Life Cycle Analysis in the Printing Industry: A Review

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Abstract

Life Cycle Assessment (LCA) is the leading tool for estimating environmental effects of products and processes. Despite this wide use, LCA analysis remains problematic and limited. Within the printing industry, one of the primary problems is non-standardized assumptions and practices. This makes it difficult, if not impossible, to compare the life cycle impacts of products. This paper will compare LCA studies performed within the printing industry in order to identify common practices, limitations, areas for improvement, and opportunities for standardization. This comparison is focused on the data sources and methodologies used in the particular studies.

Introduction

Given the pervasiveness of print, it is not surprising that many organizations are interested in the environmental impacts associated with printing through its life cycle. For example, 42% of the world's harvested industrial wood is used to make paper [1]. Within the forest products industry, the pulp and paper industry uses 84% of the energy consumed by the forest products industry [2]. A Manufacturing Energy Consumption Survey (MECS) conducted by the U.S. Energy Information Association ranked the industry as a whole as the third largest industrial consumer of energy, ranked only behind the petroleum and chemicals industries [2]. Given these impacts, a clearer understanding of the life cycle environmental impacts of printing would naturally be of interest.

While LCA is a widely used tool, it still has its drawbacks, such as expansive data requirements and high associated costs [3]. One potential mechanism to reduce these problems is to develop LCA standards. Initial attempts to standardize LCA processes have been made by the International Organization for Standardization [4, 5] and the Society of Environmental Toxicology and Chemistry [6]. These codifications are meant to establish basic guidelines while remaining broad enough to be applicable to a wide variety of practitioners.

The Electronic Product Environmental Assessment Tool (EPEAT) has taken a different approach [7]. Realizing that each industry has certain areas of major impact and assumptions specific to that industry which would carry little weight elsewhere, it has established product-specific standards. The U.S. ENERGY STAR certification program is another widely recognized certification program that has led to the wide acceptance of industry-specific Typical Electricity Consumption (TEC) procedures, which has helped to standardize energy use calculations [8, 9].

In addition to the standardization of impact assessment methods, there are also commonly used standards that quantify specific life cycle impact categories. For example, the Intergovernmental Panel on Climate Change is frequently cited for 50- and 100-year greenhouse gas (GHG) equivalent carbon dioxide (CO2e) calculations [10], as is the British Standards Institution's Publicly Available Specification 2050 (PAS 2050) on GHG emissions [11].

Despite these standards and certification programs, there is still a great deal of uncertainty and disagreement about the interpretation of the many LCA studies in the printing industry. In this paper, several LCA studies are compared in order to identify common practices, limitations, and areas for improvement and standardization.

Methodology

Analysis

Based on ISO 14040, the categories that will serve as the basis for conducting the comparisons that follow, will include the goal and scope, the inventory analysis, the impact analysis, and the interpretation of the results. The comparison of goal and scope includes the study context, the delineation of the functional unit, definition of the system boundaries, and determination of the printer system items under consideration. Comparison in this phase is focused on the data sources used and on the methodologies used in these particular studies. The comparison of impact assessment will focus largely on the particular impact categories selected and how they relate to the original goal and scope of their study. Lastly, the weighting of impact categories and a comparison of how these results were interpreted will be discussed, followed by a short discussion on the importance of the critical review.

Scope of Study

Since the focus of this research is the printing industry, the studies were selected because they either included imaging equipment or were highly relevant to imaging equipment. The term "imaging equipment" is defined in the energy-using products (EuP) preparatory studies as "commercially available product which was designed for the main purpose of producing a printed image (paper document or photo) from a digital image through a marking process" [12]. Table 1- Table 5 summarize the studies that were included in this work. It should be noted that while pulp and paper production are clearly an important contributor to the life cycle impacts of printing, explicit studies of these industries are not included in this review since their impacts are typically accounted for in the studies reviewed in this work. For the interested reader, paper and pulp industry LCAs such as those by Dias, Arroja, and Capela [13] and Miner [14] provide excellent reviews of paper and pulp industry LCA analyses.

