UBC Social Ecological Economic Development Studies (SEEDS) Student Report

A Paperless AMS

Comparing Economic and Environmental Impacts of Paper Use by AMS Staff to that of the Alternative: A Transition to iPads

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CHBE 484

10/8/2011

CHBE 484 : Green Engineering/ UBC Seeds project

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Introduction

The development of touch-pads, with Apple's groundbreaking iPad at their forefront, has brought a new question to the attention of classrooms, offices, and boardrooms worldwide: paper or electronics? The AMS student union at UBC is asking this question as well. There are approximately sixty full time employees at the UBC AMS. These employs currently operate six desktop-sized Phaser 6200 printers and 2 larger printers, a Work Centre 5740, and a Work Centre 5755, to print an average of 24 boxes of paper per year. Each of these boxes contains 5000 sheets of paper, so the total sheets of paper printed annually by the AMS staff averages to about 120,000 sheets. Hundreds of cheques are also processed annually. Since the AMS office is planning to switch to an online banking system, it would be possible to additionally reduce the paper consumption of the student union by purchasing a touch-pad/ tablet for every employee.

This feasibility study uses the iPad as the basis for tablet comparison to paper. There are several other tablets on the market that compete with the iPad in point of cost and performance. However, the company producing the iPad, Apple, has won numerous EPEAT (Electronic Product Environmental Assessment Tool) awards for some of its products, and is recognized by renowned NGO's, such as Greenpeace, for its corporate environmental consciousness (Greenpeace 2007). Thus, if tablets are to replace paper, the iPad is a competing consideration.

The primary aspects of sustainability that will be considered are the economic and the environmental impacts of paper compared to iPads. Social considerations during the use phase of these products will not be considered, though there is likely to be some "old-school" opposition to switching to tablets. However, the move towards sustainability requires some lifestyle changes, and changing to tablets from paper is certainly not a very demanding change.

Scope and Limitations

The UBC SEEDS office; Liska Richer from the UBC Sustainability office; Justin Ritchie, AMS Sustainability Coordinator; Elin Tayyar, VP Finance of the student union; and Paul Teehan, a PhD student at UBC, provided some conditions upon which this study was based. In the scenario of iPads replacing paper, the 6 Phaser 6200 printers are removed from the SUB (Student Union Building) offices. The two larger printers are kept, and it is assumed that 1/3 of the paper that is currently printed will still be printed after iPads are issued (Tayyar 2011). In other words, a switch to iPads is estimated to reduce paper consumption by 16 boxes, or 80,000

sheets. This paper is purchased from a Vancouver-based paper distribution company called White Paper Co. The paper used is virgin paper, called Polar Plus 20lb, 92 bright, and it is produced by Asia Pulp and Paper in Indonesia.

The environmental impact of transporting either the iPads or the paper to UBC is not considered in this analysis, since neither the variable origin of the iPad components, nor the assembly location for the iPads, was available. However, it should be noted that the iPads can be assumed to last at least 5 years under normal use (see iPad cost section). Without packaging and components, the iPad weighs 613 grams and sixty iPads thus weigh 36.78 kg. Alternatively, these iPads would displace approximately 363 kg of paper each year (sample calculations available in Appendix B). Considering that the paper is coming all the way from Indonesia, the transportation emissions for paper are likely to be higher than for iPads.

The iPads have a high capital cost, but cost very little after they have been purchased. The paper, on the other hand, has higher annual cost. In order to fairly compare the paper to the iPads, a 10 year time interval was selected due to the estimated 5 year lifespan of one unit, along with a cheap replacement plan that gives an additional 5 years (the iPad cost section explains this further).

