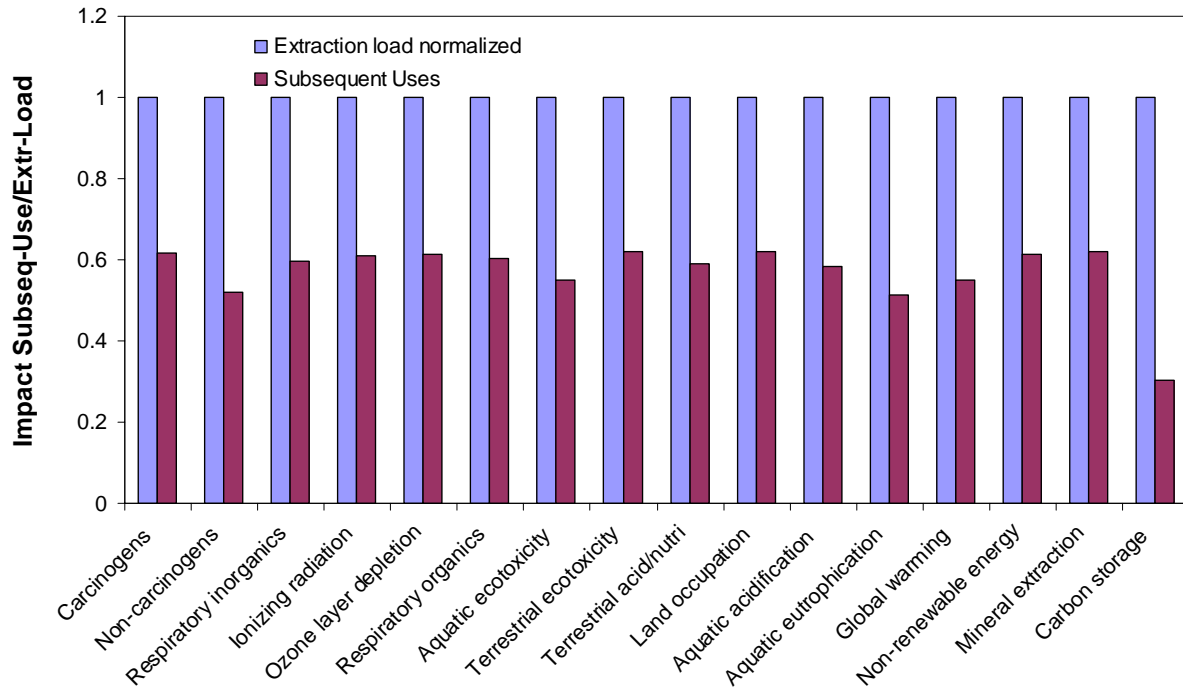
5.2 Sensitivity analysis - allocation method

In the previous LCA study performed for Resolute on Equal Offset in 2009 [Ref 3], it was considered that the paper at end-of-life goes 80% to landfill and 20% to incineration. Effects of recycling this paper were ignored. This approach is called "Extraction Load".

In the NCASI study [Ref. 1], a different approach was taken to consider end-of-life. From usage and recycling statistics, NCASI was able to compute the number of times a paper fiber is re-used as it is recycled, and this was used to allocate the environmental impact between the manufacture of virgin paper and the subsequent uses of this fiber as it is recycled. NCASI was also able to compute that about 3% of freesheet paper remains in use after 100 years, and can therefore be considered as storage and not released to the environment. This allocation method is called "Subsequent Uses" throughout this report. The details of how to apply this methodology are given in 5.3.

Shown in Figure 11 are the results of a comparison of the impact scores of Ecopaque Laser paper using these two allocation methods. For this comparison, the values for extraction load were normalized to 1 so that the relative difference between the two methods could be seen (the actual units of each impact category are different from each other). It can be seen that using the subsequent uses method results in lower impact scores. This is due to the impact being distributed between the first (or virgin) use of fiber and subsequent uses. The difference is largest for carbon storage, since 71.8% of office paper is recycled in North America.

Figure 11: Comparison of End-of-Life Allocation methods (Ecopaque Laser)



5.3 Sensitivity Analysis – loss rates and recycling

As mentioned in section 3 (Scope), the paper grades were treated as having the same loss and recycling rates. The recycling rate assumption should be accurate, since Rolute’s paper is used by the same users as a product equivalent to the UFS or CFS it is substituting, In considering the loss rate, however, it can be assumed only that the pulp fibres in the sheet can be re-used. The fillers and coating in the sheet are generally lost in the recycling of paper.

NCASI has determined [Ref. 1] that the recovery rate of office paper (UFS) is 71.8%, and when this is corrected for the quantity remaining in use after 100 years, 69.8%. The number of total uses of fibre is calculated as u=2.19 (or the number of “subsequent” uses is 1.19). The allocation factor A_v for virgin fibre is then calculated from:

$$A_v = (1-z_1) + (z_1/u) = 0.62,$$

where z_1 is 0.698 and $u = 2.19$

If we look up the fibre (i.e. pulp) content of the paper grades in Table 1, it can be seen that UFS has 74% fibre. The grade with maximum fibre content in this Table is Alternative Offset at 84% and the grade with minimum fibre content is Ecopaque Laser at 68%. If we assume that the allocation factor for UFS is 0.62 as found by NCASI already accounts for the loss of non-fibrous material (which is not clear from the study), we can calculate z_1 and u for the two Rolute grades mentioned:

Alternative Offset: $z_1 = 84/74*(0.698) = 0.792$
 $u = 1 + 84/74*(1.19) = 2.35$
 $A_v = (1-0.792) + (0.792/2.35) = 0.55$

Ecopaque Laser: $z_1 = 68/74*(0.698) = 0.641$
 $u = 1 + 68/74*(1.19) = 2.09$
 $A_v = (1-0.641) + (0.641/2.09) = 0.67$

The above calculated values for A_v were used in Simapro to calculate what difference this would make to the impact scores for these grades.