Table 1: Printer LCAs Included in Study

ID	Short Title	Author [Ref]	Product	Purpose
1	Product Env. Metrics for Printers	Ord [15] 2009	Printers	Internal design tool
2	Solid Ink LCA	Koehler [16] 2010	Solid Ink and IJ Printers	Comparative LCA
3	Eco-efficiency gains from remanufacturing	Kerr [17] 2001	Photocopier Remanufacture	Comparative LCI: re-use vs. new
4	Extended Producer Responsibility for E-Waste	Mayers [18] 2005	HP printers	Comparative LCA: End of Life
5	EuP Preparatory Studies "Imaging Equipment"	Stobbe [12] 2007	EP & IJ Printers, Copiers and MFDs	Industry baseline LCA

Table 2: Cartridge LCAs Included in Study

ID	Short Title	Author [Ref]	Product	Purpose
6	LCA Toner Cartridge C4127X	Berglind [19] 2003	HP Cartridge C4127X	Comparative LCA: Re-manufacture
7	LaserJet Cartridge Life Cycle Refresh Study	Four Elements [20] 2008	HP LJ 10A and remanu-factured cartridges	Comparative LCA: Re-manufacture
8	Life-cycle inventory of toner for xerographic processes	Ahmadi [21] 2003	Toner	LCI of toner

Table 3: Print Product LCAs Included in Study

ID	Short Title	Author [Ref]	Product	Purpose
9	Life Cycle Carbon Footprint of the National Geographic	Boguski [22] 2009	Magazine	Carbon Footprint
10	LCA: Flexographic and Rotogravure Printing	Veith [23] 2008	Packaging materials printing	Comparative LCA

Table 4: LCA Design Methodologies/Tools Included in Study

ID	Short Title	Author [Ref]	Produ ct	Purpose
11	Methodology for the Evaluation of Product Sustainability at the Design and Development stage	Silva [24] 2006	N/A	Design stage Sustainability Scoring
12	Development of a Green Scorecard	Ebner [25] 2009	Printers	Design directional indicator

Table 5: Consumer "Calculator" LCAs Included in Study

ID	Short Title	Author [Ref]	Product	Purpose
13	HP Carbon Footprint Calculator for printing	HP [26] 2009	Personal and Office Printers	Cost and Carbon Calculator
14	Xerox Sustainability Calculator	Xerox [27] 2008	Personal and Office Printers	Compare baseline and optimized print scenarios

Findings

Goal and Scope

Context

Organization affiliation and the intended use of the studies are two characteristics that have been used in this paper to identify the context of these studies. Organizational affiliation refers to the sector from which the practitioner that conducted the LCA came from. The second characteristic refers to the intended audience. These results are summarized in Table 6.

Table 6: Summary of Study Context

		Intended Audience		
		Internal Design	External Marketing	Baseline
Affiliation	Academia	2	1	4
	Industry Internal	2	3	1
	Industry External	0	3	2

While the results in Table 6 cannot be considered representative of all studies, note that academic studies were primarily conducted to establish baselines or for internal design purposes. In addition, no studies that were conducted by external consultants were used for internal design purposes, while the majority of the studies that were conducted for external marketing were at least reviewed by academia or a consultant.

Scope

This section of the paper will compare the functional unit and system boundaries decisions made is the studies identified above. The functional unit is essential as it defines the output by which products will be compared and all of the analysis parameters are therefore normalized to it. ISO defines the functional unit as the: "Quantified performance of a product system for use as a reference unit" [4] and it is "necessary to ensure comparability of LCA results" [5]. Defining a functional unit is made more complex by the multitude of functions a particular product can perform for a consumer, for example, a multifunctional (MFD) device. In addition, the factors that affect the purchase decision must also be accounted for when defining the functional unit.

There are many specific characteristics which must be consistent in order to compare functional units. For example, rate of printing, is sometimes omitted, yet it is directly related to energy consumption [12]. Other factors which contribute to the increased consumption of paper should also not be overlooked as the cumulative consumption of paper over the useful life of the printer becomes very important. Allowing for comparisons of alternatives that lead to reduced paper consumption often requires functional units that are flexibly defined to include other communications media (e.g. units of information being conveyed [25]).