Economic Analysis of Paper

To find the printing cost for the 16 boxes of paper that the iPads would replace, the sum of the paper cost, and the printer and toner cost were taken into account. All of these calculated values are shown in Appendix A, Table A1, and sample calculations for the derivation of the costs appear in Appendix B. The base cost of each box of paper is $36.95. Including HST, the annual cost of 16 boxes of paper is $662.14. The rental and toner cost of every Phaser 6200 is $100 per month, this giving an annual cost of $7,200 for printing. Thus, the total annual cost of printing 16 boxes of paper is $7862.14. To find the present value of the paper cost for a 10 year period, it was assumed that the cost of the paper, as well as the operating cost of the printers, was constant. Furthermore, an effective interest rate of 5 % was assumed. This is a reasonable assumption, since statistical inflation rates over the last 10 years in Canada show an average value of 1.66%, and current five year prime interest rates are about 3% (Bank of Canada 2010). The printing cost, in present day dollars, which the iPads would displace over the next 10 years, is $60,709.39.

Economic Analysis of iPads

Table A2 in Appendix A shows the values involved in calculating the cost of iPads. The first aspect of cost which was considered involved calculating the product use time period. The battery of an iPad 1 or iPad 2 is, on average, supposed to retain at least 80% of its original 10 hour battery life for 1000 full charge/discharge cycles (Apple, 2011)**.** An assumption that the iPads would be used for 8 hours a day, 5 days a week, was made, in order to take into consideration the fact that staff may want to take the iPads home. This is conservative assumption. The employees probably will not be working on their iPads for 8 hours of every work day, so iPad life will really be longer than estimated. An 8 hour work day for approximately 50 weeks out of the year yields a 5 year use of an iPad before it fails to retain 80% of its original charge. The next aspect which was investigated was a battery replacement plan by Apple. After the iPad fails to retain 80% of its charge, it is eligible for battery replacement by Apple for a fee of $120 per iPad, even if it is not under warranty (Apple, 2011). As long as there are no major defects other than a failed battery, Apple will allow owners to purchase the replacement (Apple, 2011). All data from the iPad will have to be recovered before it is sent to Apple, as Apple will send a new or refurbished iPad back instead of replacing the battery only (Apple, 2011). The old iPad will be disposed of and recycled in an environmentally friendly manner, according to Apple. Apple is renowned for being an environmentally friendly citizen of the world. The iPad has a mercury free display, arsenic free glass, and is completely free of brominated flame retardants such as polyvinyl chloride (Apple, 2010). Due to the fact that a battery replacement of $120/iPad yields a new iPad, a 10 year time frame was considered to compare with paper use. The 10 year capital cost of the iPad 1 and 2 , in present day dollars, are $574.59 and $686.59, respectively, per iPad. This cost includes one battery replacement, shipping for the replaced iPad, and taxes. Table 1 below shows the total cost of iPads. Currently, Apple has not made any discount offers to support this project. However, if discounts can be negotiated, the cost of switching to iPads will obviously be lower than these reported values.

Table 1: iPad Cost

	iPad 1	iPad 2
Capital Cost (tax included) /iPad	$419	$519
Battery Replacement (tax excluded)/iPad	$120	$120
Present day dollars for Battery Replacement (Incl. HST)	$105.31	$105.31
Capital cost for first 60 iPads	$28,156.80	$34,876.80
Total (Incl. HST) and 5% effective interest for 60 iPads over 10 years	**$34,475.16**	**$41,195.16**

*Note: The environmental impacts of paper use compared to implementing tablet use within the AMS were compared using the environmental impact category method.

Environmental Impact of Paper Use

The environmental impacts of using paper in the AMS were determined by conducting a literature review of previous life cycle assessments prepared for paper manufacture. For the global warming impact category (kg CO_2 equiv.), two assessments were compared to give a range of the predicted impact. Other impact categories were found from a North American LCA of the pulp and paper industry and include acidification, ozone depletion, particulate matter and eutrophication.

