Environmental Life Cycle Assessment of Commercial Analog and Digital Printing

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Abstract

The commercial printing industry is in a transition from use of offset presses to inclusion of digital technology. Digital presses enable print-on-demand which moves the printing process closer to the customer, reducing distribution and storage costs and impacts to the environment. Digital presses have the ability to print shorter runs more economically than offset, have the ability to run variable print data, and use less paper from setup and calibration processes than offset presses. In this paper, an environmental life cycle assessment (LCA) for commercial printing of marketing collateral using a competitive sheet-fed offset press and an Indigo 7000 digital sheet-fed press is presented. Four damage categories are evaluated: human health, ecosystem quality, climate change, and resources. The life cycle includes materials and energy used to make the printer, paper, and consumables; energy consumption during printing, and end-of-life of paper, printer and consumables. The LCA of commercial digital printing shows that paper has the largest potential environmental impact, with press energy consumption and consumables coming next. The printer bill of materials is inconsequential by comparison. Additionally, an environmental break-even analysis demonstrates that a digital press has a lower environmental impact than an offset press when run length lies at the economic break-even point (estimated at 3,972 4-color double-sided letter-size pages).

Introduction

Offset lithographic, flexographic, and gravure presses are representative of typical analog printing systems, with offset presses having the largest market share of the three. Analog presses use impact printing methods for transferring ink onto paper. These presses require significant setup time and materials since physical plates are used for generating and transferring images to paper. Large amounts of raw material and energy are used to make these plates, with aluminum being the largest contributor. Additional chemicals and energy are required for the lithographic processes used to image these plates. . Due to setup requirements, offset presses are primarily used for long print runs to ensure economic viability.

Digital printing is becoming more prominent in commercial printing industry due to its ability to print short runs of books, brochures, etc. economically due to reduced time and materials for setup. In the publishing industry, print-on-demand printing is allowing books to be printed on location at local bookstores. This drastically reduces warehouse and distribution requirements. The need for printing tens of thousands of books, storing them in warehouses, and distributing them long distances can now be virtually eliminated. Printing one book in a few minutes at a bookstore is now a reality. Digital presses also enable variable data printing where every page can have unique data since it doesn't require set plates for creating an image. The added value of variable data printing is highly desired in direct mail applications, for instance.

There is growing interest in the environmental impact of printing. Since paper is the primary product of printing, customers are growing more aware of the potential impacts of how we print on and use paper. The commercial printing industry produces, by far, the majority of printed media we use, whether newspapers, magazines, books, mail, or product packaging. It is the sixth largest industrial sector in the U.S. and there are over 430,000 printing companies worldwide [1].

This paper represents the first published study of the environmental impacts of using a digital press compared to an offset press for printing marketing brochures. Using life cycle assessment (LCA) methodology, all phases of a product's or system's life cycle are evaluated, including raw material acquisition, manufacture of the product or system, use of the product or system, and, finally, disposal, recycling or reuse, i.e., cradle-to-grave. This study was done in accordance with ISO 14040/14044 standards and was reviewed by an external critical review panel of industry and LCA experts.

Methodology

The method used to compare the environmental impacts of the HP Indigo 7000 press to that of a competitive sheet-fed offset press was a LCA. LCA is an environmental methodology based on quantitative analysis and results. It is considered a comprehensive methodology because it includes all relevant technical processes related to the function provided by the product or system. It also includes a wide range of potential environmental impacts linked to the inputs from the environment such as raw material extraction and outputs to the environment such as emissions to air, water, and soil from these processes. LCA is used for various applications, especially to identify opportunities to improve the environmental profile of products and product comparisons, but also for product and technology development, market claims, and policy development.

The LCA framework has been standardized by the International Standard Organization (ISO 14040, 14044) and consists of four phases: 1) Goal and scope definition, 2) Inventory analysis, 3) Impact assessment, and 4) Interpretation. Although these phases are logically and computationally sequential, they are often iterative, as the results from one phase may dictate revisiting and modifying previous phases.