The results showed that Alternative offset, with its higher fibre content, results in all impact scores being about 8% lower. Similarly, Ecopaque Laser, with its lower fibre content results in impact scores 5% higher. The carbon storage scores would not change, because the calculation in Appendix 1 already takes care of the biomass carbon content for each grade.

5.4 Sensitivity Analysis – transportation distance

In order to determine how sensitive the impact analysis is to the distance of transportation from the paper manufacturer to the customer, the distance was doubled for both the trucking and rail modes, using the Ecopaque Laser grade as a representative example. This resulted in an average impact score increase of 5%, with a range from 0% to 11%. This is fairly small compared to the overall ratios between the Alma grades and UFS impact scores.

5.5 Sensitivity Analysis – landfill degradation of paper

To illustrate the effect of taking into consideration different decomposition rates of paper in a landfill, the factors in Appendix 1 were changed to equal those for UFS for the Ecopaque Laser grade. This affected global warming and carbon storage, changing the total global warming score from $1.06 - 0.48 = 0.58$ kg CO_2 /ream to a score of $1.29 - 0.17 = 1.12$, or almost double. The UFS score was 3.01, however, still significantly higher than the Ecopaque Laser grade.

5.6 Sensitivity Analysis – economic vs. mass allocation of wood

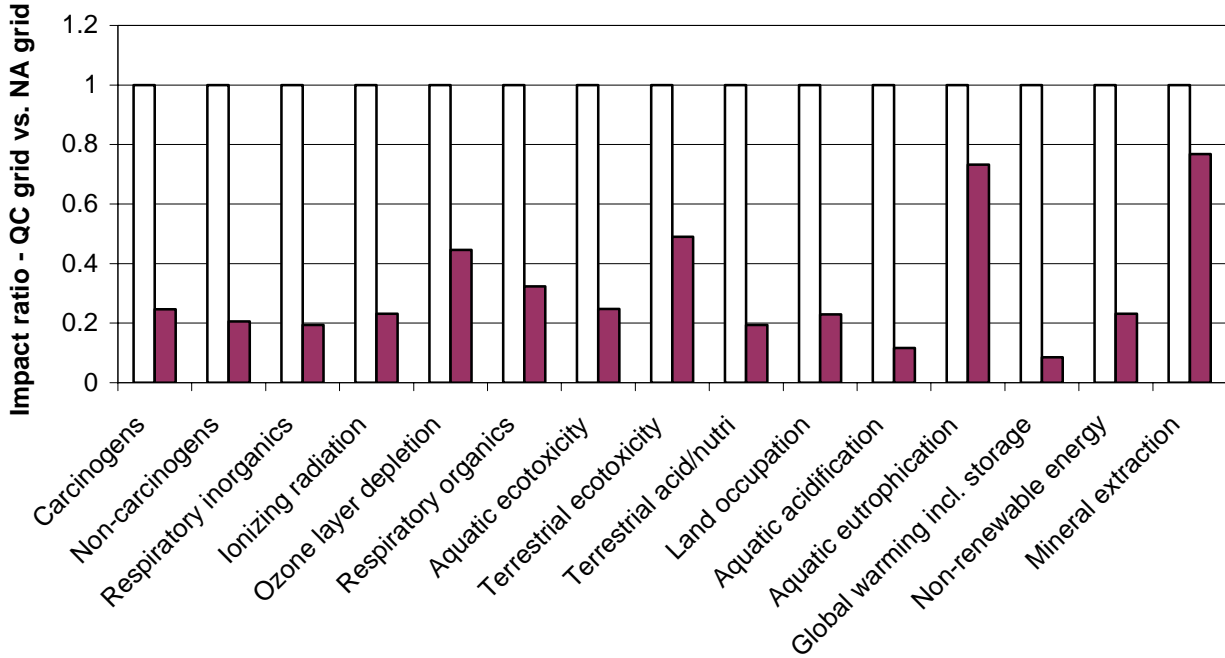
As mentioned in 3.4.6, the allocation method used by NCASI is an economic allocation that corresponds to an allocation of 91% to lumber, 6% to chips and 3% to woodwaste. As a sensitivity analysis, this was changed to represent a mass allocation of 39% lumber, 61% chips and 0% woodwaste, which was the original method used in Resolute's previous LCA study [Ref. 3]. It was found that this raised the Land Occupation impact score by a factor of 7, and the Respiratory Organics impact score by a factor of 2.6. Other scores that increased were Respiratory inorganics, Ozone layer depletion, Aquatic ecotoxicity, Terrestrial ecotoxicity, Terrestrial acid/nutri, Aquatic acidification, Global warming and Non-renewable energy, which increased by an average of 30%.

Note that mass allocation was not provided as an option for the UFS and CFS databases provided by NCASI, so this finding has no relevance to the comparison between Resolute and freesheet grades of paper being carried out here,