As mentioned earlier, the paper currently used in the AMS building is produced from Asia Pulp & Paper in Indonesia. The AMS estimates a usage of 120,000 sheets (544.3 kg) of paper annually. However, it is assumed that 40,000 sheets of paper will still be used if the iPads are implemented in the AMS. For this reason, an annual basis of 80,000 sheets of paper will be used in this comparison. The paper parameters consist of a paper grade of uncoated free sheet, a format of 8.5” by 11” and a weight of 4.54 g/sheet.

A life cycle assessment initiated by the Forest Products Association of Canada (FPAC) and the American Forest & Paper Association (AF&PA) was completed to evaluate the

environmental impact of producing a ream of office paper in North America. This LCA was carried out by the National Council of Air and Stream Improvement Incorporated, an independent non-profit research institute. Data was collected from 72 mills located throughout the US and Canada for the year 2006-2007. This is the most comprehensive study conducted for North American paper production. The system boundaries of this particular study included raw materials and energy consumption for fibre procurement, pulp and paper manufacture, and end of life fate. The waste management was determined based on data from the U.S. Environmental Protection Agency stating that 71.8% of office paper is recycled, 5.2% is burned for energy, and 23% is sent to the landfill. Transportation was also included in the analysis. The values estimated for all impact categories can be compared to those found for the iPad. The global warming potential values from this report provide an appropriate lower bound for this impact category (FPAC, 2007).

In order to get a more conservative estimate of the global warming potential impact, a second life cycle assessment was reviewed. This was completed because the paper used in the AMS is manufactured in Indonesia. Harvesting a wood chip supply in Indonesia for a pulp mill is different than harvesting in North America. Clear cut logging of tropical rainforests occurs, often without replanting of trees, resulting in the destruction of valuable carbon sinks. When logging occurs, peat lands are disrupted, thus releasing stored methane into the atmosphere and contributing heavily to greenhouse gas emissions. In addition, dirtier energy sources (fossil fuels) are used to power the mills. It can also be expected that air emission regulations are less strict in developing countries compared to North America. Consideration of these factors was included in an LCA of paper production from the company, Asia Pulp and Paper, in 2006, conducted by the Rain Forest Action Network and Japan Tropical Forest Action Network. The estimates found in this report can provide an appropriate upper bound for the global warming potential impact (RAN & JATAN, 2010)

Global Warming Potential

Table 2 below shows the upper and lower bound of the estimated global warming potential (units of tonnes of CO_2 equivalent) annually and over the chosen 10 year time span. It can be seen that the North American estimate is much lower than the estimate found from the LCA of paper production in Indonesia. This can be explained by reasons mentioned above. Both of these bounds were included to give a range of the possible impact. Depending on the literary

source, and on where the wood for paper production was harvested, there is massive variability in the magnitude of global warming impact.

Table 2: Lower and Upper Bounds for Global Warming Potential estimates for paper manufacture

Impact Category	Unit	North American Estimate (per 80,000 sheets)	North American Estimate (over 10 years)	Indonesian Estimate (per 80,000 sheets)	Indonesian Estimate (over 10 years)
GWP	tonnes CO2 equiv.	0.68	6.80	6.75	67.5

Additional Impact Categories

Table 3 displays values for the other four impact categories including acidification, particulate matter, ozone depletion and eutrophication. Because these numbers were taken from the LCA done for paper production in North America, they give a conservative estimate when making a case for iPad implementation.

Table 3: Impact categories and their emissions for paper use over 10 years

Impact Category	Unit	Paper (over 10 years)
Acidification	kg SO_2 eq.	73.3
Particulate Matter	kg PM eq.	10.9
Ozone Depletion	mg CFC-11 eq.	416
Eutrophication	kg N eq.	12.4

Effect of Toner

The toner considered for this analysis was assumed to be that used by common Xerographic processes. An LCA was found for toner used in Xerographic processes ((Ahmadi et al, 2003)). This LCA only considered the actual toner used to produce a marking on paper, and did not consider the plastic housing for particular toners. The boundaries of the LCA include the processes necessary to manufacture the raw materials for the toner production (Ahmadi et al, 2003). Both recycled and solid waste fates at the end of the toner's life were considered in the

analysis as well. Transportation at all stages of production was accounted for (Ahmadi et al, 2003). The environmental impact categories which were used from this toner analysis include emissions of carbon dioxide, sulphur dioxide, and particulate matter. The basis of the toner LCA was 1 metric ton of toner produced.