The goal of this study was to compare the life cycle environmental impacts of one digital press manufactured by HP, the Indigo 7000, to that of a specific competitive 4-color, sheet-fed offset press with sizeable market share. The scope includes deciding on what is going to be modeled, sometimes called "function", i.e., the function of the product we are going to compare, functional unit, choice of impact categories, impact assessment method, system boundaries, principles for allocation, and data quality requirements. The function for this study is defined as the use of 8-page, letter sized, duplex printed, 4 color brochures as marketing collateral. The functional unit is defined as one 8-page brochure used for marketing collateral with the following characteristics: 4 process colors at 60% coverage, duplex pages, printed on 100 lb coated paper, and printed as part of a 993 brochure print job, estimated to be at the economic break-even point of the Indigo 7000. Both the Indigo 7000 press and the offset press are judged to provide brochures that are functionally equivalent.

System boundaries identify life cycle stages, processes and flows that are included in the LCA. The life cycle stages of brochures used as marketing collateral that were included in this LCA are shown in Figure 1.

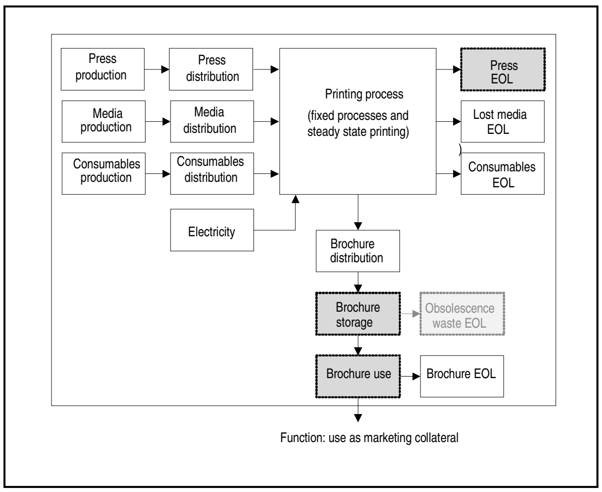


Figure 1. *System boundary for printing of brochures. White boxes are included processes, gray boxes with dashed lines are excluded processes which are assumed negligible, and faded box with dashed lines is included for scenario analysis only.*

The process flow diagram is representative of the system boundaries for brochures printed on either press. The system boundaries cover the entire life cycle, from cradle-to-grave of the press, paper, consumables, and brochure. The reference to fixed processes for the printing process is only relevant for the offset press and includes prepress, makeready and washup. Life cycle inventory (LCI) is a mass and energy balance over the system, where only the environmentally relevant flows are considered.

There were two types of data used for this study: primary data and secondary data. Primary data refers to data collected specifically for this LCA such as press bill of materials, press energy consumption during printing, paper consumption including printed paper and paper losses, and consumption of consumables. HP provided the Indigo 7000 primary data and an offset press expert collected the offset press data. Secondary data refers to data used in the LCA that was not collected for this study such as raw material extraction, production of materials, and electrical power generation. A European database, ecoinvent 2.0, was used for most processes and materials used in this study.

Three life cycle impact assessment (LCIA) methods were used: IPCC 2007 100 year characterization factors were used for calculating the carbon footprint, IMPACT 2002+, which was the main impact method, was used for calculating the impacts to human health, ecosystem quality, and resources, and the ReCiPe method was used for calculating the impact of water footprint.

IMPACT 2002+ method translates the LCI into 15 midpoint impact categories, shown in Table 1. Midpoint categories are meant to give information at the level of distinct environmental problems. For a given impact category (e.g. carcinogen) the ratio between the potential impact of a unit of any given flow (e.g. emission of 1 kg furan to water) and that of the reference flow (1 kg chloroethene to air) is called a characterization factor. The total impact for a given category equals the sum of all the elementary flows contributing to the impact category, as calculated during the inventory phase, times the corresponding characterization factor.

Table 1. Midpoint categories of IMPACT 2002+ LCIA method and their associated damage categories

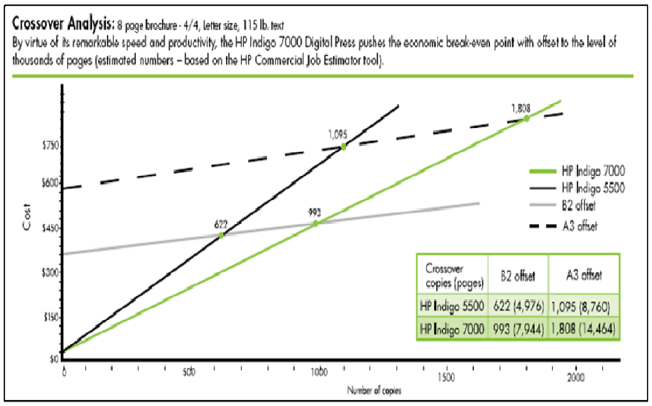
Midpoint impact category	Corresponding damage category
Carcinogens	Human Health
Non-Carcinogens	
Respiratory inorganics	
Ionizing radiation	
Ozone layer depletion	
Respiratory organics	
Aquatic ecotoxicity	Ecosystem Quality
Terrestrial ecotoxicity	
Terrestrial acid/nutri	
Land occupation	
Aquatic acidification	n/a
Aquatic eutrophication	
Global warming	Climate Change
Non-renewable energy	Resources
Mineral extraction	

