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Merja Kariniemi & Minna Nors

# Environmental performance of digital printing

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VTT Technical Research Centre of Finland, Vuorimiehentie 5, P.O. Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 4374

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**Keywords** digital printing, environmental impacts, indicators

# Abstract

The objective of this literature study is to summarise the present situation and future prospects of digital printing technologies and markets, to review the existing publicly available information on the environmental impacts of digital printing, and to present suitable indicators for assessing the environmental performance of digital printing.

Digital printing methods have developed considerably in recent years, both in terms of quality and productivity. New products based on the variable data printing capability of digital printing have been introduced. Digital methods have also taken market share from mechanical printing methods in the on-demand and short-run production of traditional products. The market share of digital printing will continue to increase in the future.

There is little published research on the environmental impacts of digital printing. The analysed literature indicates that digital methods have a higher energy and ink/toner consumption than mechanical methods, but their chemicals and water consumption and waste output are lower. Paper consumption and emissions to air are difficult to assess due to the lack of data. More research is needed to obtain a better and more reliable understanding.

Environmental indicators used in earlier studies of printing can be used for digital printing as well. These include physical and monetary input and output figures like energy and materials consumption, emissions and waste output. The suitable functional units are the weight and the surface area of products, e.g. tonne of printed products or million duplex printed A4 sheets.

# Preface

This study is a part of a larger research project "Lean development with renewable resources" (Leader) that started in 2007. This study has been conducted mainly by Pentti Viluksela from Helsinki Metropolia University of Applied Sciences. The coordination of this study was from VTT.

The Leader project has been funded by Metsäliitto, Myllykoski, Stora Enso and UPM-Kymmene, Graafisen Teollisuuden Tutkimussäätiö (GTTS, The Graphic Industry Research Foundation) and The Finnish Funding Agency for Technology and Innovations – Tekes.

# Contents

# List of abbreviations

| | |
|---|---|
| BAT | Best available techniques |
| BREF | BAT reference document (of the EU) |
| CAGR | Compound annual growth rate |
| CD | Compact disc |
| CDI | City development index |
| CEO | Chief executive officer |
| CO2e | Carbon dioxide equivalent |
| CF | Carbon footprint |
| CIJ | Continuous (stream) inkjet |
| CML | Centrum voor Milieu-kunde Leiden |
| CMYK | Cyan, magenta, yellow, key (process colours) |
| CS | Continuous stream (inkjet) |
| CSR | Corporate Social Responsibility |
| CSWO | Coldset web offset |
| CTP | Computer to plate |
| DfE | Design for environment |
| DM | Direct mail |
| DNA | Deoxyribonucleic acid |
| DOD | Drop on demand (inkjet), also DoD |
| DPDA | Digital Print Deinking Alliance |
| EA | Emulsion aggregation |
| EF | Ecological footprint |
| EBIT | Earnings before interest and tax |
| ECI | Environmental condition indicators |
| EDF | Environmental Defence Fund |
| EDIP | Environmental design of industrial products |
| EDSF | Electronic Document Systems Foundation |
| EEA | External environmental accounting |
| EEIO-LCA | Environmentally extended input-output life cycle assessment |
| EMA | Environmental management accounting |
| EMS | Environmental management system |
| EP | Electrophotography |
| EPE | Environmental performance evaluation |
| EPI | (a) Environmental performance indicator (b) Environmental performance index |
| ERPC | European Recovered Paper Council |
| ESI | Environmental sustainability index |
| EU | European Union |
| EVI | Environmental vulnerability index |
| EWI | Ecosystem well-being index |
| FSC | Forest Stewardship Council |
| G3 | Sustainability Reporting Guidelines (version 3, published in 2006) of the GRI |

| | |
|---|---|
| GDP | Gross domestic product |
| GFN | Global Footprint Network |
| GHG | Greenhouse gas |
| GNP | Gross national product |
| GPI | Genuine progress indicator |
| GRI | Global Reporting Initiative |
| GWP | Global warming potential |
| HABITAT | United Nations Centre for Human Settlements |
| HAP | Hazardous air pollutant |
| HC | Hydrocarbon |
| HDI | Human development index |
| HFC | Hydrofluorocarbon |
| HPI | Happy planet index |
| HSWO | Heatset web offset |
| HWI | Human well-being index |
| ID | Identity |
| IFAC | International Federation of Accountants |
| IJ | Inkjet |
| INGEDE | International Association of the Deinking Industry |
| IPA | Isopropanol, isopropyl alcohol |
| IPCC | Intergovernmental Panel on Climate Change |
| IPPC | Integrated Pollution Prevention and Control (EU directive) |
| ISEW | Index of sustainable economic welfare |
| ISO | International Organization for Standardization |
| IUCN | International Union for the Conservation of Nature and Natural Resources |
| KTH | Kungliga Tekniska Högskolan |
| LCA | Life-cycle assessment |
| LCI | Life cycle inventory analysis |
| LCIA | Life cycle impact assessment |
| LED | Light-emitting diode |
| LMV | Lost materials value |
| LPI | Living planet index |
| LWC | Lightweight coated |
| MEMA | Monetary environmental management accounting |
| MEMS | Microelectromechanical system |
| MINT | Miljönyckeltal |
| MIPS | Material input per service unit |
| MSDS | Material safety data sheet |
| MPI | Management performance indicator |
| NEF | New Economics Foundation |
| NIP | Non-impact printing |
| NMVOC | Non-methane volatile organic compound |
| NPO | Non-product output |
| OLED | Organic light-emitting diode |
| OPC | Organic photoconductor |
| OPI | Operational performance indicator |
| PDCA | Plan–Do–Check–Act (management cycle) |
| PDMS | Polydimethylsiloxane |

| | |
|---|---|
| PE | Polyethylene, polythene, polyethene |
| PEFC | Programme for the Endorsement of Forest Certification schemes |
| PEMA | Physical environmental management accounting |
| PFC | Perfluorocarbon |
| P-LCA | Process-based lifecycle assessment |
| PM | Particulate matter |
| PMS | Pantone matching system |
| PO | Production output |
| POD | Print on demand |
| POP | Persistent organic pollutant |
| PSDS | Product safety data sheet |
| REACH | Registration, Evaluation, Authorisation and Restriction of Chemical substances |
| RFID | Radio frequency identification |
| RIT | Rochester Institute of Technology |
| ROG | Reactive organic gas |
| SC | Supercalandered |
| SFO | Sheet-fed offset |
| SME | Small and medium enterprises |
| SRA | Supplementary raw format A (formats for untrimmed raw paper according to ISO 217:1995) |
| SWOT | Strengths, weaknesses, opportunities, and threats |
| TTF | Toner transfer fusing |
| TVOC | Total volatile organic compound |
| UN | United Nations |
| UNDP | United Nations Development Programme |
| UNECE | United Nations Economic Commission for Europe |
| UV | Ultraviolet |
| VCA | Vegetable (oil-based) cleaning agent |
| VOC | Volatile organic compound |
| VTT | VTT Technical Research Centre of Finland |
| WFN | Water Footprint Network |
| WHO | World Health Organization |
| WI | Well-being index |
| WWF | World Wide Fund for Nature |

# 1. Introduction

*"Why doesn't the print industry do more to fight its corner in terms of its CSR profile?"*

*Mark Line, Two Tomorrows*[1]

## 1.1 Background

The effects of climate change, natural resources depletion and corporate social responsibility (CSR) are being felt everywhere, including the printing industry. Many opinion formers claim that moving away from print media to electronic and digital alternatives is environmentally preferable. Opponents of this shift argue that few industries are as sustainable as the paper and printing industry. However, there are many technological issues to be addressed when assessing the environmental and other sustainability issues of the printing industry and when measuring and comparing the various printing techniques and production processes.