5.7 Sensitivity to Electrical Grid

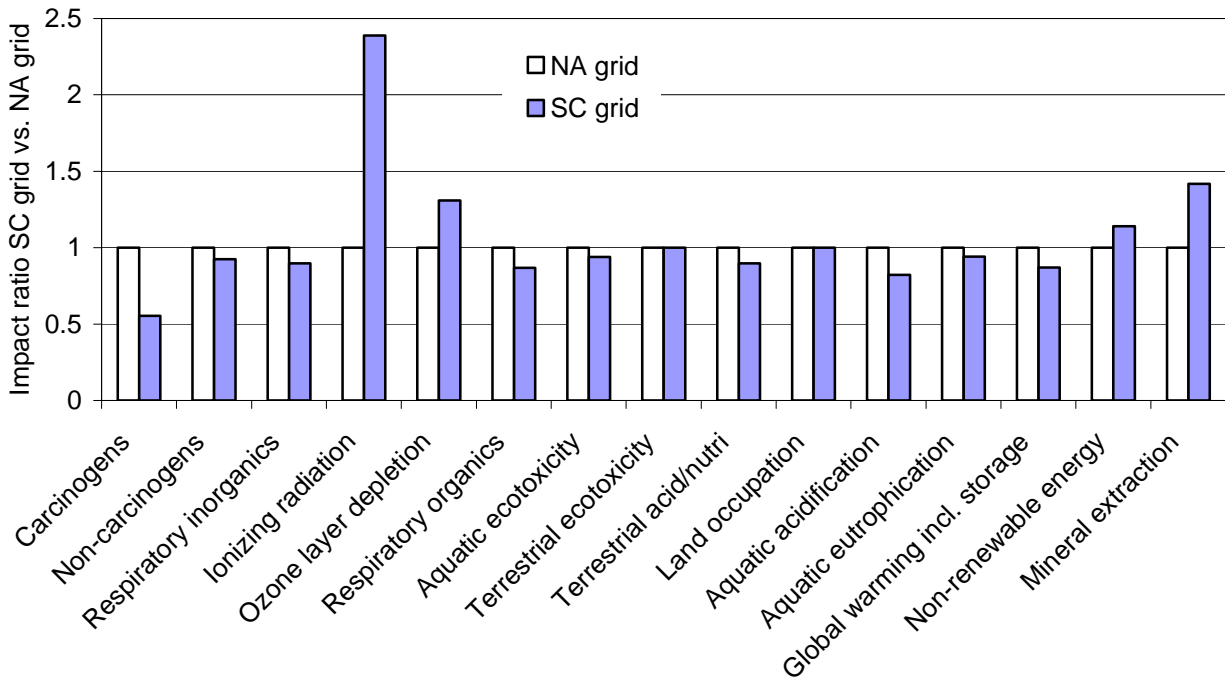
In order to understand how much the different sources of electricity in the state or provincial grid are to producing high or low impact scores, a sensitivity analysis was performed where the electricity source was set to the North American average. The Alternative Offset grade was chosen at Alma for this analysis. The results are shown in Figure 12. On the y axis is the ratio of the mill's score using the QC grid to its score if the North American average were used. The most obvious conclusion of this analysis is that the Quebec-sourced electricity used in Alma is a significant factor in producing low impact scores.

Figure 12 Sensitivity analysis for QC grid vs. NA average grid



A separate analysis was done for the AbiBow Max paper grade in Catawba, and is shown in Figure 13. This analysis shows that, impacts are similar for most categories except carcinogens (SC grid has lower impact score) and ionizing radiation (SC grid has higher impact score),

Figure 13 Sensitivity analysis for SC grid vs. NA average grid – AbiBow Max grade



5.8 Sensitivity to LCA methodology

At the suggestion of NCASI, the impact analysis was repeated using a different analysis tool, since different methods can result in different results, especially with the evaluation of carcinogens and non-carcinogens. The TRACI impact assessment method developed by U.S. EPA (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) was used for this analysis, and the analysis was done on Alma's Ecopaque Laser grade as well as the UFS. The results showed that the ratio of Carcinogens impact score with TRACI was 0.215, compared with 0.245 using IMPACT 2002+, which is of a similar order of magnitude. The ratio of Non-carcinogens impact score, however was 0.731, compared with 0.020 using IMPACT 2002+, which is about 37 times higher. This shows that methodology can affect the LCA results greatly for this impact category. It does not change the conclusion that Alma's Ecopaque Laser paper has a lower impact score than UFS, however.

5.9 Comments on Precision and Limitations of Study

Life Cycle Analysis is not an exact science. Certain assumptions have been made during this study, and certain strategies for representing data when direct measurements are not available. This can affect the uncertainty of the results.

Uncertainty can arise from two sources: uncertainty in the inventory data and uncertainty in the characterization factors. These are discussed separately below.

The inventory data with the most precision are the material flows, described in Tables 1-2 and the energy data, described in Tables 3-4. Precise figures based on a year of manufacturing each paper grade were used for the Resolute paper grades. The UFS and CFS material flows and energy data are based on an average of the majority of the North American producers of these grades (75% of UFS and 80% of CFS); an average of 100% of the industry might be slightly different. The data with the least precision are the releases to soil, water and air, since measurements are made infrequently, and reporting requirements are different in the US and Canada. Since some data on releases to the environment are not available directly from US mills, other strategies for estimating these data were used, both by NCASI for the UFS and CFS mills, and by the author for Catawba, as described in 3.4.3.

Another uncertainty studying the inventory data is the accuracy of background data associated with factors such as chemical production, transportation and land use, since the ecoinvent database uses data based on the European model. For instance the manufacture of a certain chemical in Europe may be by a different method or with a different energy efficiency than the North American production. Although distances and modes for transportation of products to the paper mills are generally accurate, the assumptions of fuel efficiency may be different in Europe than in North America. And finally, land use assumptions may be different in Europe, where there is less available space for development than in North America. In terms of the Resolute vs. freesheet comparisons, the error would be somewhat consistent for all grades, (though not identical given that different chemicals and fuels are used).

Uncertainty in the characterization factors has been assessed by the creators of the IMPACT 2002+ method [Ref. 6]. Table 7 lists the degree of uncertainty associated with each impact midpoint.

Since this study is a comparative assessment between Resolute paper grades and their freesheet equivalents, it would be useful to comment on how the amount of uncertainty in the impact scores compares to the differences found between the Resolute paper grades and the equivalent freesheet grades. Using the comments above and Table 7, we can make the following evaluations:

Alma (Figure 7): All scores for Alma are much less than the UFS scores, so there is a very high degree of certainty that Alma paper grades have lower impact scores than UFS in all categories shown.

Catawba (Figure 9): The non-renewable energy impact score for Catawba is no different from UFS within the uncertainty of the results. There is a high degree of certainty that the impact scores are lower than UFS in all other categories.