As shown in Table 1, thirteen of the fifteen midpoint categories can be modeled to an endpoint level, resulting in four damage categories.

Once all needed data were, system modeling was carried out using a commercial LCA software, SimaPro 7.1.6, developed by Pre, Netherlands. This software allows calculation of life cycle inventories and impact assessment, contribution analysis, parameterization and related sensitivity analysis, and uncertainty analysis.

Results

All life cycle impacts were evaluated at the economic break-even point, i.e. the job size for which the total costs are the same for both the offset and digital press. This break-even point has been progressively rising as digital technology evolves. The break-even point used in this study was based on an estimate calculated with the online HP Commercial Job Estimator [2], which shows that both presses are economically equivalent at 993 8-page, four color, double-sided, letter-size brochures (see Figure 2).



Crossover copies (pages)	B2 offset	A3 offset
HP Indigo 5500	622 (4,976)	1,095 (8,760)
HP Indigo 7000	993 (7,944)	1,808 (14,464)

Figure 2. Break-even analysis for 8-page brochure.

The relative potential impacts of the two printing options at the economic break-even point as evaluated with IMPACT 2002+ at endpoint levels are shown in Figure 3. The Indigo 7000 press has lower potential impacts across all four endpoint impact categories. The endpoint impact category results are 19% (ecosystem quality) to 26% (climate change) lower for the Indigo 7000 compared to the offset press.

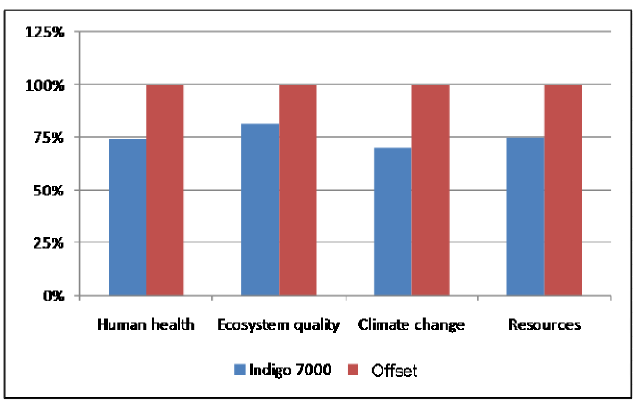


Figure 3. Comparison of two printing options at economic break-even point, normalized to the impact of the offset press.

Results for the relative potential impacts for the 15 midpoint categories are shown in Figure 4. Most midpoint impact categories follow the same trend as the endpoint categories: for 13 of the 15 midpoint categories, printing on the Indigo 7000 is associated with a reduction in impact ranging 9-73% lower compared to the offset press. The increase in respiratory organics impact is due to higher potential volatile organic compounds (VOC) emissions of the Indigo 7000 during printing, but this represents less than 1% of the overall endpoint impact for VOCs. The drastic decrease in aquatic ecotoxicity impact associated with the Indigo 7000 is from not using aluminum plates for printing as does an offset press, in which anodizing of the aluminum plates is the main culprit.

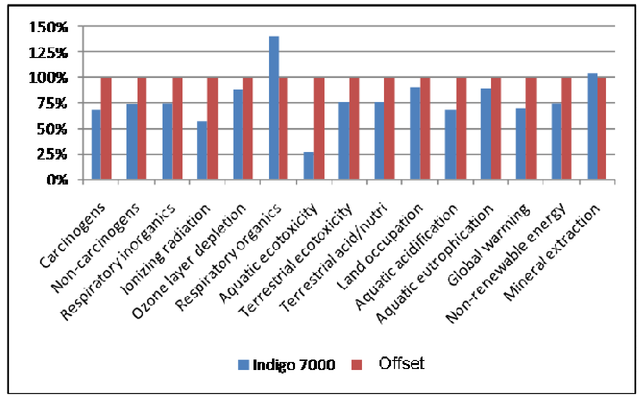


Figure 4. Comparison of two printing options at economic break-even point, normalized to the impact of the offset press.