From the technical point of view, digital printing is the fastest growing sector of the printing industry. During the past 15 years, digital techniques have become more reliable and cost-effective. Productivity of digital printing systems has improved thanks to faster presses and integrated finishing devices. At the same time, the range of alternative paper grades and other printing substrates available has expanded considerably, and the print quality has improved to approach a level commonly referred to as "offset quality".

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[1] http://www.twotomorrows.com/news/print-industry-should-come-out-fighting-csr/ (19.8.2009).

Parallel to its technical development, digital printing has moved in to take a share of existing print markets, mainly in short-run jobs. Digital methods do not use a master (a fixed printing plate or cylinder), which leads to a much faster make-ready and production start compared to traditional printing methods. In the production of documents, publications and books with a print run of 1000–2000 copies or less, electrophotography is gaining ground from sheet-fed offset. In the outdoor advertising and poster market, wide-format inkjet is challenging screen-printing.

Digital printing methods have also enabled the emergence of new products and applications. Unlike the traditional methods, each digitally printed page can be different from the previous one, which facilitates variable data printing, customisation, electronic collation and print on demand. The technology has existed for many years. While it was slow to take off at first, its applications are gradually becoming increasingly popular.

According to Pira, both the print quality and the speed of digital printing techniques will improve in the near future (see Figure 1). This will bring both toner-based and inkjet printing to the quality level of offset. Electrophotography can be seen as a mature technology, while inkjet still has considerable development potential. The only mechanical printing method showing quality improvement is flexography, which is mainly used in the packaging printing sector (Smyth 2008).

While digital printing techniques have progressed in technology and market applications in the printing industry, climate change and greenhouse gas emissions have become the urgent overarching theme in business, engineering and everyday life. The environmental impacts of digital printing are widely believed to be smaller than those of mechanical printing methods. This is mainly due to faster make-ready and the absence of platemaking and its related chemicals, materials, emissions and wastes. However, there is little public scientific research available to support this assumption. According to a Finnish study, electrophotography consumes considerably more energy and inks per one tonne of printed matter than sheet-fed offset, but requires less water and chemicals and produces less waste (Viluksela et al. 2008).

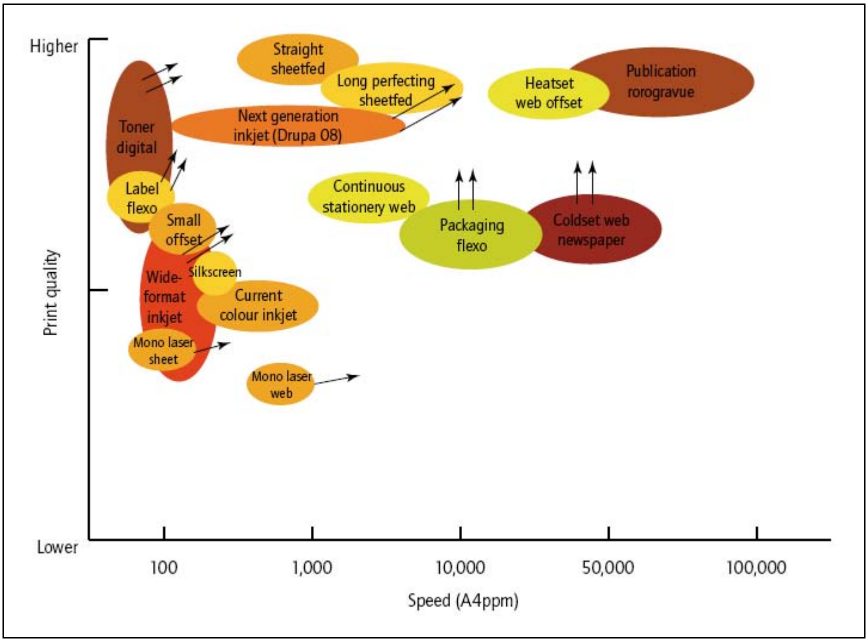


Figure 1. Future technology map of commercial print processes according to Pira International Ltd (Smyth 2008).

## 1.2 Objective and scope of the report

This literature study concentrates on digital printing, the most prominent growth sector within the printing industry. The study covers the two main digital printing techniques, electrophotography (also known as xerography and laser printing) and inkjet. Other, less dominant digital printing methods are briefly mentioned. From the product and application point of view, the focus is on publication printing, although other product groups are also covered in lesser depth.

The study has three objectives:

– to summarise the present situation and future prospects of the methods and technologies of digital printing (Chapter 2), as well as the applications and markets of digitally printed products (Chapter 3)
– to identify and analyse the existing publicly available information on the environmental and sustainability aspects of digital printing (Chapter 4)
– to analyse various means, methods and frameworks of assessing the environmental performance of digital printing (Chapter 5).

## 1.3 Digital and mechanical printing methods

Mechanical printing methods, sometimes also called the analogue methods, represent the traditional way of printing, based on a fixed master – printing plate, cylinder, stencil, etc. The master has image areas, which accept and transfer ink, and non-image areas, which stay void of ink. Ink is applied onto the image area of the master and transferred onto the substrate – paper, board, plastic, etc. – with contact and nip pressure. The transfer can be made directly from master to paper, or indirectly via a rubber-coated blanket cylinder. The latter is typical in indirect lithography, commonly known as offset lithography or simply offset.

Digital printing does not utilise a physical master, and the printed image is formed anew for each printed copy. Ink transfer onto the substrate does not require mechanical contact or pressure; therefore, digital printing methods are often called non-impact printing (NIP). The "masterless" technique has two distinct benefits: consecutive copies can be different from each other, and the printing process becomes simpler and faster thanks to the elimination of master production (platemaking, etc.).

A summary of the main printing methods is presented in Table 1. Digital printing methods are outlined in detail in Chapter 2. Information on mechanical printing methods can be found in many publications, e.g. Kipphan (2001), Peacock (2003), Johansson et al. (2006), Viluksela et al. (2007) and Oittinen and Saarelma (2009).