A challenge in the analysis of the toner used by the AMS was to calculate how much toner was used. The "mass of toner" used as the basis for the toner LCA only considers the mass of the final marking material on the printed document. To calculate the mass of toner used by the AMS, a blank piece of letter sized paper was weighed to be 4.4731g. The paper was then printed on with 80% coverage; the final mass was recorded as 4.6297g. Coverage of 80% yielded a toner mass of 0.1566g. It was assumed that the coverage on average for printed paper was 12%. The mass required for 12% coverage was calculated to be 0.02349g/sheet of paper. For an annual printing demand of 80,000 sheets per year, the mass of toner used was calculated to be 1.88 kg/year. Over a 10 year time frame the mass of toner produced is 18.8kg. This was used to calculate the environmental impact potentials which are shown in Table 4**.** Appendix B shows the calculations for how these values were derived.

Table 4: Environmental Impact Potentials for 18.8 kg of toner

Global Warming Potential (kg CO2 equiv.)	**Acidification (kg SO2 equiv.)**	**Particulate Matter (kg PM equiv.)**
300.1	2.44	0.96

As seen in Table 5 the environmental impact of the toner is not very significant. However, it is important to note that the LCA source used did not consider the impact of the raw material extraction for the materials used to make the toner, only the processing of the raw material as inputs to the toner production process. Thus the actual lifecycle impact of the toner is likely larger than reported.

Environmental Impact of iPad Use

The environmental impact of implementing iPads in the AMS is based on the 60 iPads requested for use by the AMS staff and another 60 which will be required after 5 years of use when replacement is necessary. The basis is therefore 120 iPads for the 10 year time frame.

The same five impact categories that were used to assess the environmental impact of the paper are used for the iPad. Again, a lower and upper bound will be looked at for the global warming potential category to express the variability in expected emissions.

Paul Teehan, a graduate student at UBC, was able to help with this part of the analysis. The estimated values for the five impact categories (including the lower bound for GWP) were found by Paul, who completed a tear down analysis of an iPad 1 and inputted the weights of each component into MeeUP, an LCA database tool, to find the environmental impact of each material. These could then be summed and converted to the effective impact category (Teehan 2011). The impact of an iPad 2 can be assumed to be equal or less than the iPad 1, since the iPad 2 weighs less than the iPad 1. The GWP found by Paul's teardown analysis for the iPad 1 was compared to an estimate in an environmental report released by Apple (Apple, 2010). All of these predicted impacts can be seen below in Tables 5.

Table 5: Environmental impact of iPad implementation over 10 years

Impact Category	**Unit**	**iPad (120 tablets)**	
Global Warming Potential	tonnes CO_2 eq.	Lower Bound 4.68	Upper Bound 15.6
Acidification	kg SO_2 eq.	42.5	
Particulate Matter	kg PM eq.	4.8	
Ozone Depletion	mg CFC-11 eq.	negligible	
Eutrophication	kg N eq.	negligible	

Overall Environmental Impact Normalization and Comparison

Table 6 displays the completed comparison between paper and toner versus iPad use over ten years. It is observed that implementing iPads in the AMS would lessen the environmental impact of continuing to use paper as the determined values are lower in every category. Although

the outcome is evident, the dimensionless score and weighting factor method was used nonetheless to determine a normalized comparison. The results of this ranking method can be seen in Table 7. The average weighting factors were determined from a class poll conducted during a Green Engineering Lecture. For sample calculations, refer to Appendix B.