Functional units typically include an aspect of time to allow for products with various useful life expectancies to be compared on an equal basis. The use period can have a significant degree of variability since it depends on more than simply when the machine is expected to go into disrepair; often machine replacement can be due to advances in technology rather than the loss of functionality. Within the surveyed literature the useful life of imaging equipment ranged from 2 to 8 years. An alternative to the use period is the number of images or documents for the life of the equipment.

A comparison of the assumptions behind the functional units used in the studies reviewed in this work is insightful. Table 7 shows the studies that have functional units that consider page output. When considering page outputs it is important to also consider the type of printer and the speed of that printer.

Table 7: Printer Usage Assumptions

(a)

ID	PPM [1]	Printer Type	Pages
6	17	LaserJet	30,000
7	25	LaserJet	100
2	50	Color Laser MFD	1,200,000
3	100 [3] 65 [4]	5100 B&W Copier DC 265 B&W Copier	12,000,000
8	135	B&W Copier [5]	22,000,000
12	User Input	User Input	10,000,000
1	User Input	User Input	User Input
13	User Input	User Input	User Input (10,000)[7]
14	User Input	User Input	User Input

(b)

ID	Pages/Month	Average Coverage	Time Period[2]
6	2,500	5%	1 Year (3 Cartridges)
7	Not Available	Not Available	Not Available
2	25,000	5-6%	4 Years (1 Device)
3	100,000	Not Available	10 Years Max[6]
8	611,111	6%	3+ years[6]
12	Not Available	5-6%	User Input
1	Not Available	Not Available	User Input
13	Not Available (833)[7]	Not Available	User Input (5 Years)[7]
14	Not Available	Not Available	Results Annualized

[1]Printer speed is indicated by prints per minute (PPM)
[2]Time periods are either the time limitations on the study or the expected useful life of the devices being studied.
[3]Xerox 5100 Copier Specifications
[4]Xerox Document Centre 265 DC Specifications
[5]Xerox (1997) Product Safety Data Sheet
[6]Limit on imaging device useful life
[7]These are the default settings used.
"Not Available" data are those that were not provided in the publications or reports.
"User Input" data are variable data that the tool user must enter at the beginning of the assessment.

System boundaries

Life-cycle stages refers to the cradle to grave process a product goes through from the acquisition of the raw materials, through production, use, and eventual end-of-life disposition (re-use, re-manufacture, recycle, disposal). Accurately quantifying all flows into and out of the product system would be extremely costly and time intensive. As a result, system boundaries are set to distinguish which impacts will be included. Inappropriate boundary selection risks that LCA results will not sufficiently reflect reality, leading to incorrect interpretations [28].

Most of the studies examined, including the design decision tools, do consider inputs from all stages of the product lifecycle. This does not mean, however, that all inputs from each stage are accounted for. In addition, the depth to which the environmental impacts for these inputs are accounted for is also varied.

The main life-cycle stage delineations used in this paper have been taken from ISO 14040 [5]. Two modifications were made for this analysis. Packaging has been separated from the production stage since it was an important consideration in some studies, particularly those focusing on consumables. Likewise, transportation was separated out because several studies focused on re-use and re-manufacture, where equipment must be collected and transported to be re-manufactured. Both transportation and packaging are included in multiple stages, meaning inclusion isn't always directly stated. A case could be made for separating out energy supply, considering the significance of the impact associated with this component; however, all the studies included this component to some degree.

In addition to the system boundaries, which represents the breadth of the data that was in the respective studies, the quality of data is also of importance. The National Geographic life-cycle carbon footprint study serves as an example of how multiple parts of the supply chain can collaborate to develop a better assessment, collecting data with greater breadth, depth and accuracy [22].

For each study, a short description of data collected during each stage of the life-cycle has been determined, which led to a loose grading system of A to E, similar to that used in Boguski [22], to evaluate the level of detail at which each life-cycle stage was explored. Some studies were missing parts of production, such as assembly, or were simply basing impacts on bill of material masses. The results of this grading effort are shown in Table 8.