Table 7: Uncertainties in IMPACT 2002+ characterization factors

Midpoint or Endpoint category	Level of uncertainty
Human toxicity (carcinogenic and non-carcinogenic)	High
Respiratory inorganics	High
Ionizing radiation	High
Ozone layer depletion	Medium
Aquatic ecotoxicity	High
Terrestrial ecotoxicity	Very high
Terrestrial acidification/nitrification	High
Aquatic acidification	Low
Aquatic eutrophication	Low
Land occupation	High
Global warming	Low
Non-renewable energy	Low
Mineral extraction	Medium
Human Health endpoint	High
Ecosystem quality endpoint	High
Global warming endpoint	Low
Resources endpoint	Low

5.10 Water Usage Comparison

Water use impact assessment methodologies are still under development, and therefore water use was not made part of the LCA study. Nonetheless, water use is often a metric of interest in sustainability programs. In NCASI's study, figures were reported for the amount of water used for the aggregate UFS and CFS samples to manufacture the paper. Water use figures available from Resolute were used to produce the data in Table 8 for comparison. Typically, over 90% of the water used in the paper manufacturing process is returned to the environment in liquid form. For the Alma mill, data were calculated for the arithmetic average ream weight for the grades of paper analysed in this study.

Table 8: Water Use during Paper Manufacture

	UFS	Alma (avg)	CFS	Catawba AbiBow Max
kg/ream	133	90	78	94

6 CONCLUSIONS

The principal findings of this study are listed below:

1. Life Cycle Impact Analysis of six Resolute paper grades made in Alma, QC shows that the differences in impact score between these grades can be explained principally by differences in basis weight, filler type and coating binder. Paper with a similar thickness can be made at a lower basis weight, which lowers some environmental impacts. Synthetic clay uses more energy and processing than a mined filler such as clay or calcium carbonate. Starch and latex used as coating binders have different environmental attributes.
2. Comparison of Resolute's Ecopaque Laser paper made in Alma, QC to typical North American UFS paper shows that the Life Cycle Impact scores are much lower for Ecopaque Laser. This is due principally to differences in basis weight, amount and type of fuels used, carbon footprint of the electricity grid (which is very low in the case of the Alma mill), filler type, pulp type (mechanical or chemical), chemicals used and paper decomposition in landfills.
3. Life Cycle Impact comparison between Catawba's AbiBow Max grade to CFS showed that the AbiBow Max grade has lower impact scores across all but one category. The impact score for

Non-renewable Energy was about the same, due to a high level of nuclear energy in the electricity supplied in South Carolina (51% vs. 16% in the CFS study).

The UFS and CFS grades referred to in these conclusions are calculated aggregates of UFS and CFS manufactured in North America. Some individual mills will have higher impact scores and some will have lower impact scores than this calculated average.

7 CRITICAL REVIEW

A critical review was carried out by a third-party expert panel. The panel consisted of the following members:

1. Christine Burow (chairperson of panel), Christine Burow Consulting
2. Michael Bradley, Director Technology and Sustainability, Canfor Pulp LP
3. Jean-François Ménard, Analyst, CIRAIG, Department of Chemical Engineering, École Polytechnique de Montréal.

7.1 General comments:

An initial report was submitted on November 13, 2011. The panel commented that “the report was clearly written, easy to understand and well illustrated, data sources were mostly clearly explained and no major inconsistencies or issues with the results, analysis and conclusions were found.”

The panel also found that “there is a need to further document the report in terms of modelling choices (datasets used and assumptions for example), results, their interpretation (including verification), conclusions and limitations... The methods used to carry out the LCA follow the general framework and procedure outlined by the ISO Standards and are scientifically and technically valid. Being destined to support a comparative assertion intended to be disclosed to the public, this study does however need to push further the level of detail, the verification of the results and conclusion through sensitivity and uncertainty analyses.”

In response to these comments, more details were added on the sources of data and the calculations involved, and five sensitivity analyses were added to the study. The new version was submitted on January 6, 2012, and the panel had a few more comments, which were responded to and are listed in the table of comments as #56 and #57. The general comments of the panel after the final version were:

“The review panel has completed an assessment of the revised LCA report dated January 26th, 2012. These are the panel’s conclusions:

- the issues raised in the panel’s initial review dated December 16th, 2011 have been addressed to the panel’s satisfaction;
- the panel’s assessment is that the report complies with ISO guidelines, including sections 5.2 and 5.3 of ISO 14044, with the exception that the NCASI study used is not yet public and that the specific datasets used in the modeling of the Resolute and adapted NCASI systems are not detailed.”

7.2 Specific comments:

In addition to the general comments above, there were several individual comments and suggestions made to improve the study. The practitioner’s response is given below for each comment.

#	Page, section	Comment	Response
1	3, Section 3	Use the terminology functional unit	Corrected
2	4, Section 3	Do all paper grades have equivalent loss rates during the use stage?	Added sensitivity (section 5.3)
3	4, Section 3	Explain the functional unit for CFS and any explanation why a ream is used for CFS (not the normal format for CFS). Additional details of how AbiBow Max compares in use would be helpful	Done. Added comments in Scope section.