Table 6: Completed environmental impact analysis and weighting factors

Impact Category	**Weighting Factor (%)**	**Unit**	**Paper + Toner over ten years (80,000 sheets a year)**		**iPad (120 tablets)**	
Global Warming Potential	25.6	tonnes CO_2 eq.	Lower Bound 7.1	Upper Bound 67.8	Lower Bound 4.68	Upper Bound 15.6
Acidification	14.4	kg SO_2 eq.	75.7		42.5	
Particulate Matter	30.6	kg PM eq.	11.8		4.8	
Ozone Depletion	16.1	mg CFC-11 eq.	416.0		negligible	
Eutrophication	13.3	kg N eq.	12.4		negligible	

Table 7: Dimensionless score results

	Paper + Toner	**iPads**
Using Lower Bound	10	3.7
Using Upper Bound	10	2.6

Energy

When considering the energy use of the printers vs. the iPads, it can be assumed that the emissions from energy use are negligible, since the source of power for product use originates from hydroelectric power dams. However, the energy use will present an associated cost of power. This is not to say that hydroelectric dams have no environmental impact. Rather, the environmental impact is associated with the construction of the dam and has a constant effect on the environment. Measured power demand for charging an iPad was 10W for a charge time of 3.5 hours. The energy use per charge is found as 0.035 kw•hr (Kilowatt-hour). The 120 iPads that are predicted to be used over a 10 year period will require 1000 charge/discharge cycles per iPad. This implies that the total energy use for the iPads will be 4200kw•hr. The current cost per kw•hr is $0.07 per kw•hr (BC Hydro, 2011). Assuming that electricity cost will be constant over

the next 10 years, and neglecting interest rate (since the cost is minimal anyway), the energy for the iPads was calculated to be $294. The 6 Xerox Phaser 6200 printers in the AMS, which use approximately the same amount of electricity as an HP 1505n printer, are predicted to use about 60kw/year/printer (Hewlett Packard, 2007). For the 6 printers, the total energy use over 10 years is estimated to be 3600 kw•hr. Then the cost of supplying energy to the printers is $252. This is a reduction of $42 over 10 years, compared to using iPads; an insignificant cost difference, when considering the overall $19,514 estimated cost difference between iPads and paper. Table 8 shows the comparative energy cost over 10 years, as well as the total cost comparison. The environmental impacts of the energy use associated with production are not included in this section of the analysis, as they are accounted for in the environmental impact section.

Table 8: Product energy costs and Total cost comparison between iPad use and Paper use.

	iPads	**Printing**
Energy cost	$294	$252
Total cost	$41,489.16	$60,961.39

Considerations and Recommendations

- The paper is produced in Indonesia and the data used for its LCA assumes North American paper production. This is a very conservative estimate for the paper case and represents a much better case for the paper than what is actually expected.

- The global warming potential for the paper case, when considering land use, is likely to be closer to the upper bound of 67.8 tonnes CO2e over 10 years. The upper bound for the IPad's CO2e emissions was reported at 15.6 tonnes CO2e, which is about one quarter of the upper bound of the paper production CO2e emissions. This suggests that the IPad case is likely to be far cleaner than the paper case in terms of global warming potential.

- There is uncertainty in all of the LCAs used, which is unavoidable. Data for the iPad could be out by a factor of 2 or more in some categories. In this case, the environmental impact of the iPad compared to the paper case will be approximately equal. (this is the best possible case for the paper).

- Economically, the iPad presents a better case than the paper does, using the costs given by the AMS and using a conservative effective interest rate. The economic analysis is the most accurate aspect of the comparison of iPads to paper, since this section is based on fewer assumptions than the environmental impact section. The present day cost of switching to iPad 2's is about $41,195. However, this replaces a paper and printing cost of $60,709. The payback period of the switch to Ipad 2's is approximately 6.2 years.