Table 1. Comparison of the main printing methods (adapted from Viluksela 2007).

| Method | Master | Ink type | Substrates | Main application |
|---|---|---|---|---|
| Sheet-fed offset | Yes | Paste-like liquid (high viscosity) | Paper, plastic, etc. | Publications, stationery, packaging |
| Cold-set web offset | | | Uncoated paper | Newspapers |
| Heat-set web offset | | | Paper | Magazines |
| Rotogravure | Yes | Low viscosity liquid | Paper, plastic | Magazines, packaging |
| Flexography | Yes | Low viscosity liquid | Paper, plastic | Packaging |
| Screen-printing | Yes | Medium to high viscosity | Paper, plastic, textiles, etc. | Posters, labels, textiles |
| Electrophotography | No | Toner (powder or liquid) | Paper | Documents, books, labels, packaging |
| Inkjet | No | Liquid | Paper, plastic, etc. | Documents, marking, direct mail, posters, newspapers |

# 2. Digital printing techniques and their development prospects

*"Offset litho, toner and inkjet printing will all co-exist because there are good reasons to use all of them. The digital printing wars are upon us: toner vs. inkjet, and within inkjet, CIJ vs. DOD, solvents vs. aqueous, roll vs. sheet and greyscale vs. binary."*

*Frank Romano*[2]

Digital printing techniques can be classified according to the image formation method, ink type and workflow. Figure 2 presents an outline of the masterless digital printing methods. The two dominant methods today are electrophotography (also known as xerography or laser printing) and inkjet. These are discussed in more detail in sections 2.1 and 2.2 below. The role of the other digital printing methods is only marginal – the recently updated book of Oittinen and Saarelma (2009) covers inkjet and electrophotography, and excludes the other digital printing methods. Similarly, they are excluded from this study.

[2] http://www.proprint.com.au/InDepth/159746,welcome-to-inkjet-20.aspx/2 (4.11.2009).

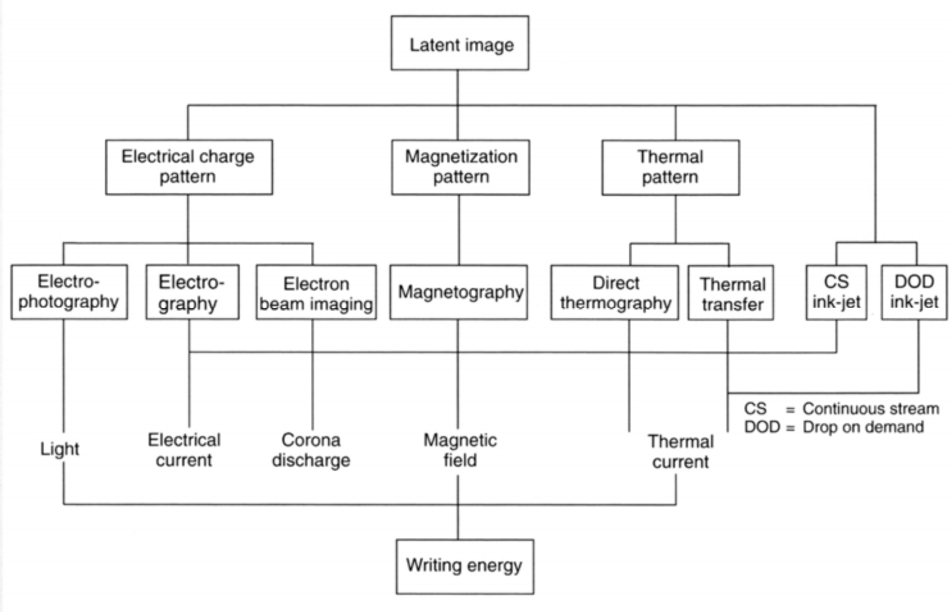


Figure 2. Major categories of non-impact printing methods (Oittinen and Saarelma 2009).

## 2.1 Electrophotography

### 2.1.1 Technology

Electrophotography is based on an image carrier surface that is photoconductive and can be charged electrically. The image is formed by discharging parts of the photoconductive surface, typically with a laser or a LED array. A powder or liquid toner attaches to the image areas of the photoconductive surface, and electrostatic forces transfer the toner onto the substrate. The toner is then fixed to the paper, usually with the help of a heated fuser roll. The toner binder melts and adheres to the paper surface. The photoconductive surface is cleaned mechanically and electrically, and charged for the next imaging (Figure 3) (Kipphan 2001, Oittinen & Saarelma 2009). More detailed information on the technology is presented below.

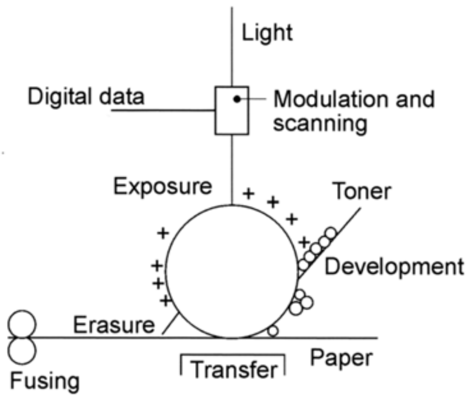


Figure 3. The principle of digital electrophotography (Oittinen and Saarelma 2009).

### 2.1.2 Toners and toner fusing

The early years of electrophotography were characterised by a mediocre print quality and a very limited selection of paper grades and other substrates. Printing equipment manufacturers commissioned their own paper brands to ensure acceptable print quality. Proprietary toners are developed and optimised for each press type. Thus, the printing companies had very little or no choice regarding toners and paper – a very different operating model compared with the traditional printing business. In recent years, the choice of papers has widened thanks to the technical developments of the electrophotographic printing technology, but ink supply is still limited to the proprietary, press-specific toners. (Tolliver-Nigro 2006, Milmo 2008, Henry 2009.)

Most of the electrophotographic printing applications utilise **dry toner**, e.g. toner in powder form. Two-component powder toners are called developers, and they consist of larger carrier particles (iron and additives, diameter about 80 μm) and smaller toner particles (pigment and resin binder, diameter 5–20 μm). In the developing station, toner particles attach to the carrier. Application rollers transfer the developer to the photoconductive drum. Toner particles are transferred onto the drum, and the carrier particles return to the developer unit. Additional toner (also called dry ink) must be added to the developing unit to replace the consumed toner (Kipphan 2001, Xerox 2009a). Examples of magenta developer and dry ink compositions are presented in Table 2. The information is taken from the respective Material Safety Data Sheets (MSDSs).

Single-component toners can be magnetic or non-magnetic. In magnetic toners, pigment and binder surround a core of iron oxide. Since there is no separate carrier, the inking process is simple. However, the toner requires a high content of iron oxide, and is only suitable for black inks. Non-magnetic toners are only used in low speed printers that produce limited-quality output. (Kipphan 2001.)