4	4, Section 3.1.1	What type of Kraft pulp (northern or southern hardwood or softwood) is used for the UFS considered in the comparison?	Added clarification in 3.2
5	4, Section 3.1.1	Add the amount of energy from biomass cogeneration for Alma, in order to match details provided in text of other AbiBow mills	None used - added comment in 3.1.1
6		Table 1: Add caliper; Add note that UFS from NCASI study (add these to the tables for other mills too)	not detailed by NCASI. Statement about caliper equivalency removed, as it is too general a statement (doesn't apply to all comparisons being made).
7	6, Section 3.4	Is there an EMS or ISO system in place at these mills that provide an addition level of data quality assurance?	Both mills have an ISO 9001 quality system and an ISO 14001 EMS in place.
8		For clarity, describe Figure 1 as the processes included in the LCA	Done.
9	6, Section 3.4	How does the forest factor into the impact of the different sheets (the boundary excludes the forest and yet properties of wood fibre affect paper properties which affect required filler levels, starches etc., also plantation forests (USA) have significant energy, chemical inputs versus natural forests).	Forestry operations are included in the background processes. Added wording in 3.4
10	6, Section 3.4	Include a more complete description of the boundaries selected and why, ie clays, chemicals etc.	Done.
11	7, Section 3.4	The process diagram could be detailed further for each system, identifying the source of the wood fibres for example. This would facilitate understanding what electric grid mixes are involved in each system. Transport distances should also be shown in this diagram.	Done.
12	7, Section 3.4.1	What version of the ecoinvent database was used? How far goes the adaptation to the North American electric grid, e.g. all background unit processes are connected to this grid?	Version 2.2 (2010). Added in 3.4.1. Also added description of adaptation to NA grid in 3.4.1.
13		All ecoinvent datasets used in the modelling of the compared systems should be clearly identified and any modifications documented.	See previous comment.
14	7, Section 3.4.1	Provide a description of the component that was added to calculate the carbon storage	Added description in Appendix 1.
15		Does the switch to ecoinvent cause any implications on the analysis, does it significantly change the outcome of the industry results compared to NCASI's LCA?	The ability to switch libraries was built into the NCASI UFS model and it was found that impacts changed more than 10% in only four categories : Carcinogens, Ionizing radiation and Land occupation decreased to 0.27, 0.24 and 0.41 of the ecoinvent scores, while Mineral extraction increased to 1.39 times the ecoinvent score. The impact/ effort ratio was judged too low to do the same for a Resolute grade.
16	7, Section 3.4.2	How valid is the assumption of equal distribution distances for all paper grades?	Added sensitivity study in 5.4
17	7, Section 3.4.2	Add details on CFS	Done.
18	7, Section 3.4.3	The NPRI uses a threshold approach to reporting which is not exactly consistent with the LCA approach of including all emissions from a process no matter the amount, how consistent is complementing the US mills data with the generic ecoinvent datasets with only using the NPRI data for the Alma mill?	This is a limitation of the study and has been added in section 5.9.
19	7, Section 3.4.4	How was the allocation of steam and electricity done? Is the method used consistent with the one used for the NCASI study?	The annual data were analyzed and allocated using the practitioner's experience and judgment. NCASI used data from Fisher (comments added).
20	7, Section 3.4.4	Sentence is incomplete "Higher heating values of fuels were used."	Fixed.
21	9, Section 3.4.6	Why use the University of North Carolina studies, does this differ from the approach in the NCASI study?	The UNC study is the same study NCASI used in their analysis. A sensitivity study was added in 5.5.
22	9, Section 3.4.6 and Appendix 1	What is the composition of the biogas produced from the decomposition of the different grades of paper? The calculation procedure for the methane and carbon dioxide emissions should be detailed further (assumptions and calculations).	Details added in Appendix 1.

23		The discussion on the differences observed between the paper grades could be further detailed. For example, the Alternative Offset shows the lowest indicator results for several categories (all the ecosystems quality related ones) but is mentioned only for the Land Occupation category.	Added comments.
24	11, Section 4.2	Why only compare UFS and the Ecopaque Laser but still call this section "Comparison of Alma paper grades to UFS"?	To simplify the graph, used Ecopaque Laser to represent all Alma grades. The actual score for each Alma grade is obtained from Fig. 4 ratios * Fig. 3 ratios.
25		What explains the difference for the Mineral extraction category?	Added explanation.
26		The UFS uses 13,8 g/m2 of fillers and binding agents (essentially calcium carbonate which is "mined with little processing") whereas the Ecopaque Laser uses 16,5 g/m2 of fillers and binding agents (including synthetic clay which "requires more energy and chemical processing") but you suggest that explains why the second shows lower impact scores than the first? Provide further details for this.	The figures the reviewer provides are incorrect. The numbers in Tables 1-4 are actually in % of total air dry weight. Further explanation of mineral extraction impact score was added.
27	11, Section 4.2	d. Explain that filler type is the only one that increases the impacts from Alma grades	Done.
28	12, Section 4.2.2	Figure 4 does not show that the Ionizing radiation category result for the Ecopaque Laser is 70% that for the UFS, but more only around 62 or 63%.	Corrected.
29		For the IMPACT 2002+ method Primary non-renewable energy and Mineral extraction do not represent the same quantity, the first is simply the energy content of the fuels extracted whereas the second represents the surplus energy needed to extract an additional kilogram of a further depleted stock.	Added comment in 4.2.1d.
30	12, Section 4.2.2	Last sentence is not clear, sentence starting "The impact on human health of the presence"	Clarified.
31	13, Section 4.2.3	in Figure 3, the Equal Offset Book paper grade seems to show the lowest Global warming score and the highest Carbon storage score of all Alma paper grades but on Figure 6, it seems that it is the Alternative Offset grade that shows the lowest carbon footprint. Figure 7 puts the Equal Offset Book grade ahead of the Alternative Offset, how is that consistent?	Figures 3 and 7 were incorrect. This has now been corrected and all the Figures are consistent.
32	13, Section 4.2.3	Is storage in the product included? (same question for the other mills)	Yes. Added phrase to 3.4.1.
33	14, Section 4.2.4	Provide more explanation of the methodology used to remove impact categories with insignificant impacts	If midpoint contribution to the endpoint < 3% in all grades compared, considered negligible. Added comment.
34	14, Figure 7	The labelling of the endpoint categories at the top of the figure should be revised.	Fixed.
35	15, Section 4.3	Less analysis is provided compared to Alma	More analysis was added.
36		What was the analysis methodology for the damage assessment?	Clarified.
37	15, Section 4.2.5	Explain why there are transportation differences in Table 6, e.g. mill to customer or raw material to mill, etc.	Explanation added.
38	17, Section 4.4	Provide more details on impact from zinc (including why this is an issue at this mill and not the others)	Explanation added.
39	18, Section 4.5	Why not provide the same level of detail in the results analysis for the Catawba mill paper grades as for the Alma mill ones?	Done.
40	19, Section 4.6	The differences between the mills should be detailed further.	More analysis was added.
41	21, Section 5.1	How are the results from the 2009 study different than this study?	Added more details.
42		Are the changes between the years 2006-2007 and 2010 related to a lasting change in production parameters or simply an indication of annual and regular changes?	Added more details.
43		How were adjusted the sawmill data to an economic allocation, what data were used? How would have the results and conclusions change if a mass allocation method was used for the sawmill data? A sensitivity analysis on allocation method should have been done.	Sensitivity analysis included and added in section 5.6.
44		Further explanation should be provided for the recycling allocation methods presented, how do the system boundaries change, what are the allocation factors used for the affected unit processes?	See section 5.3 for details.
45	21, Section 5.1	Point 3, add the description of the wood allocation into Section 3.4	Comments added in 3.4.6 and 5.6.
46	21, Section 5.3	How was included and modeled the recycling process in the Subsequent Uses approach? The temporary storage of carbon in the paper over the 100	A terminal boundary of 100 years was used for product in use. This