There are no strong trends concerning lifecycle stage omissions. Transportation and packaging were lacking high quality data and are ignored in many of the studies. Raw materials acquisition is missing in the greatest number of studies, likely because the practitioners faced difficulties in obtaining upstream data. When it was included, the typical approach to raw materials acquisition and component manufacture by suppliers is to retrieve database impact attributes based on masses from a bill of materials obtained by disassembling the product.

It is also hard for practitioners to determine adequate upstream cut offs, as many times there are unknown processes involved in the production of component materials. Surprisingly, considering the difficulty in accurately estimating it, the end-of-life stage was the most populated. This is partly due to the focus of design tools on re-use and recyclability. Given the difficulty in estimating end-of-life practices, none of the core studies could be scored an "A". Trends in each stage will be discussed the next.

Table 8: Graded life-cycle stage data

	Cartridge Remanufacture		Baseline Academia		Comparative		Design Tools			Calculators		Baseline Industry		
Stage\ID	**6**	**7**	**5**	**4**	**10**	**2**	**11**	**12**	**1**	**13**	**14**	**3**	**9**	**8**
Raw Materials	B	B	C	C	B	B	B	C	B	D	C	C	A	B
Production	B	C	C	E	B	B	E	C	B	C	C	C	A	A
Transportation	B	B	B	E	C	B	E	B	C	D	D	C	B	B
Use	B	B	B	E	A	B	B	B	C	B	C	E	E	B
End of life	B	B	B	B	C	B	B	B	C	D	C	B	B	B
Packaging	B	B	C	B	D	B	B	C	E	D	B	D	E	C

A- Primary data measured on site during the phase. All relevant aspects seem to have been accounted for.
B- Database data or literature referenced data. May be missing part of a process.
C- Incomplete data or estimates, but still representative of some impacts in this stage
D- Stage was not included in study scope
E- NA, was excluded due to lack of applicability to study goals

Materials Acquisition Stage

It is very important to account for the raw materials and energy use upstream in the supply chain. Commercial print's greatest manufacturing cost is the paper used [29] and the majority of the environmental impact also comes from paper. Many paper suppliers have performed LCAs, but they tend to be unwilling to disseminate that proprietary information to their customers [personal communication, device manufacturer]. In cases where suppliers don't have environmental metrics data, there is concern that the cost to procure such data will be forced upon them [personal communication, Original Equipment Manufacturer]. Even if the supplier is willing to supply the results data, the lack of a standardized method for accounting for all attributes would mean results couldn't be compared interchangeably between different suppliers, and assumptions might unknowingly be changed from stage to stage of the LCA.

Production

Boguski [22] went as far as to include overhead operating impacts such as development and marketing staff and travel. This is not typically expected of an LCA, but acts as a reminder that the number of impact sources seems almost limitless if some cut-off criteria are not implemented. The two studies that were missing this stage were either focused on end-of-life [18] or simply left it out because other aspects were thought to have greater impact [24].

Use Phase

In almost the entirety of the studies examined, the electricity and paper used during the use phase were said to have had the most significant impacts for the imaging device. Due to the importance of the use phase, there is an increased importance placed upon user characteristics, habits and settings. As a result, sustainability services such as print optimization have gained popularity [30]. This trend started with office equipment but seems to be becoming more relevant for consumer printers [personal communications, OEM].

Options such as N-up and duplex printing also reduce the impact of print significantly. When using such strategies it is important to have supporting use data, so that these are accurately accounted for. For example, the level to which duplexing is expected to reduce paper use is debated since many documents printed are less than one page in length according to Lyra Research [12]. Xerox estimates that about 20% of documents are printed double sided [25]. Several of the print use patterns and assumptions that have already been described are difficult to estimate as "use patterns are of course highly diverse" and "there are no basic or comprehensively representative use patterns even for one and the same device" [12].