Table 2. Examples of electrophotographic magenta developer and toner compositions (weight percentages) (Xerox 2009a, Kodak 2009).

| **Company** | **Kodak** | **Xerox** |
|---|---|---|
| Press model | Nexpress 3000 | iGen4 |
| Developer composition | 90–95% strontium ferrite<br>1–10% polyester resin<br>0.1–1% colourant<br>0.1–1% charge agent | Iron powder (90-97%)<br>Polyester resin (3-6%)<br>Red pigment (0.1-0.5%) |
| Toner (dry ink) composition | 80–95% polyester resin<br>5–15% red colourant<br>1–5% charge agent | Toner (100%)<br>- Polyester resin<br>- Red pigment<br>- Amorphous silica<br>- Titanium dioxide |
| MSDS IDs | No. A-1048, rev. 7/15/08 | 000000021263/Version 1.3 |

Conventional dry toners are manufactured by grinding the composite of binder, colourant and additives into a powder, and screening the powder to achieve the desired size distribution. Binders must be suitable for the pulverising process, which precludes the use of “softer” compounds like waxes. When using these conventional toners, fuser oil must be applied to the fuser roll to prevent the toner particles from adhering to it. The main component of fuser oil is polydimethylsiloxane (PDMS), a non-volatile polymeric organosilicon material consisting of $(CH_3)_2SiO$ structural units. PDMS is widely used in many industrial applications. (Smyth 2008, Anon 2008, Anon 2009.)

So-called chemical toners are manufactured with an alternative technique: toner particles are grown chemically rather than pulverised mechanically. This leads to a much tighter size tolerance and improves print sharpness. This also permits the use of melting wax as the binder, enabling a lower fusing temperature. The use of fuser oil can be eliminated (Smyth 2008, Anon 2008). The older toners were based on styrene acrylate binder whereas the new chemical toners use polyester resins as the binder (Tolliver-Nigro 2006).

There are two main approaches for **fusing** or fixing the toner onto the paper. The more common method is a hot roll fuser, consisting of the fuser roll and the pressure roll (Figure 4). Nip pressure varies between 0.5–2 Mpa, and the surface temperature of the fuser roll is normally in the range of 150–190 °C. As the printed substrate passes through the fuser nip, the thermoplastic toner polymers soften, coalesce, melt and sinter, and become fixed onto the paper (Azadi et al. 2008). Hot roll fusing causes some problems, especially in high-volume printing: mechanical component wear, high energy consumption, limitations to the substrates and register problems due to moisture evaporation from paper (Freedman 2007).

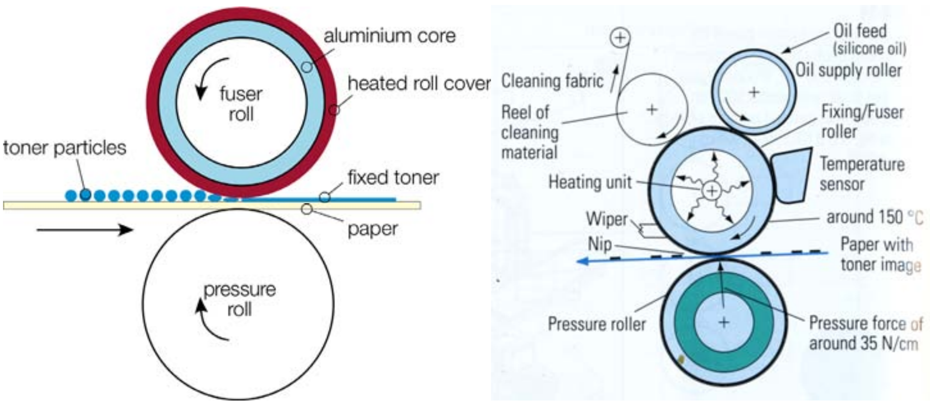


Figure 4. Left: A schematic diagram of the fusing process (not in scale; adapted from Azadi et al. 2008). Right: The fixing unit of Océ (Kipphan 2001).

The newer contactless methods offer faster fusing and require special toners. In flash fusing, the toner and substrate are exposed to pulsing or flashing radiation, which fixes the toner in an instant without any contact. Xerox uses an array of xenon lamps with reflectors to deliver the IR-rich flash, and the toners contain components that absorb IR energy. In addition to high-speed fixing, contactless flash fusing has other advantages: the toner absorbs more energy than reflective white paper, paper is heated only in a thin layer at the surface, and fixing does not remove much moisture from the paper, reducing problems of shrinkage and curl as well as static electricity. Flash fusing is used in some high-volume web presses like the one-colour Xerox 495 Continuous Feed printer and the Xerox 490/980 Continuous Feed colour printer (Freedman 2007, Xerox 2009c). Océ's contactless fusing is specified as one-pass infrared fusing (Océ 2009b).

Xeikon is developing an UV-curable toner, which would offer several advantages: higher heat resistance of the print (up to 280 °C, high enough for food packaging purposes) and a more flexible ink film than with the traditional toners (Deprez et al. 2005, Xeikon 2009).

Some presses, most notably the HP Indigo, use **liquid toners**. According to the MSDSs of HP (2009b), the liquid toners, called ElectroInks, have petroleum hydrocarbon (< 80%) as their main component. An example of the ink composition is presented in Table 3. The VOC content of the ink is approx. 650 g/l, its boiling point is 188 °C and flash point > 64 °C. The imaging oil used in the printing process consists of the same petroleum hydrocarbon (< 100%), which is an aliphatic compound belonging to the isoparaffinic solvents commonly used in low-odour paints and household cleaning chemicals (Total 2003). In printing, the latent images of separated colours are inked with the respective liquid toners. The toner image is transferred to a heated blanket cylinder, where most of the volatile toner component is evaporated. The remaining toner is then transferred onto the print substrate. In newer Indigo models, the evaporated hydrocarbon is recovered and re-used (Thompson 2008).

Table 3. Composition of HP's ElectroInk 4.0 Cyan liquid electrophotographic ink (HP 2009b).

| Component/substance | CAS number | % by weight |
|---|---|---|
| Petroleum hydrocarbon | 90622-58-5 | < 80 |
| Trade Secret blue colourant | Proprietary | < 10 |
| Trade Secret | Proprietary | < 2.5 |
| Fluoropolymer resin | 9002-84-0 | < 1 |

### 2.1.3 Electrophotographic presses

EP presses can use a multipass or singlepass system. In multipass, one printing unit is used for printing several colours, and the paper sheet passes the unit multiple times. Singlepass presses have separate printing units and can deliver all colours – normally four (CMYK) – in a single pass. For duplex printing (printing on both sides of the paper), there are three alternative equipment designs:

– The one-side printed paper sheet is reversed in a duplexing unit and the other side is printed using the same printing unit (many sheet-fed production printers, e.g. Xerox DocuColor 5000, use this system).

– The press consists of two consecutive printing units with a sheet or web turning unit between them (some high-volume sheet and web printers, e.g. Xerox Concept Color 220 and Océ VarioStrem 8000 Twin, utilise this system).
– The printing unit is constructed to print simultaneously on both sides of the paper (in the Océ Gemini duplexing unit, the toner is transferred and fused onto both sides of the substrate) (Océ 2009).

Different techniques can be used to transfer the image from the photoconductive drum onto the paper. Toner can be transferred to the paper either directly or indirectly using a transfer drum or belt. Several singlepass transfer systems are presented in Figure 5.