		year time period was not mentioned before and should be detailed further. How is that storage different than the one in the landfilled paper? Should this 100 temporal boundary be considered for other elementary flows or environmental aspect? IMPACT 2002+ does not consider long-term (i.e. beyond 100 years in the future even though the ecoinvent database includes them for some disposal unit processes), but considers the global warming potential of greenhouse gases over a 500 year horizon (it uses the IPCC 500 year horizon characterization factors), is that consistent with this temporal boundary? The ReCiPe method (also available in the SimaPro software) does include these long term emissions (with its Egalitarian version) and could have been used in a sensitivity analysis; it also combines the Global warming category in both the Human health and Ecosystem endpoint category.	was chosen to match the methodology used in the NCASI study. It was decided not to analyze this further through sensitivity analysis, since our judgment is that this will add minimal value to the study. The key differences in global warming potential have been clearly identified and detailed.
47		Does "Fossil fuel" refer to the production of the fuel or simply its combustion, or both? Further detail could be provided, for example which fossil fuel, what emissions associated with that fuel, etc.	The vast majority is due to its use on site or in the electricity grid, as backed up by Tables 3-5.
48		No percentage value is given for "Fertilizer for corn (starch)".	100%. Added.
49	22, Section 6	Point 1, Some of these points improve the performance and some detract, suggest separating them between ones that have a positive or negative effect.	It's not that simple to separate - some points have both a positive and negative effect.
50		The last point is probably the most important one since the AbitibiBowater paper grades were considered on a mill by mill basis whereas the only UFS and CFS industry average (or at least representing 75% of the North American market for the UFS) was considered for the competing products. The min and max range of values could have been used for the UFS and CFS, if available, to provide a more detailed and broader perspective on this comparative study.	The min and max values are not available from the NCASI study.
51		The carbon footprint results are distinguished by life cycle stages or processes not categories.	Clarified.
52	In general	Do not refer to the impacts of the systems but to their impact scores or their impact category indicator results since these only point to potential environmental impacts and not to actual ones, being the results of applying characterisation models and factors to inventoried elementary flows.	Corrected throughout.
53		The same goes when referring to "midpoint categories whose impacts are insignificant" (that terms usually refers to statistical significance and should be avoided when no tests were done to reveal such level of assurance) rather than to their negligible contributions to their related endpoint category.	Corrected throughout.
54	7, Section 3.4.3	Suggest organizing this information into a table	This was judged too labour intensive with minimal value added, since the data are publicly available by website.
55	9, Section 3.4.7	Change "The IMPACT 2002+ method results in calculated environmental impacts in 15 "midpoint" categories." to "The IMPACT 2002+ method provides potential environmental impact scores for 15 midpoint or "problem" categories."	Done.
Second Round Review Comments			
56	Data transparency	You should be as transparent as possible on the exact data that were used to model the systems; does the information you provide enable someone else to come up with the same results? How reproducible is the modelling? For the foreground processes, you indicated the source of the emission data and for the material and energy inputs, but it would be best if you actually provided (in the appendixes) the exact flows that were modelled and the datasets that were used to model the inputs and outputs (waste to be treated) of the systems.	There is enough information on the Resolute material and energy flows in the first 8 tables, and I have referenced where to find the releases to the environment on the internet (NPRI in Canada and TRI in the USA). On the UFS and CFS side, NCASI has done an excellent job of documentation, in a 292-page report with 81 pages of appendixes, but the clients of the NCASI study (FPAC and AF&PA) have not yet approved the release of this study to the public. I cannot thus be more transparent on this half of the study
57	Uncertainty	There is no uncertainty analysis, which is an ISO requirement for LCA studies used in support of comparative assertions disclosed to the public. There are two components to the results uncertainty, the inventory data uncertainty and the characterization factors uncertainty. Both should be addressed in the report. The first one can be addressed qualitatively through a data quality assessment or quantitatively through a Monte Carlo analysis, the second can only be addressed qualitatively for now.	I have now added a few paragraphs more to describe the uncertainty of the inventory data and characterization factors; data on the latter come from the IMPACT 2002+ user guide.

8 REFERENCES

1. "Life cycle assessment of North American printing and writing paper products, Final Report", prepared for AF&PA and FPAC by NCASI, June 18, 2010.
2. "EPA, Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks", 3d edition, Sept. 2006, EPA Report 530-R-02-006.
3. "Life Cycle Assessment of Resolute's Equal Offset Paper compared with Uncoated Freesheet", report to Third Parties, November 2009, <http://www.resolutefp.com/LCA/>, accessed on Dec 17, 2011.
4. Mark Goedkoop & Renilde Spriensma, "The Eco-indicator 99: a Damage-oriented method for Life Cycle Impact Assessment" 22 June 2001; www.pre-sustainability.com/download/misc/EI99_annexe_v3.pdf, accessed on Sep 4, 2011.
5. O. Jolliet, M. Margni, R. Charles, S. Humbert, J. Payet, G. Rebitzer, R. Rosenbaum, Impact 2002+: A new life cycle impact assessment methodology, International Journal of Life Cycle Assessment 8 (6) (2003) 324–330.
6. S. Humbert, M. Margni and O. Jolliet, "Impact 2002+: User Guide", October 2005, available from <http://www.sph.umich.edu/riskcenter/jolliet/downloads.htm> .