- It is assumed that over 10 years, the iPads will provide enough functionality to serve the basic needs of the AMS staff. The purchase of the battery replacement plan does not necessarily need to happen right away when the battery charge drops below 80%. The iPads will still be very functional with an 8 hour battery life. This also decreases the cost of the iPads.

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A special thank you to the following individuals for their help with this project:

Liska Richer

Paul Teehan

Elin Tayyar

Justin Ritchie

Dr. Xiaotao Bi

Winter, 2011 CHBE 484 class

APPENDIX A

Raw Data and Given Parameters

Table A1: Annual paper use

Current # of boxes of paper used	24
# of boxes of paper displaced using ipads	16
# of sheets per box	5000
Mass per 500 sheets(lb)	5.00 lb
Annual mass paper displaced (kg):	362.9 kg
10 year paper displacement (kg):	3628.7 kg
Cost per box of paper ($)	$36.95
Cost per box of paper incl. HST ($)	$41.38
Annual displaced paper cost ($)	$662.14
Rental and toner cost per small printer ($/month)	$100.00
# of small printers to be displaced	6
Annual printer & toner displacement cost ($)	$7,200.00
Total annual cost printing displacement($)	$7,862.14
Assumed effective interest rate	0.05
Present value of 10 year printing displacement ($)	$60,709.39

Table A2: iPad requirements

# of executive AMS employees:	60
Ipads per exec. employee	1
# of ipads to purchase initially	60
Cost of Ipad 2 ($)	$519.00
Cost of Ipad 2 (incl. HST) ($)	$581.28
Initial Cost of Ipad 1 ($)	$419.00
Cost of Ipad 1 (incl. HST) ($)	$469.28
Ipad replacement cost (once battery life expired) ($)	$120.00
Ipad replacem.cost (incl. HST) ($)	$134.40
Battery life (# of full charge/disch. cycles)	1000
Running time/ full charge(hrs)	10
Ipad running time over battery life (hrs)	10000
Use during working day (hrs)	8
# of working days/week (days)	5
# of working weeks/year	50
Annual use per ipad (hrs/year)	2000
Battery life of ipad (years)	5.0
Assumed effective interest rate	0.05
Present value of battery replacement in 5 years ($)	$105.31
10 year capital cost of ipad 2 ($)	$686.59
10 year capital cost of ipad 1 ($)	$574.59
10 year cost to have 60 ipad 2s ($)	$41,195.16
10 year cost to have 60 ipad 1s ($)	$34,475.16

Table A3: Weighting factors from CHBE 484 class				
GWP	Smog Formation	Acidification	PM10/ Respiratory & Health imact	Eutrophication
35	10	10	35	10
30	10	10	40	10
30	15	15	30	10
30	20	10	30	10
25	20	15	25	15
20	15	20	25	20
15	10	25	30	20
25	25	15	30	5
20	20	10	30	20
Average weighting factors (%)				
25.6	16.1	14.4	30.6	13.3