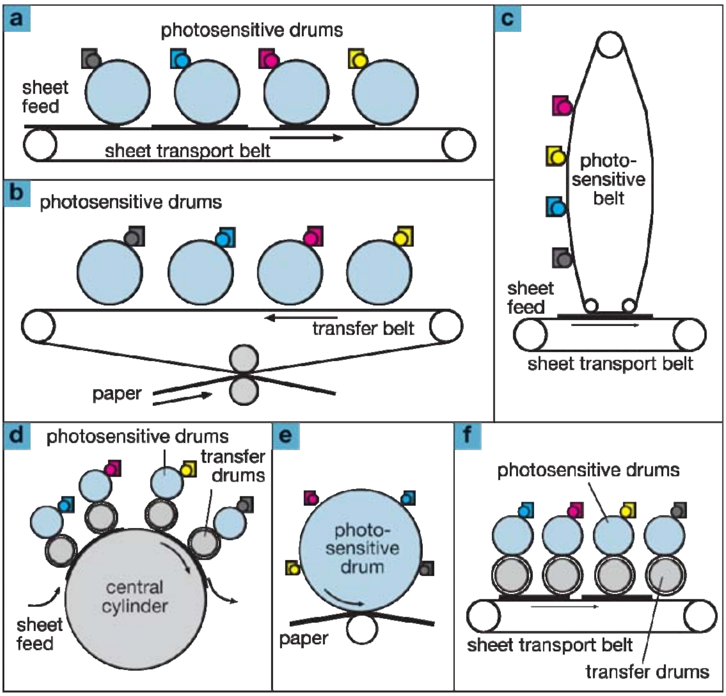


Figure 5. Image transfer solutions for single-pass sheet-fed electrophotographic systems: a) direct transfer from drum to paper one colour at a time; b) transfer from drums to transfer belt and then to paper, all colours at once; c) image formation on a photosensitive belt and transfer to paper; d) transfer via a rubber-covered cylinder to paper; e) toner transfer to a single image drum and onto paper; f) transfer from drum to paper via transfer drums (adapted from Viluksela et al. 2007).

The speeds of **sheet-fed EP presses** range from 50–120 A4 pages per minute for four-colour printing and 100–288 pages per minute for one-colour presses. Most printers have a maximum sheet size of SRA3 (32 x 45 cm), and some B3 (36 x 57 cm). Larger sheet sizes and print areas are considered difficult to achieve (Henry 2009).

Most production printers offer duplexing through turning the sheet and printing it again using the same printing units. Twin-engine duplexing printers have two consecutive printing units, like the one-colour Xerox Nuvera 288 EA and the four-colour Xerox iGen 220 Concept Color (Xerox 2009). Océ's Gemini system, used in a one-colour VarioPrint press, prints and fuses on both sides of the sheet at the same time, using toner transfer fusing belts (Océ 2009).

According to the equipment supplier information, the web widths of all **web EP presses** is roughly 50 cm. Xeikon 8000 offers 230 colour A4 duplex pages per minute with a web speed of 17 m/min. The fastest Xerox web presses are the Xerox 650/1300 Continuous Feed one-colour printer and the Xerox 490/980 Continuous Feed four-colour printer, which at the fastest configuration achieve an output of 1300 and 980 A4 pages per minute, respectively. The corresponding maximum web speeds are 91 and 69 m/min. Flash fusing is used to fix the toner. Océ ColorStream 10040 prints 168 four-colour duplex pages with a web speed of 59 m/min. Océ uses contactless infrared radiation fusing.

Many electrophotographic presses have **in-line finishing** options and other **add-ons**. These include roll feeders for sheet-fed presses (e.g. Kodak NexPress), additional printing units suitable for varnishing or printing additional colours (e.g. HP Indigo, Kodak NexPress), booklet makers with wire stitching, folding and front edge trimming (Xerox, Kodak, Océ) and perfect binding units (e.g. Canon ImagePress 7000). Digital press manufacturers develop standardised linkages to various postpress devices in collaboration with the finishing equipment suppliers (Smyth 2008).

### 2.1.4 Future prospects

For some time, EP will remain the dominant choice for document printing applications for some time. Technical developments will probably take place in the area of contactless fusing, toner technologies and printing speeds, such as high-speed web printing. According to some views, EP will soon reach its performance limits, and will lose market share to inkjet in those product groups and applications where both can operate (Henry 2009, Smyth 2008). Although liquid ink EP offers some advantages, it seems that dry toner technology will remain dominant.

A SWOT analysis of electrophotographic printing presented in Smyth (2008) is shown in Table 4. Most of the strengths and opportunities apply to inkjet as well, and are inherent to digital printing. Based on the more recent literature, the first two opportunities can today be considered strengths leading to growing markets (see Chapter 3). The three first weaknesses are also recognised in the article of Henry (2009), and the prospects for overcoming these weaknesses are regarded as minimal (Henry 2009). According to the analysed literature, increased print quality and productivity are the key strengths that make electrophotography more competitive. This will enable electrophotography to continue taking some of the existing short-run markets from offset.

Table 4. SWOT analysis of electrophotographic printing according to Pira International Ltd. (Smyth 2008).

| | |
|---|---|
| **Strengths**<br>Document printing collation<br>Variable data<br>Low-cost set-up<br>Quality<br>Ease of use | **Weaknesses**<br>Limited format and substrate weight<br>Speed and capacity<br>Cost, click charge<br>Reliability/quality of some systems |
| **Opportunities**<br>Variable data personalisation and versioning<br>New products, photobooks, transpromo<br>Coatings | **Threats**<br>Electronic media<br>Inkjet |

## 2.2 Inkjet

### 2.2.1 Technology

In inkjet printing, small droplets of liquid ink are sprayed from nozzles onto the paper or other substrate. The two basic techniques are continuous inkjet and drop-on-demand inkjet. In the former, a continuous stream of droplets is charged according to the signal describing the print image. The charged (non-printing) droplets are deflected.. In drop-on-demand, the print signal generates droplets when needed by thermal, piezo or hotmelt methods (Figure 6).

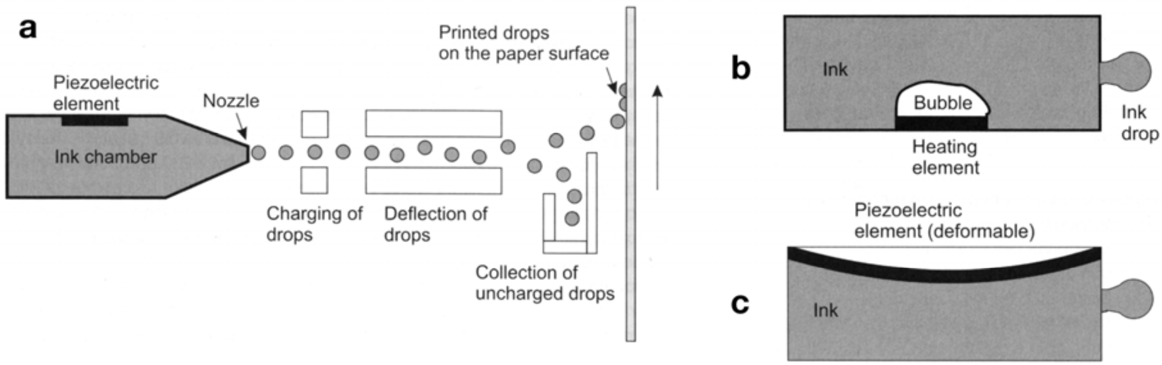


Figure 6. Principles of inkjet techniques: a. continuous inkjet, b. thermal drop-on-demand inkjet, c. piezoelectric drop-on-demand inkjet (Oittinen and Saarelma 2009).

