



## Comparative life cycle assessments: The case of paper and digital media



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### ARTICLE INFO

#### Article history:

Received 4 October 2012  
Received in revised form 2 October 2013  
Accepted 15 October 2013  
Available online 18 November 2013

#### Keywords:

Life cycle assessment  
Electronic media  
Paper media  
Moore's Law

### ABSTRACT

The consumption of the written word is changing, as media transitions from paper products to digital alternatives. We reviewed the life cycle assessment (LCA) research literature that compared the environmental footprint of digital and paper media. To validate the role of context in influencing LCA results, we assessed LCAs that did not compare paper and print, but focused on a product or component that is part of the Information and Communication Technology (ICT) sector. Using a framework that identifies problems in LCA conduct, we assessed whether the comparative LCAs were accurate expressions of the environmental footprints of paper and print. We hypothesized that the differences between the product systems that produce paper and digital media weaken LCA's ability to compare environmental footprints. We also hypothesized that the characteristics of ICT as an industrial sector weaken LCA as an environmental assessment methodology. We found that existing comparative LCAs offered problematic comparisons of paper and digital media for two reasons – the stark material differences between ICT products and paper products, and the unique characteristics of the ICT sector. We suggested that the context of the ICT sector, best captured by the concept of “Moore's Law”, will continuously impede the ability of the LCA methodology to measure ICT products.

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### 1. Introduction

The consumption of the written word is changing. Newspapers, magazines, books and other paper products are being replaced by a complex system of interconnected electronic devices. The nature and pace of this transition is uneven. Some paper media products and publishers may survive, while others adapt or disappear. Given the importance of sustainability – broadly defined as activities that do not compromise the well-being of future generations (United Nations, 1987) – it is worth considering the implications of a shift from paper to digital media from an environmental perspective.

The Internet and Information and Communication Technologies (ICT) are transforming the profile of the global economy and impacting the environment. ICT includes technologies such as desktop and laptop computers, smartphones, e-readers, software, peripherals and connections to the Internet that fulfill information processing and communications functions. The impact of ICT on the global economy is complex. Berkhout and Hertin (2004, p.903) studied the direct, indirect, and structural impacts of the ICT sector. They found that the sector and its impacts are “complex, interdependent, deeply uncertain and scale-dependent.” Hilty et al. (2006, p.1618) worried that “there is some risk that ICT will become counterproductive with regard to environmental sustainability.” They encouraged a systematic view of ICT to ensure its application is used in support of sustainable development.

Williams (2011, p.354) encourages a broad view on the impacts of ICT, suggesting that the “energetically expensive manufacturing process, and the increasing proliferation of devices needs to be taken into account.” Andrae and Anderson (2010) found that not all LCAs of ICT products are created equally. They found desktop and laptop LCAs to be the least consistent of the consumer products they examined, rooted in subjective choices and different system boundaries and lifetimes. Malmodin et al. (2010) found that in 2007 the ICT sector produced 1.3% of global greenhouse gas emissions and used 3.9% of global electricity. Given the growth of the ICT sector since 2007, this figure has likely increased.

Researchers have studied the environmental trade-offs between traditional and web-based retailing (Edwards et al., 2010), between working at the office or at home (Mokhtarian et al., 1995), between different music delivery methods (Weber et al., 2010), and between paper-based telephone directories and online equivalents (Zurkirch and Reichart, 2002). One of the most frequently considered transitions is that from paper to digital media. Products such as invoices, telephone directories, textbooks, office paper, magazines and newspapers all have digital alternatives.

The environmental impact of these trade-offs has most commonly been measured by means of a life cycle assessment (LCA), a rigorously defined and transparent methodology for quantifying environmental burdens associated with the creation, use and disposal of products and systems. LCA is rooted in efforts to compare products, with a seminal study conducted in 1969 that examined the differences between various beverage containers (LeVan, 1995). The tool was extended to other comparisons contrasting, for example, paper and plastic bags,

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cloth and disposable diapers or steel beams and dimensional lumber. All of these comparisons are trade-offs between two product systems that can be defined in a straightforward way. The trade-off between paper and digital media, however, is more complex. Digital products can replace paper consumption, but this is not their only function. Researchers have also found that increased digital media consumption does not necessarily reduce paper media consumption (Sellen and Harper, 2001). These compounding factors suggest that the ICT sector may strain LCA's ability to make meaningful comparisons. It is this idea that we intend to test. We hypothesize that the differences between the product systems that produce paper and digital media weaken LCA's ability to accurately compare environmental footprints. We also hypothesize that the characteristics of ICT as an industrial sector weaken LCA as an environmental assessment methodology. To test this latter hypothesis, we also examined LCAs that looked exclusively at ICT products.