9 Glossary of Terms and Abbreviations Used

Aquatic acidification – caused by releases of inorganic substances such as sulphates, nitrates and phosphates to water.

Aquatic ecotoxicity – represents fresh water (streams and lakes) ecotoxicity due to emission of substances (e.g. heavy metals).

Aquatic eutrophication – caused by releases of inorganic substances such as nitrates and phosphates to waterways, which stimulate the growth of aquatic plant life and usually leads to depletion of dissolved oxygen.

Black liquor – spent cooking liquor from the kraft pulping process, containing hemicellulose and lignin.

Carbon storage – the permanent storage of carbon-containing material, preventing its release into the atmosphere as CO₂.

Carcinogens and non-carcinogens – provides estimates of the cumulative toxicological risk and potential impacts associated with a specified mass of a chemical emitted into the environment.

Chemical pulping – a wood pulp high in cellulose content with a 45-50% yield from wood, made by dissolving, removing and using lignin and some hemi-cellulose in the wood as a fuel to provide energy for the process.

DALY – Disability Adjusted Life Years - a unit used to normalize the different midpoint impacts contributing to the Human Health endpoint.

Ecopaque (EP) – a family of uncoated freesheet substitute grades manufactured by Resolute .

EPA – the U.S. Environmental Protection Agency.

Global warming – impact due to the emission of greenhouse gases.

Hog fuel – a mixture of bark and wood fibre used as a biomass fuel in a biomass boiler.

Synthetic clay – a high-brightness pigment manufactured from inorganic chemicals, nominally sodium aluminosilicate.

Ionizing radiation – takes into account human health effects related to releases of radioactive material to the environment over the life cycle (e.g. nuclear waste from power plants).

Land occupation – considers the impact of the occupation of an area, e.g. for agriculture or forest.

LCA – Life Cycle Analysis

LCI – Life Cycle Inventory – the second phase of the LCA process (after goal and scope)

LCIA - Life Cycle Impact Assessment – the third phase of the LCA process

Mechanical pulping – a high-yield (90-95%) wood pulp that is made by applying mechanical energy to wood, separating the wood fibres without removal of lignin.

Mineral extraction – takes into account the additional energy needed to process mineral ore.

NCASI – National Council for Air and Stream Improvement

Non-renewable energy – characterizes the amount of non-renewable energy used and is expressed in MJ of primary energy.

Ozone layer depletion – quantifies impacts of UV radiation on human health caused by emission of chemicals into air (e.g. chlorofluorocarbons).

PDF – Potentially Disappeared Fraction of species – a unit used to normalize the different midpoint impacts to the Ecosystem Quality endpoint.

Respiratory inorganics and organics – takes into account epidemiological impacts associated with respiratory diseases caused by pollutants that are released into air only (e.g. inorganic: PM₁₀, PM_{2.5}, TPM, NO_x, SO₂; organic: VOC, methane).

SGW – Stone groundwood – a mechanical pulp made from grinding logs against a grindstone.

Terrestrial ecotoxicity – the environmental impact from substances that have toxic effects to living organisms in soil (usually heavy metals)

TMP – Thermomechanical pulp – a mechanical pulp made from wood chips between two rotating disks.

UFS – Uncoated freesheet, which is a type of paper manufactured from bleached chemical pulp and filler (usually calcium carbonate), and although it is uncoated, is surface treated in a size press with starch and other ingredients.

APPENDIX 1: Carbon storage and methane release data

In order to calculate carbon storage and methane release data for paper in a landfill, first it was assumed the landfill operates under anaerobic conditions, where about one-half of the carbon that degrades is converted to biogenic CO₂ while the other half is converted to CH₄. Some released CH₄ is oxidized to biogenic CO₂ before exiting the landfill. About 10% of the methane is considered to become oxidized as it moves through the surface layers of the landfill [Ref. 2]. It is also estimated that 59% of all landfill CH₄ is generated at landfills with recovery systems. However, at those sites, it is usually assumed that only 75% of the methane is collected and destroyed, meaning that 44% of methane generated in municipal solid wastes is collected and destroyed in recovery systems.

In [Ref. 2] the different decomposition behaviour of newsprint and office paper in a landfill was described. In order to calculate the values below, it was considered that the TMP portion of the sheets behaves like the newsprint in this study (85% of carbon stored), while the kraft pulp portion behaves like the office paper in the study (12% of carbon stored). The methane release is then calculated from the following formulae:

$$\text{Methane released} = \text{Biomass carbon content} * (1 - \text{fraction carbon stored}) * 0.5 * 16/12 * 0.888 * 0.56,$$

where 0.5 is the portion of decomposed carbon converted to methane, 16/12 expresses the molecular wt. of methane over the atomic wt. of carbon, 0.888 is the conversion to the 11.2% moisture in the landfill and 0.56 is the fraction of methane released, as discussed above.