In the **piezoelectric drop on demand** (DoD) inkjet technique, the droplets are formed when the electric signal causes a piezoelectric crystal to expand, which creates a pressure wave forcing a droplet out of the printhead nozzle. **Thermal inkjet**, also known as a bubble jet, works in a similar manner, but the pressure wave is generated by heat and vaporises a small quantity of ink (Palmer 2008, Robinson 2009). Most of the production inkjet printers use piezo printheads. HP's new T300 web press uses thermal technology – the disadvantage is the limited life span of the printhead, which must be replaced much more often than piezo heads (Cleary 2009). Kipphan (2001) mentions a third method, electrostatic inkjet, but this is not included in the more recent literature.

In the **continuous stream inkjet** technique (CS or CIJ), ink droplets are continually generated through pumping ink to the ink chamber and creating high-frequency acoustic pressure waves using a piezo-electric crystal. The wavefield forces ink droplets out from the printhead. The frequency of droplet generation can be 64,000–165,000 droplets per second. Charge electrodes apply an electrical charge to the droplets, and the charged droplets are steered using deflectors. Droplets can be either left uncharged or charged selectively according to the signal of the printed image. CS technology has been used in applications that require high volume and medium quality, e.g. transactional printing, marking and coding (Heilmann and Antikainen 2009). CS printheads are used in the Kodak Versamark VT and VX presses as well as in the new Prosper printers (Kodak 2009b).

While the **printheads** of home and wide-format inkjet printers scan back and forth across the width of the page/sheet, production printers use a stationary printhead. Modern printheads are scalable, meaning that several printheads can be combined to provide printing across the full width of the web (so-called single pass printing). At the same time, printheads are becoming smaller and more lightweight (Palmer 2008, Cleary 2009).

There are two main methods of manufacturing printheads. Printheads made by machining carbon laminates can deliver ink droplets of 10–200 pl (picolitres). The higher end is suitable for industrial marking and coating applications. The other alternative, micro-electromechanical system or MEMS, is based on silicon compounds and results in printheads capable of producing droplets below 10 pl, suitable for high-quality applications and variable-sized ink droplets. (Cleary 2009.)

### 2.2.2 Inks

Inkjet ink types, their main properties and the corresponding printhead technologies are presented in Table 5 (Hakola & Oittinen 2009). Inks must have a low viscosity to enable jetting of droplets, but low viscosity increases dot gain as well as ink spreading and penetration into porous substrates. The inks consist of vehicle (usually 60–90%), colourant (pigments or dyes; 1–10%), binder, surfactants, humectants and additives. (Hakola & Oittinen 2009.)

The colourant can be pigment or dye. Soluble dye inks have provided better performance with respect to jettability and nozzle clogging, but the print quality on porous substrates has been limited due to high ink absorption. Pigment-based inks have provided better print quality on porous substrates, because more of the colourant stays on the surface of the substrate. Pigment inks have had problems with nozzle clogging, but new pigment manufacturing techniques have alleviated the problem (Hakola & Oittinen 2009, Heilmann & Antikainen 2009). Kodak offers both dye and pigment inks for its Versamark VL presses; most of the customers opt for the dye inks because they are 30% cheaper than pigment inks. However, pigment inks work better with glossy coated papers (Cox 2009c).

Table 5. Inkjet ink properties and application areas (Hakola & Oittinen 2009).

| | Ink type | Viscosity (mPa·s) | Ink layer thickness (µm) | Drop volume (pl) | Drying |
|---|---|---|---|---|---|
| **Thermal ink jet** | Water-based | 1–5 | < 0.5 | 6–30 | Absorption, evaporation |
| **Piezoelectric ink jet** | Water-, oil-, and solvent-based | 5–20 | < 0.5 | 4–30 | Absorption, evaporation |
| | Hot melt | 10–30 | 12–18 | 20–30 | Solidification through cooling |
| | UV-curing | 15–30 | 10–20 | 10–30 | Radiation cross-linking |
| **Continuous ink jet** | Solvent-, water-, MEK (methyl ethyl ketone)-based | 1–5 | < 0.5 | 5–100 | Absorption, evaporation |

Water-based inks are cheaper than other liquid inks, but have problems with lightfastness and waterfastness. Solvent-based inks have low surface tension, making them well suited to non-porous substrates, and they dry quickly by evaporation. Common solvents include alcohols, ketones and glycols. 80–90% of the ink is evaporated and leads to VOC emissions. Oil-based inks contain hydrocarbons or glycols, dry by absorption and produce medium print quality. (Hakola & Oittinen 2009, Heilmann & Antikainen 2009.)

UV inks are becoming popular in label, packaging and wide-format printing, and UV printing is the fastest-growing sector of inkjet printing (Hakola & Oittinen 2009). According to Agfa, UV inks offer immediate curing, wide choice of substrates and reduced ink consumption (8–10 ml/m$^2$ instead of 12–14 ml/m$^2$) compared with solvent-based inks. The environmental advantage is the elimination of VOCs (Agfa 2007).

Hotmelt (phase change) inks are based on three main components: resins, waxes and the pigment. The solid ink turns liquid when heated up to 80–150 °C. The ink solidifies immediately when deposited onto the print substrate. Ink does not penetrate into the paper, and there is very little dot gain (Pekarovicova et al. 2003, Palmer 2008). This technology is used in the Xerox ColorQube 9200 solid ink printer (Xerox 2007b, Palmer 2008) and in the Océ ColorWave 600 printer (Océ 2010). The above sources do not mention the printhead type, but according to Wikipedia, solid ink printers use piezo printheads. Xerox is also working on a high-volume inkjet system based on “cured gel” inks, a modification of the solid ink technology, probably employing UV curing (Cleary 2009).

### 2.2.3 Inkjet papers

Up to recent years, inkjet printing has required special papers to prevent the problems associated with inkjet inks: ink spreading, ink bleeding on multicolour printing, show-through and smearing. In some inkjet applications, like wide-format and labels, UV inks and curing can be used to address these problems. In high-volume document printing, low-cost water-based inks are required to ensure sufficient cost-efficiency. There are two ways to approach the problem: the inkjet process and inks can be developed to allow printing on widely-used offset paper grades (newsprint, uncoated woodfree and coated grades), or new paper grades can be developed to fit the high-volume inkjet printing systems. (Cleary 2009b.)

In a Finnish study, it was found that different types of papers are required for water-based and UV inkjet inks. Papers with a micro-porous surface, ideal for water-based inkjet inks, reduce print gloss and density. The optimal paper for UV inks has a dense surface that enables ink to stay on the paper surface without penetration (Puukko et al. 2009).