Table A4. Life Cycle Impact (per unit) of Products

Nr	Life cycle Impact per product:	Date	Author
0	Products	0	vhk

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	**Total**	**BUTION**		Disposal	Recycl.	**Total**	
	Materials	**unit**									
1	Bulk Plastics	g			**81**			73	8	**81**	**0**
2	TecPlastics	g			**0**			0	0	**0**	**0**
3	Ferro	g			**2**			0	2	**2**	**0**
4	Non-ferro	g			**138**			7	131	**138**	**0**
5	Coating	g			**0**			0	0	**0**	**0**
6	Electronics	g			**242**			139	103	**242**	**0**
7	Misc.	g			**189**			9	179	**189**	**0**
	Total weight	g			**651**			228	423	**651**	**0**
	Other Resources & Waste							debet	see note! credit		
8	Total Energy (GER)	MJ	240	31	**271**	**65**	**117**	19	20	**-1**	**452**
9	of which, electricity (in primary MJ)	MJ	93	3	**96**	**0**	**116**	0	12	**-12**	**200**
10	Water (process)	ltr	85	2	**87**	**0**	**1**	0	11	**-11**	**77**
11	Water (cooling)	ltr	27	9	**36**	**0**	**0**	0	2	**-2**	**34**
12	Waste, non-haz./ landfill	g	306	35	**342**	**58**	**136**	129	35	**95**	**631**
13	Waste, hazardous/ incinerated	g	66	1	**66**	**1**	**3**	175	13	**162**	**233**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	26	2	**28**	**6**	**5**	1	1	**0**	**39**
15	Ozone Depletion, emissions	mg R-11 eq.	negligible								
16	Acidification, emissions	g SO2 eq.	54	11	**65**	**265**	**30**	3	9	**-7**	**354**
17	Volatile Organic Compounds (VOC)	g	0	1	**1**	**382**	**0**	0	0	**0**	**384**
18	Persistent Organic Pollutants (POP)	ng i-Teq	5	0	**5**	**0**	**1**	1	0	**1**	**7**
19	Heavy Metals	mg Ni eq.	6	0	**6**	**3**	**2**	5	2	**4**	**14**
	PAHs	mg Ni eq.	40	1	**40**	**0**	**1**	0	1	**-1**	**40**
20	Particulate Matter (PM, dust)	g	8	3	**11**	**4**	**1**	24	0	**24**	**40**
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	44	0	**44**	**0**	**1**	2	7	**-5**	**40**
22	Eutrophication	g N	0	0	**0**	**0**	**0**	0	0	**0**	**0**
23	Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

APPENDIX B

Sample Calculations

Sample Calculation

Paper

Mass of paper used annually by AMS staff:

Given: - 24 boxes of paper used annually by AMS staff
- 5000 sheets paper per box
- type of paper = Polar Plus, 92 bright (virgin) type (Tayyar, 2011)
- 500 sheets of 20 lb bond paper, with a dimension of 17" × 22" weigh 20 lb, so regular sized paper, with a dimension of $8\frac{1}{2}$" × 11" = 5 lb / 500 sheets (HowStuffWorks, Inc. 1998-2

∴ Mass of paper used annually = $\frac{24 \text{ boxes}}{\text{year}} \times \frac{5000 \text{ sheets}}{\text{box}} \times \frac{5 \text{ lb}}{500 \text{ sheets}} \times \frac{0.45359 \text{ kg}}{\text{lb}}$

= 544.31 kg paper per year

Paper displaced by iPads (assuming $\frac{1}{3}$ of paper is still printed):

mass = $\frac{2}{3}$ × 544.31 kg paper/year = 362.9 kg kg/year

# of boxes = $\frac{2}{3}$ × 24 boxes = 16 boxes

# of sheets = $\frac{2}{3} \times 24 \text{ boxes} \times \frac{5000 \text{ sheets}}{\text{box}}$ = 80,000 sheets paper

Cost of displaced paper (per year) = $\left(\frac{\$36.95}{\text{box}}\right)\left(1.12\right) \times 16 \text{ boxes}$ = $662.14

Annual printer and toner displacement savings:

= 6 printers displaced × $\frac{\$100}{\text{printer} \times \text{month}}$ × 12 months = $7,200

Total annual printing displacement cost = $7,200 + $662.14 = $7,862.14

Present value of 10 year printing displacement = $\frac{\text{Operating cost}\left[(1+\text{interest})^{\text{years}}-1\right]}{(\text{interest})(1+\text{interest})^{\text{years}}} = \frac{\$7,862.14\left[(1+0.05)^{10}-1\right]}{0.05(1+0.05)^{10}}$ = $60,709.39

iPad: Cost & life expectancy:

iPad running time over battery life = # of charge/discharge cycles per battery life × running time per charge

= 1000 charge/discharge cycles × 10 hrs / charge

= 10,000 hrs running time

Annual use per iPad: Assuming a use of 8 hours per working day, 5 working days per week, and 50 working weeks per year:

Annual use per iPad = 8 hr/day × 5 days/week × 50 weeks/year = 2000 hrs/year

Expected battery life of iPad = Running time per battery life ÷ annual use per ipad

= 10,000 hrs ÷ 2000 hrs/year = 5 years

Cost of purchasing ipad 2 (incl. HST) = $519.00 × 1.12 = $581.28

When battery life drops to 80% of original battery life, the iPad is replaceable for $134.40 (incl. HST).
Assuming a 5% annual effective interest rate, the present value of this iPad replacement cost in 5 years is: (also assuming the cost doesn't change)

Present value = Future value / (1 + interest)^years = $134.40 / (1 + 0.05)^5 = $105.31 (Bi, 2004)

Total cost for iPad 2's over 10 years = ($105.31 + $581.28) × 60 = $41,195.16

Energy Cost:

Ipad: 10 W/Charge × 3.5 hr charge time × Kw/1000 W × 2000 Charges × 60 Ipads × $0.07/Kwh

= $294 over 10 years

Printers: 60 Kwh/year × 10 years × 6 printers × $0.07/Kwh = $252 per 10 years

Environmental Impact of toner:

Mass of toner per sheet of letter sized paper with 80% coverage = 0.1566 g toner / sheet

To calculate the mass of toner for 12% coverage:

$$\left(0.1566\ \frac{g\ toner}{sheet}\right)\left(80{,}000\ \frac{sheets}{year}\right)\left(\frac{1\ kg}{1000\ g}\right)\left(\frac{0.12}{0.80}\right) = 1.88\ \frac{kg}{year}$$

For 10 years: mass of toner = $18.8\ kg \times \frac{1\ mton}{1000\ kg} = \boxed{1.88\times10^{-2}\ mton}$

Using the environmental impact potentials from Ahmadi et al:

$$\boxed{CO_2:\quad GWP = \left(\frac{16\times10^{3}\ kg}{mton} \times 1.88\times10^{-2}\ mton\right) = 300.1\ kg\ CO_2}$$

GWP = "Global Warming Impact"

Acidification Potential: (AP)

$$\boxed{AP = \frac{130\ kg\ SO_2}{mton} \times 1.88\times10^{-2}\ mton = 2.44\ kg\ SO_2}$$

Particulate Matter (PM):

$$\boxed{PM = \frac{51\ kg}{mton} \times 1.88\times10^{-2}\ mton = 0.96\ kg\ PM}$$

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Dimensionless Score Method:

Making Use of the GWP Upper bounds:

	Paper	Ipad
Global Warming Potential	10	2.3
Acidification Potential	10	5.61
Particulate Matter	10	4.07
Ozone Depletion	10	0
Eutrophication.	10	0

Normalized Impact:

Paper: $(10 \times 0.256) + (10 \times 0.144) + (10 \times 0.306) + (10 \times 0.161) + (10 \times 0.133)$
$= 10$

Ipad: $(2.3 \times 0.256) + (5.61 \times 0.144) + (4.07 \times 0.306) + (0 \times 0.161) + (0 \times 0.133)$
$= 2.64$

Making Use of the GWP Lower bounds:

	Paper	Ipad
Global Warming Potential	10	6.59
Acidification Potential	10	5.61
Particulate Matter	10	4.07
Ozone Depletion	10	0
Eutrophication	10	0

Normalized Impact:
Paper: $(10 \times 0.256) + (10 \times 0.144) + (10 \times 0.306) + (10 \times 0.161) + (10 \times 0.133) = 10$
Ipad: $(6.59 \times 0.256) + (5.61 \times 0.144) + (4.07 \times 0.306) + (0 \times 0.161) + (0 \times 0.133) = 3.7$

* Note: A normalized impact does not necessarily need to be done for this case as paper showed to have higher emissions in all categories. If other numbers had been found, this is how it would be used.