The carbon footprints of the two presses are shown in Figure 5 at the economic break-even point of 993 brochures. The results show that the carbon footprint of brochures printed on the Indigo 7000 is lower than that of printing the same brochures on an offset press. Paper has the largest carbon footprint with almost 70% of the potential impact for this category. Energy consumption and consumables are the next two largest contributors to the carbon footprint after paper. Low and high intensity refers to press utilization for a given day in how many hours a press is actually printing. Low and high intensity represents 4 and 10 hours printing, respectively.

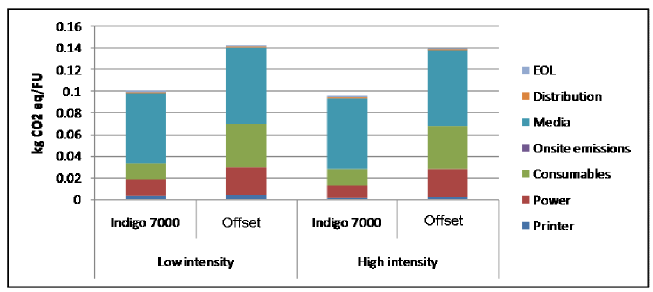


Figure 5. Comparison of carbon footprints at economic break-even point for two press utilization intensities, IPCC 2007 100 yr impact method.

In low press utilization, the Indigo's carbon footprint is 30% lower than the offset press. This number climbs to 32% in the high press utilization scenario. The biggest contributor to the offset press's larger carbon footprint is due to its energy consumption and consumables impacts.

The water footprints of the two presses are shown in Figure 6. The water footprint of the Indigo 7000 is 59% lower than for the offset press. This large difference is due primarily to the high water usage during the anodizing process of the aluminum plates used in the offset press. Since the offset press is a four color process, it requires separate aluminum plates for each color for each unique print job. The water footprint associated with paper is also significant for both presses.

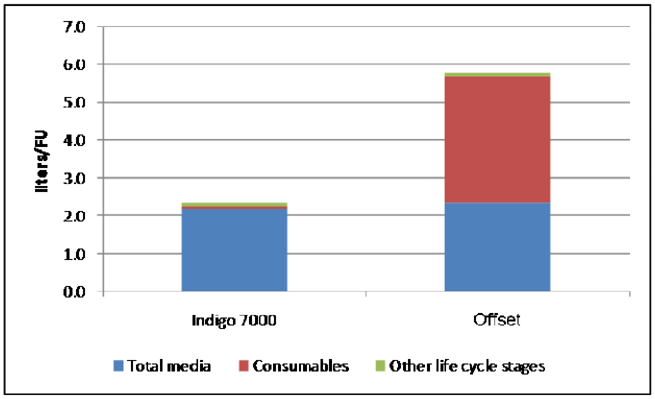


Figure 6. Comparison of the water footprint of the two presses at the economic break-even point and at low press utilization.

All the results shown so far were for a fixed number of printed brochures, i.e., 993 brochures at the economic break-even point. However, the fixed impacts (prepress, makeready, washup) associated with an offset printing are not negligible, but their importance on a "per functional unit" basis decreases as the number of printed brochures increases. At sufficiently high job sizes, the impacts of the offset press will be lower than that of the Indigo 7000. The number of printed brochures at which the environmental impacts are the same for both presses is referred to as the environmental break-even point.

The results of environmental break-even analysis are shown in Figure 7 for only carbon footprint, but the trends are the same for the other three endpoint categories. Carbon footprint impact is shown per functional unit compared to job size in number of brochures printed for a single print job. The break-even point is where the offset line crosses the Indigo 7000 line for a given graph. In all four impact cases, it can be seen that the impacts per functional unit of offset printing drop very rapidly during the first 1000 brochures printed