Some paper manufacturers have developed grades that will suit most inkjet applications. These would be the preferred choice when the end customer requires a higher-class product image. Inkjet press manufacturers are developing solutions to enable the use of standard paper grades in their presses. Kodak’s new inks have less wetting agent, improving ink setting and drying. Fuji uses a pre-coating solution to flood coat the sheet, and a coagulant in the ink to ensure the bonding of the ink to the paper surface. HP uses an extra printing unit to apply a special bonding agent to those areas of the paper that will later receive ink (Cleary 2009b).

### 2.2.4 Inkjet presses

The range of inkjet presses extends from small-scale A4 size home and office printers to high-volume web presses and wide-format presses. In industrial production, inkjet has established itself in the area of wide-format printing, with printing widths ranging from one to three metres, and the available substrates include various papers, plastics and textiles. Some wide-format presses can print to rigid materials, and some presses combine inkjet with screen-printing (e.g. Agfa’s MPress).

At Drupa 2008, several new web inkjet presses were introduced. The HP Inkjet Web Press, later named T300 Color Inkjet Web Press, has a web width of 76.2 cm and a web speed of 122 m/min. It uses water-based pigment inks with hot air dryers (HP 2009). Kodak's concept press Stream, later named Prosper, can be configured to different web widths. It uses a continuous inkjet system capable of producing different droplet sizes. According to Kodak, the water-based nanopigment inks allow printing on coated stock without special coating. A one-colour imprint application, Prosper S10 Imprinting System, is already available as part of a Muller Martini forms offset press (Brunner 2009b). A prototype for book printing, named Prosper Color XL Press, was demonstrated in July 2009, having a web width of 650 mm and a speed of 200 m/min (Hamilton 2009). In the sheet-fed side, the B2 size (520 x 720 mm) prototypes of Fuji and Screen resemble sheet-fed offset presses of the same format (Cleary 2009, Smith 2009).

Inkjet units have long been used in addressing and in marking of packaging, but the new developments offer higher quality monochrome and colour imprinting. Heidelberg has developed a DoD inkjet system that can be integrated into packaging lines to add monochrome or colour variable data printing. The system is marketed under the name Linoprint and is based on UV curing technology. Several manufacturers' printheads can be used. (Heidelberg 2008, Linoprint 2009).

### 2.2.5 Future prospects

The surveyed literature indicates that inkjet is undergoing strong development in productivity, print quality and choice of substrates. Through the recent improvements in printheads and ink formulations, inkjet is becoming well suited to many graphic and non-graphic applications, and it is predicted to take a share of offset markets. In transactional and transpromo printing, inkjet will continue to compete with electrophotography. In outdoor advertising and other wide-format applications, inkjet already has a well-established strong position in the market, where serigraphy is losing market share.

Up to now, high quality inkjet printing on paper has required special papers with suitable surface and absorption properties to control dot gain and ink penetration. Developments in the inkjet technology and materials, such as the bonding agent technology of HP, will enable the use of newsprint and other cheaper bulk paper grades (Cleary 2009b). The simplicity and flexibility of the printing process combined with versatile ink formulation give inkjet many possibilities in non-graphic applications as well (Romano 2009).

A SWOT analysis of inkjet printing by Smyth (2008) is presented in Table 6. Based on the literature, the listed strengths have been or are being transformed into business applications, and the opportunities are being realised. There are technical initiatives underway to eliminate weaknesses – e.g. the HP T300 inkjet web press features a bonding agent to enable printing on various standard paper grades, and two hot air dryers for water-based inks. Variable data capabilities are being developed in tandem with press developments (Brunner 2009b, HP 2009, Cleary 2009b). Kodak's Versamark presses have been in the market for a decade (Cox 2009c), so even the new technology risk seems to be exaggerated (the nature of the risk is not specified). Bennett (2008) regards the cost of inkjet inks as the main driving force behind the rise of inkjet: "The company that has the courage to break the cartel on ink costs will have the advantage in this digital press revolution" (Bennett 2008). Deinkability, regarded by Tribute (2009) as the biggest environmental problem of digital printing, is not included in this SWOT.

Table 6. SWOT analysis of inkjet printing, according to Pira International Ltd (Smyth 2008).

| | |
|---|---|
| **Strengths**<br>Non-impact<br>Ink cost and productivity dependent on coverage<br>Wide variety of applications<br>Wide variety of inks<br>Easily used in a hybrid line<br>Wide format<br>Irregular shapes can be printed directly | **Weaknesses**<br>High quality on coated paper not here in 2008; concept shown<br>New technology risk<br>Complex data transfer for high-speed variable print<br>Water-based ink drying |
| **Opportunities**<br>Faster, wider fixed-head single pass<br>Packaging<br>Coating for decoration and security<br>Material deposition | **Threats**<br>Electronic bill presentation and payment |

## 2.3 Discussion on digital printing methods

### 2.3.1 Digital vs. mechanical

According to the literature referred above, digital printing methods will take existing markets from mechanical methods. The main technical drivers are

- high enough print quality for the respective products and applications
- expanding choice of suitable paper grades and other substrates
- improved output speed and productivity.

The same drivers open up new possibilities in the markets where the variable print content capability of digital printing is required: print on demand, versioning and personalisation. The next chapter presents a closer look at the products and applications.

There is also a possibility of hybrid production, i.e. combining mechanical and digital printing in the same production line, or adding high-quality digital imprinting to a finishing or packaging line. For example, Kodak Prosper S10 imprinting units are combined with offset web presses (Brunner 2009b), Agfa :M-Press combines an inkjet and screen-printing press (Agfa 2009), and Linoprint, a four-colour inkjet printer, can be integrated into a packaging line (LinoPrint 2009). Considering the increased speed and quality and relatively compact design of inkjet printheads, this trend may grow in the future. Electrophotography has more limited prospects in this area.

### 2.3.2 Inkjet vs. electrophotography

Electrophotography is a relatively mature technology that has established itself in the digital printing market. Inkjet technology is presently undergoing strong development, and has several advantages (Palmer 2008, Romano 2009, Smyth 2008):

- inkjet inks cost less than toners
- inkjet printheads are simple, have fewer parts and lower power requirements
- inkjet is scalable, and larger sheet sizes and web widths can be achieved
- inkjet has potential for high print quality
- inkjet inks have wide formulation possibilities, e.g. for different substrates
- thick and rigid substrates can be printed with inkjet.

From the environmental point of view, “large toner-based systems have high power requirements with equally large power units and severe environmental requirements. Inkjet requires much less of all that” (Romano 2009). Unfortunately, this statement is not supported by any data.

### 2.3.3 Digital presses

The three important factors for digital printing systems are print quality, output and cost. When analysing the costs, one must remember the added value and savings that digital printing can offer when compared to mechanical printing. For example, extra stocks and returned copies can be eliminated with print on demand, and personalisation can improve the effectiveness of a marketing campaign.