End-of-life

End-of-life is a stage of the life-cycle where large discrepancies exist in LCA practices and the print industry is no exception. A major contributor to this is that waste management differs by locality and not all options can be taken into account [31]. For the print industry, recycling rates and the impact of different methods can cause significant differences in outcomes, mainly due to the impact of paper [32]. This has led some sectors of the industry to focus on de-inking to increase recyclability [33]. There is some controversy about how to account for the environmental impacts of deinked paper [21, 22].

Remanufacturing and re-use is another area of debate for the print industry. All of the design tools examined in this work have included remanufacturing in some form in their analyses. Inconsistent end-of-life assumptions were seen within the studies. Some studies addressed this issue by using sensitivity analysis (e.g. [18]).

Specific to the end-of-life assumptions for cartridges, even cartridges that are not remanufactured, are recycled to a high degree. This is reflected in the imaging equipment studies, which have baseline landfill assumptions of only 1-2%. An important factor in these two imaging equipment studies was that they were conducted in the European Union where they must adhere to the WEEE Directive for imaging equipment end-of-life. The paper end-of-life assumptions may indicate that the use of the printed paper plays an important role if it may require long term archiving of the paper.

Transportation

With increased globalization, transportation due to outsourcing can contribute to environmental impact. In many cases this is low hanging fruit, as reduction of transportation also has a cost savings associated with it. Many (seven) of the studies didn't include data on transportation, most likely because of the difficulty in collecting these data outweighed the relatively small impact when compared to the impact of energy use and paper.

Packaging

Inclusion of packaging may seem unimportant, but the inclusion can be significant to the results of some studies, especially when it is included for consumables [16]. It seems that the impact of packaging, such as that used to ship the printer itself, is minimal, but that of the packaging used for consumables can add up over the useful life to have a significant impact. Five of the studies omitted packaging data completely in their assessment.

Print Consumables

Transportation and packaging are not the only data that are sometimes omitted. As discussed with the functional unit, paper is sometimes removed from comparative assessments under the assumption that the differences between the products will not have an impact on paper. Removing paper from the assessment will make other differences more notable (as a percent of total impact). This should only be done for comparative LCAs where the effect of paper is the same for both products, where the functional unit includes prints and equivalent print rates are being compared. Even in these cases, best practice would be to still display results with and without paper as a sensitivity analysis.

Cartridges

It is difficult to deal with the life-cycle of cartridges without getting into a discussion of their remanufacture. Some companies have made claims in sustainability reports of environmental impact reductions due to their cartridge remanufacture programs. Lexmark recently made claims of an up to 60% carbon footprint decrease for remanufactured cartridges [34], while others have argued that in reality they have a negative impact due to reduced print quality [20]. Despite the fact that the studies are not in agreement, the EuP estimates that only 10% to 15% of cartridges are remanufactured [12]. Berglindand and Eriksson [19] concluded that cartridges account for a small fraction of environmental impact of the printing system leaving remanufacturing only advantageous under certain circumstances.

Ink and toner

Estimates of ink, toner and cartridge consumption are consistent, with yield testing requirements set forth in ISO/IEC. It is clearly an important area of focus primarily from the fact that it has the potential to contribute to emissions and airborne particulates, impacts the recyclability of the substrate and is derived from process intensive manufacturing. One of the studies performed an LCA on the toner life-cycle, including its use and recycling from paper at end-of-life [21]. Other studies focused on the print consumables' packaging, reducing the environmental impact through safer adhesives, improved materials selection and increasing the recyclability [35]. In commercial printing there is greater focus on inks and solvents due to their volatility. A major concern for commercial print shops has become Volatile Organic Compounds (VOC) and air emissions. This issue exists with office printers on a smaller scale, as they are also a source of particulate matter, ozone and VOCs [36].

Life Cycle Inventory (LCI)

Life-cycle inventory analysis defines and quantifies the flow of materials and energy into, through and out of a product system (ISO, 2006a); this section focuses on identifying and dealing with uncertainty. Two sources of preventable data quality issues typically occur; those due to data gaps and those due to use of proxy or generic data [3]. Many of the studies in this work included sensitivity analysis which used different assumptions for uncertain parameters such as recycling rates. A substantial barrier to adoption of LCA metrics has been cost of collecting the necessary data (personal communications, packaging label printer). When an LCA is performed, practitioners often note difficulty in obtaining accurate data. Five studies specifically note that this difficulty impacted their results.