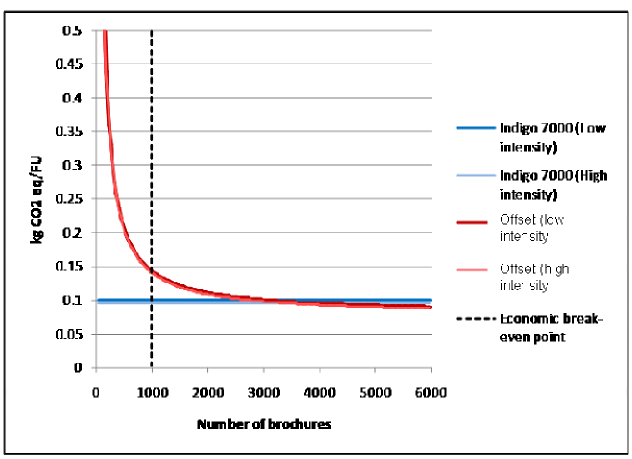


Figure 7. Carbon footprint per functional unit as a function of printed brochures. Dashed line represents the economic break-even point.

Figure 8 shows the environmental break-even evaluated on a cumulative basis versus on a functional unit basis similar to the economic break-even analysis shown in Figure 2. What this shows is that the Indigo 7000 is environmentally preferable at run lengths of 3000 brochures or less compared to economically preferred run lengths of 993 brochures or less. So, when the Indigo 7000 is running at the economic break-even point or less it is in the environmental preferred region as well.

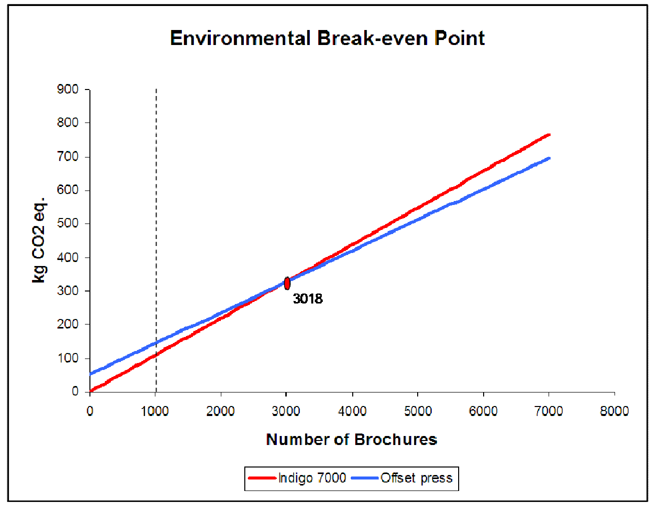


Figure 8. Cumulative environmental break-even as a function of printed brochures. Dashed line represents the economic break-even point.

Conclusions

Although there will always be uncertainty relative to the actual numbers one arrives at in an LCA, the results of this study indicate clearly that, at the economic break-even point as determined by HP's cost estimator and for the specific type of marketing collateral considered, the potential impacts of printing marketing collateral on the Indigo 7000 are lower than those of printing on the competitive offset press. The actual percentage reduction in potential impacts associated with substituting a print job on an offset for one on the Indigo 7000 varies according to a number of parameters, modeling choices, and impact category. However, for the majority of the impact categories, there is a robust reduction for job sizes equal to the economic break-even point. The results also suggest that there will always be a job size after which the impacts of printing on the Indigo 7000 are larger, although these can be quite high (e.g. above 34,000 brochures for water footprint).

A number of sensitive parameters were identified that could lower the potential environmental impacts of printing. Some of these are directly related to the press design (e.g. energy consumption, design of consumables). However, there are a number of parameters that were identified which are actually under the control of the print service provider: size of base sheets used, press utilization, and the speed at which a press is run.

References

[1] Helmut Kipphan (ed.), Handbook of Print Media (Springer-Verlag, New York, 2001) pg. 8.

[2]http://h10088.www1.hp.com/gap/download/UK_7000_BRO_Stream_Low.pdf

Author Biography

Tim Strecker received his PhD in chemical engineering from Washington State University (1994). He has worked in various aspects of digital printing at Hewlett-Packard since 1996. Most recently his research has focused on life cycle assessments of commercial and industrial printing systems and implementation of environmental metrics for product and technology development.

Pascal Lesage received his PhD in chemical engineering from the École Polytechnique de Montréal (2005). Since then, he has been active both on the research (CIRAIG) and applied (Sylvatica) fronts of life cycle assessment. He is currently associate professor at the École Polytechnique de Montréal and an independent LCA consultant.