LCA excels in considering discrete trade-offs between product systems that can be clearly defined and in comparing products that are discrete substitutes. A paper or plastic bag is a straightforward consumptive choice. The same cannot be said for paper or digital media. Studies suggest that the more discrete and precise the trade-off considered, the more effective the LCA is as a tool of environmental assessment (Gaudreault et al., 2007a,b). Earlier research has also shown that the LCA is constrained in its ability to compare at all, with Finnveden (2000, p.299) suggesting "it can in general not be shown that one product is environmentally preferable to another, even if this happens to be the case." Should process  $x$  or  $y$  be employed to minimize environmental footprint? Would product  $a$  or  $b$  have a smaller environmental footprint? These are the questions that LCAs can and should answer. But sometimes the relationships between  $x$  and  $y$  are enormously complex. Managing this complexity imposes unavoidable uncertainty and a resulting series of assumptions. How does the LCA perform in assessing a complex consumptive choice? Further, how does the LCA perform when complexity lies not just in a lack of a discrete trade-off, but in the fundamental character of one of the subjects being studied? This paper is an effort to answer these questions by reviewing comparative LCAs that have examined paper and digital media. By doing so, we aim to elucidate the strengths and weaknesses of LCA as a comparative tool. Further, we seek to strengthen our understanding of the role that context plays in LCAs, and in this particular case, the context of the ICT sector. We focus on ICT throughout our paper because we believe this sector warrants particular scrutiny. It is disruptive to many aspects of the global economy and several industrial sectors beyond paper-based media, with direct, indirect and behavioral effects. It is changing rapidly, with new products, processes and devices emerging. Forestry and paper production are not without environmental impacts, with land-use change, emissions from production, and the creation of waste as prominent examples. For a review of issues associated with paper LCAs see Gaudreault et al. (2007a,b).

## 2. Methods

We describe an analytical framework for assessing problems in the conduct of an LCA, and our methods for selecting comparative LCAs and validating our results through ICT LCAs. We organize the results around problems identified in an analytical framework. We describe the problem, examine how it is addressed in comparative LCAs, and then assess the approach of ICT LCAs.

### 2.1. Framework for assessing problems in LCAs

An LCA is a four-step tool designed to estimate the potential environmental impact of a product, process or system (ISO, 2006). These four steps, and the challenges that occur at each stage, are summarized by Reap et al. (2008a,b). The authors suggest six

challenges that are of particular concern: functional unit definition, boundary selection, allocation, spatial variation, local environmental uniqueness and data availability/quality. These six challenges structured our review of comparative LCAs that examine paper and digital media. Reap et al. (2008a,b) identified these challenges as most important because they had significant influence over study results and adequate solutions are available to ameliorate impacts. We describe the specifics of each challenge in the Results section, followed by our analysis of comparative LCAs and ICT LCAs.

We chose studies that specifically examined potential trade-offs between paper and digital media for several reasons. Paper and digital media are very distinct product systems, and we wanted to gauge the robustness of the LCA when comparing such different units of analysis. Further, the ICT sector is a dynamic and growing industry that has disrupted many existing industrial sectors. The idea of the "paperless office" was held up as an environmentally preferable future (Sellen and Harper, 2001). The phrase "please consider the environment before printing this email" is often appended to emails. It suggests that printing on paper is bad for the environment, while sending an email is innocuous. We wanted to understand whether this assumption that digital media is preferable is supported by academic research. We searched academic databases for peer-reviewed literature on the subject, but also considered publically available technical reports and white papers. In the end, this left us with seven studies which we summarized using the six key challenges in Reap et al.'s (2008a,b) analytical framework. The studies reviewed are listed below.

- Deetman S, Odegard I. Scanning Life Cycle Assessment of Printed and E-paper Documents based on the iRex Digital Reader. 2009. Institute of Environmental Sciences, Leiden University
- Enroth M. Environmental impact of printed and electronic teaching aids, a screening study focusing on fossil carbon dioxide emissions. *Adv. Print. Media. Technol.* 2010;36, 1–9.
- Gard DL, Keoleian GA. Digital versus print. Energy performance in the selection and use of scholarly journals. *J. Ind. Ecol.* 2003;6(2):115–32.
- Hischer R, Reichart I. Multifunctional electronic media – traditional media. The problem of adequate functional unit. A case study of a printed newspaper, an internet newspaper and a TV broadcast. *Int. J. LCA* 2003;8(4):201–8.
- Kozak G. Printed Scholarly Books and E-book Reading Devices: A Comparative Life Cycle Assessment of Two Book Options. 2003. Center for Sustainable Systems, University of Michigan
- Moberg Å, Johansson M, Finnveden G, Jonsson A. Printed and tablet e-paper newspaper from an environmental perspective – a screening life cycle assessment. *Environ. Impact. Assess.* 2010; 30(3), 177–191.
- Moberg Å, Borggren C, Finnveden G. Books from an environmental perspective – part 2: e-books as an alternative to paper books. *Int. J. LCA* 2011; 16(3): 238–246.
- Toffel MW, Horvath A. Environmental implications of wireless technologies. News delivery and business meetings. *Policy Analysis* 2004;38(11):2961–70.

Reap et al.'s (2008a,b) framework provided the concepts and theory necessary to identify whether inaccuracies in LCAs result from a failure to implement the LCA methodology appropriately. But the framework cannot identify whether there are problems outside the scope of LCA methodology that influence results. To identify the potential of context to influence comparative LCA results, we triangulated our results by also using ICT LCAs that did not attempt to compare one product to another. The underlying logic is that if the same problems are identified in both comparative LCA s and ICT LCAs, we can better gauge the role of context in influencing LCA results.

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