Data sources

The commonly used databases and methodologies are worth noting, as are the standards and certifications which industry LCAs and decision tools are based on. Figure 1 shows the most commonly cited certifications and standards, with the number of studies that referenced them.

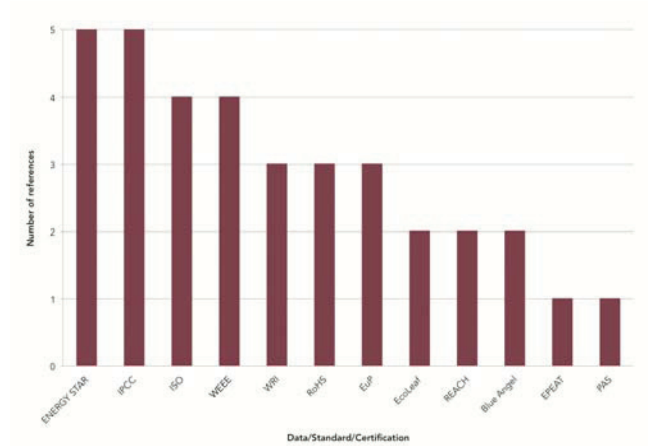

Figure 1: Referenced data, standards, and certification sources within studies

Life Cycle Impact Assessment (LCIA)

Life-cycle impact assessment converts the inventory data collected during the inventory analysis into environmental impact estimates using a two-step process of classification and characterization [5]. This is a complex and somewhat subjective process, which is why such care has been taken to identify where data has come from. The solution has been to utilize impact assessment software which adheres to published methods and often includes multiple databases. The discussion of data in this section will mainly focus on specific data sets, data quality and the pros and cons of alternative methodologies.

Methodologies

When lifecycle inventory data representing the raw materials and processes involved are converted into environmental impact categories the results are considered midpoints, such as energy use or CO2e [37]. Endpoints require an additional step where impact categories are aggregated through weighting factors (Examples: Eco-Indicator 99, EPS 2000, IMPACT 2002, EDIP) [38]. The further toward an endpoint a study gets, the more influence the methodology used has. Some studies choose to present results as endpoints, others just as inventories of impacts.

Impact Categories

Life Cycle publications which intended to differentiate products based on their different environmental impacts tend to focus on 3 or 4 main impacts instead of presenting some end result weighted score or a more complete set of impacts [3]. This is what can be seen with many of the LCAs meant for external audiences reviewed in this work. Practitioners selectively limit the number of impact categories so as to not overwhelm the reader with information that is relatively less important. The danger in this is that impact categories have to be normalized to determine significance relative to one another. Studies performed by academia are more likely to include all impact category results, even if they are very small or not relevant. There are several reasons for omitting impact categories, mainly a lack of standards [40], lack of data, the belief that the category is irrelevant or lack of consideration within the methodology being used [3].

Global warming was the leading impact category of the studies (excluding energy use). This is likely due to the importance placed on CO_2 emissions in recent years. There is also a universally accepted standard (IPCC 100-years). Other emissions had far less emphasis as there seemed to be less attention placed on the impacts of toxicity and human health, even though this would seem to be a priority impact [3]. This may be due to the fact that impacts that are a threat to human health are already being regulated. The notable exception, however, is in the commercial print industry were VOCs are very important and have standards for determining emission, such as ECMA-328 [39].

Another impact category that did not receive much attention in the studies was resource depletion, with the exception of energy use. While it is more natural to treat energy consumption as a midpoint rather than an impact category as it contributes to other end point impacts such as GWP, it was treated here as an impact category since many studies did not differentiate between the end points which energy use was allocated to. This is not too surprising given the economic implications of energy consumption.

Waste receives a lot of attention considering the high level of uncertainty in end-of-life data, which is consistent with LCAs outside of the print industry. Ekvall [40] presents some methodologies specific to paper end-of-life and recycling.