Similarly, the CO₂ stored is calculated from:

$$\text{CO}_2 = \text{Biomass carbon content} * \text{fraction carbon stored} * 44/12 * 0.888.$$

	Grade Name	TMP content	Biomass carbon content	Fraction of Carbon stored	kg Methane released/kg	kg CO ₂ stored/kg
	UFS	0	0.417	0.12	0.121	0.163
	CFS	0	0.323	0.12	0.093	0.126
Alma grades	EO	0.692	0.432	0.625	0.053	0.878
	EP Off	0.702	0.433	0.632	0.052	0.892
	EP Laser	0.680	0.430	0.616	0.054	0.862
	EP Jet	0.680	0.430	0.616	0.054	0.862
	EO Book	0.722	0.436	0.647	0.051	0.920
	AO	0.835	0.470	0.730	0.042	1.116
Catawba	AbiBow Max	0.150	0.347	0.230	0.088	0.259

APPENDIX 2: Impact scores for Resolute paper grades, UFS and CFS

Alma

Midpoint Category	Units	Alternative Offset	Equal Offset	Eq Offset Book	Ecopaque Offset	Ecopaque Laser	Ecopaque Inkjet	UFS
Carcinogens	kg C2H3Cl eq	6.09E-02	6.18E-02	6.71E-02	6.26E-02	6.90E-02	5.56E-02	2.82E-01
Non-carcinogens	kg C2H3Cl eq	9.48E-03	9.97E-03	1.05E-02	1.12E-02	1.28E-02	1.37E-02	6.56E-01
Respiratory inorganics	kg PM2.5 eq	5.28E-04	5.23E-04	5.57E-04	5.89E-04	7.15E-04	6.57E-04	3.40E-03
Ionizing radiation	Bq C-14 eq	1.88E+01	1.60E+01	1.77E+01	1.74E+01	1.92E+01	1.97E+01	3.09E+01
Ozone layer depletion	kg CFC-11 eq	7.68E-08	7.11E-08	7.68E-08	8.36E-08	1.01E-07	1.01E-07	1.13E-06
Respiratory organics	kg C2H4 eq	3.06E-04	2.96E-04	3.18E-04	3.09E-04	3.36E-04	3.09E-04	1.26E-03
Aquatic ecotoxicity	kg TEG water	9.29E+00	1.23E+01	1.24E+01	1.28E+01	1.40E+01	1.59E+01	5.42E+02
Terrestrial ecotoxicity	kg TEG soil	8.93E+00	1.10E+01	1.11E+01	1.11E+01	1.17E+01	1.37E+01	7.72E+02
Terrestrial acid/nutri	kg SO2 eq	1.22E-02	1.26E-02	1.33E-02	1.43E-02	1.71E-02	1.63E-02	8.37E-02
Land occupation	m2org.arable	6.94E-02	7.98E-02	8.29E-02	7.97E-02	8.12E-02	1.02E-01	2.98E-01
Aquatic acidification	kg SO2 eq	2.57E-03	2.62E-03	2.78E-03	3.15E-03	4.28E-03	3.72E-03	2.57E-02
Aquatic eutrophication	kg PO4 P-lim	1.10E-04	1.12E-04	1.18E-04	1.49E-04	1.95E-04	2.01E-04	4.31E-04
Global warming	kg CO2 eq	8.46E-01	8.49E-01	9.02E-01	9.20E-01	1.06E+00	1.02E+00	3.22E+00
Non-renewable energy	MJ primary	1.31E+01	1.31E+01	1.40E+01	1.42E+01	1.62E+01	1.50E+01	4.01E+01
Mineral extraction	MJ surplus	1.85E-03	1.59E-03	1.80E-03	2.27E-03	3.12E-03	3.05E-03	6.26E-04
Carbon storage	kg CO2 eq.	-5.96E-01	-4.62E-01	-5.08E-01	-4.68E-01	-4.82E-01	-4.82E-01	-2.17E-01

Endpoint Category		Alternative Offset	Equal Offset	Eq Offset Book	Ecopaque Offset	Ecopaque Laser	Ecopaque Jet	UFS
HUMAN HEALTH	DALY	5.71E-07	5.71E-07	6.12E-07	6.23E-07	7.34E-07	6.59E-07	5.02E-06
ECOSYSTEM QUALITY	PDF*m2*yr	1.59E-01	1.87E-01	1.93E-01	1.90E-01	1.99E-01	2.37E-01	6.54E+00
CLIMATE CHANGE	kg CO2 eq	2.50E-01	3.87E-01	3.02E-01	4.52E-01	5.77E-01	5.42E-01	3.01E+00
RESOURCES	MJ primary	1.31E+01	1.31E+01	1.40E+01	1.42E+01	1.62E+01	1.50E+01	4.01E+01

Catawba

Midpoint Category	Unit	AbiBow Max	CFS
Carcinogens	kg C2H3Cl eq	9.07E-02	3.00E-01
Non-carcinogens	kg C2H3Cl eq	7.41E-02	1.01E+00
Respiratory inorganics	kg PM2.5 eq	2.80E-03	4.37E-03
Ionizing radiation	Bq C-14 eq	1.40E+02	2.45E+01
Ozone layer depletion	kg CFC-11 eq	1.67E-07	1.08E-06
Respiratory organics	kg C2H4 eq	5.92E-04	1.30E-03
Aquatic ecotoxicity	kg TEG water	1.17E+02	7.07E+02
Terrestrial ecotoxicity	kg TEG soil	2.62E+02	1.02E+03
Terrestrial acid/nutri	kg SO2 eq	5.67E-02	9.92E-02
Land occupation	m2org.arable	1.78E-01	4.01E-01
Aquatic acidification	kg SO2 eq	1.56E-02	3.45E-02
Aquatic eutrophication	kg PO4 P-lim	1.42E-04	3.64E-04
Global warming	kg CO2 eq	3.04E+00	4.22E+00
Non-renewable energy	MJ primary	4.98E+01	4.84E+01
Mineral extraction	MJ surplus	1.37E-03	1.99E-03
Carbon storage	kg CO2 eq.	-3.74E-01	-1.59E-01

Endpoint Category		AbiBow Max	CFS
HUMAN HEALTH	DALY	2.45E-06	6.72E-06
ECOSYSTEM QUALITY	PDF*m2*yr	2.33E+00	8.66E+00
CLIMATE CHANGE	kg CO2 eq	2.66E+00	4.07E+00
RESOURCES	MJ primary	4.98E+01	4.84E+01