Breadth and Depth of Assessment

In an attempt to summarize much of what has been reported upon up to this point, a breadth and depth assessment process is developed. To determine the breadth of the assessment, the stage data evaluations from Table 8 were average across context group; to assess depth the impact category inclusion data from Figure 1 were averaged for each of context group.

For impact categories, a score of 1-4 was assigned for the number of studies including each category, and then these scores were averaged. For stage data, numerical scores were assigned from A=4 to D=1. Grades of E were not averaged, as these were excluded from their respective studies for specific reasons rather than data collection difficulties. Impact categories could be skewed, however, all context groups, with the exception of academia, had categories which were both included and excluded in all studies within the group. This can also be seen in greater detail on Figure 2.

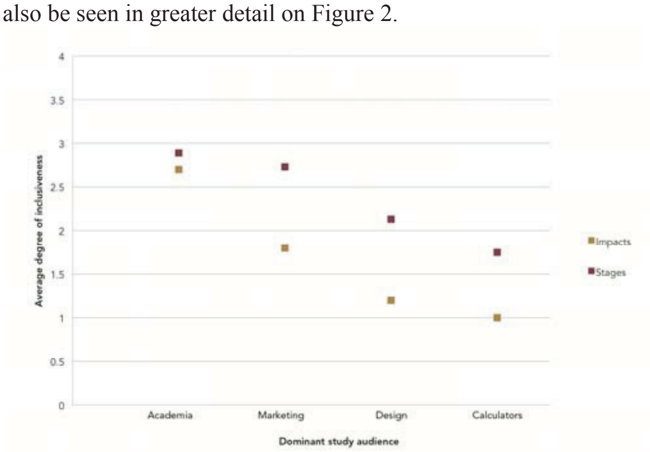

Figure 2: Breadth and depth of assessments in studies

Academia was the most inclusive of both stage data and impact categories, which is not surprising given the focus on establishing baseline data and presenting replicable results. Studies performed for external marketing purposes had the same level of stage data, but ranged from 2.3 to 3 on a 4 point scale. It was interesting that external marketing studies were more inclusive than those for internal design. This may suggest that internal design tools have been streamlined beyond the point which is best for external communications, but not to the point that they inhibit good decision-making.

Reporting and critical review

Performing LCAs internally has the advantage of keeping data proprietary [Personal communications, print shop]. Several major companies have performed LCAs and published improvement results for marketing purposes [34] or within their sustainability reports [41, 42]. The actual quantitative results and the complete assessment have not been published, which ensures that proprietary information isn't disclosed. Recognizing the desire to retain proprietary information but also balance the necessity to keep transparency and accountability has led to ISO's requirements on reporting and critical external review ISO [5].

Conclusions and Further Research

There has been a great deal of activity in environmental impact assessment within the printing industry in recent years. It is clear that a great deal of effort and expense has been put into these assessments. While each of these analyses has served specific purposes, the printing industry has expressed the need to be able to make meaningful comparisons across studies. The analysis performed in this work has not only confirmed this inability to make the cross comparisons across studies, but it has also identified sources of discrepancies and variability.

Some of the important observations made in this work, as well as implications for future work are summarized below:

- Both design decision tools and full LCA have a role in a company's environmental sustainability program.
- An approach to standardization needs to include the standardization of measurement methods. By following this approach more cross study comparisons will be facilitated.
- Like most LCAs, those performed in the print industry still lack reliable data for early lifecycle of paper and end-of-life since these are still difficult to agree on. Some uncertainty issues can be solved by increasing data and data transparency through inclusion of meta-data or reviews.
- Products have diverse functional values beyond simple document production. Standardization of the functional unit and the use assumptions that are interwoven within it has high potential to increase quantitative comparability across studies. At the same time, caution to not define the imaging devices function by paper allows for comparison of alternative media.
- Consumer behavior has the potential to be the greatest environmental impact reducer. In addition, some of the most significant assumptions are those on use behaviors. The gathering of use data and its variability needs to be the focus of future work.
- Consumables should continue to be examined closely.

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