Different operating models have an effect on the cost structure: EP markets are closed – the printing equipment manufacturer usually supplies toners and consumables against a click charge. The charge per page is constant regardless of ink coverage. IJ printing equipment manufacturers obtain the printheads from specialised companies, and printing companies purchase suitable inks from ink suppliers according to their needs. Ink costs are directly connected to ink consumption. Cost comparisons are difficult, but inkjet inks are generally considered cheaper than toners. Print jobs with high ink coverage, however, become relatively cheaper with EP due to the constant click charge. (Henry 2009, Romano 2009.)

The studied literature does not provide a consistent view on print quality. The quality factor most commonly referred to is the output resolution. The substrate is often indicated to have a strong impact on the reproduction of tone, colour and details, and the present development work in the industry includes both optimising paper properties for the print method in question as well as optimising the printing process to enable the use of standard (offset) paper grades. In addition, many new inkjet systems can create different droplet sizes and therefore can produce greyscales instead of binary output. All these factors make a quality assessment of printing systems difficult. However, digital printing is in many cases said to have reached “offset quality” (without any technical explanation). Or, as Frank Romano puts it, “quality... [is] coming into alignment with industry needs” (Romano 2009).

The output speed of the presses is a more straightforward issue. The equipment manufacturers’ output figures are usually, but not always, based on simplex A4 images per minute. To illustrate the present situation, the output speed of selected digital presses, some of them still in the pilot testing phase, is presented in Figure 7. The data is obtained from equipment manufacturers' websites and/or data sheets. Smyth (2008) predicts that electrophotographic presses will reach B2 format and a speed of 200 pages per minute (per print engine) by 2018, while inkjet web presses run at 10 m/s and have 1.5 m wide fixed printheads (Smyth 2008). The corresponding calculated output would be 14,000 A4 pages per minute.

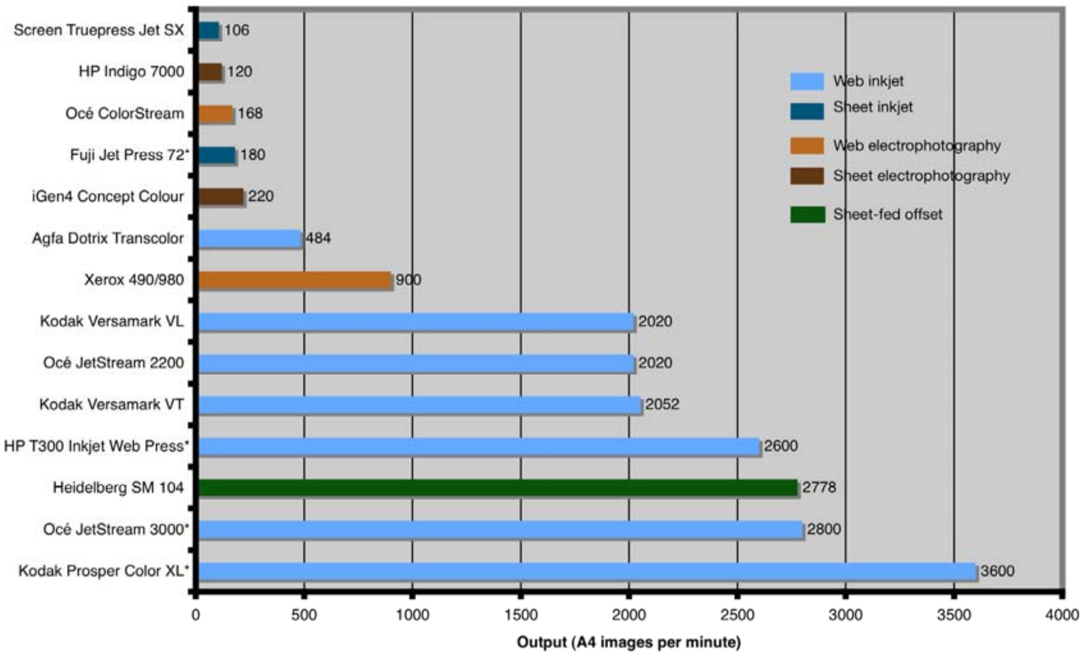


Figure 7. Selected digital presses and their output speeds. Source data from equipment manufacturers. Presses marked with * are in the piloting stage (Feb 2010).

### 2.3.4 Technical comparison

The main technical features of electrophotographic, inkjet and offset printing are presented in Table 7. The information is based on the analysed literature and practical experience from the printing processes. The materials requirements and waste output of press supplies are difficult to compare, but in platemaking and make-ready, digital printing methods seem to have some advantages over the offset process.

Table 7. Comparison of technical characteristics of electrophotographic, inkjet and offset printing.

| | **Electrophotography** | **Inkjet** | **Offset** |
|---|---|---|---|
| Platemaking process | No plates, no chemicals | No plates, no chemicals | Plates, chemicals + chemical waste |
| Press supplies + waste | Frequent replacement of toner cartridges<br>Infrequent replacement of OPC drums/belts, corona wires, etc. | Frequent replacement of ink cartridges<br>Infrequent replacement of printheads | Frequent use of cleaning chemicals and rags, fountain solution additives<br>Plate waste |
| Make-ready | Infrequent calibration (little paper waste) | Infrequent calibration (little paper waste) | Colour registration, inking and ink/water balance for each job (more paper waste) |

**Summary: digital printing tecniques**

- Both electrophotography and inkjet have considerably improved in recent years in terms of print quality, productivity and choice of substrates.
- Electrophotography will soon reach its limits in terms of print quality and productivity.
- Inkjet still has additional potential for speed and quality improvement
- Inkjet printheads are compact and can be fitted to packaging and printing linres for imprinting applications.
- Inkjet and its inks can be developed and used for a wide variety of applications, including non-graphic ones.

# 3. Applications, markets and prospects for digitally printed products

*"The truth is that the book as invented in the 15th century has not been bettered as a compact, transportable and 'sustainable' receptacle for almost all the human imagination can devise."*

*Simon Jenkins, The Guardian*[3]

It is predicted that ten years from now, several print product groups will have declined or even disappeared, for example business forms, office stationery, directories and cheques (Smyth 2008). However, there will still be a strong demand for traditional printed products. The main changes will probably be related to (Smyth 2008)

- more personalisation and versioning
- more colour
- faster production cycles
- smaller print runs
- lower environmental impacts (and more certificates and labelling to prove it).

At the same time, new products outside the sphere of printed communication will be introduced, for example printed electronics. From the consumer point of view, print will be abandoned if other applications provide better means of communication and providing information or entertainment. Many printed prod-

[3] The Guardian, Friday 16 May 2008: http://www.guardian.co.uk/commentisfree/2008/may/16/politicalbooks .booksnews.

ucts will become a part of larger services, combining print with websites, etc. (Smyth 2008).

In this chapter, major product groups and applications of digital printing will be introduced. The literature indicates that most of these emerging or growing applications are based on the capability of digital printing methods to print without a master, i.e. being able to produce different consecutive prints.

## 3.1 Print on demand

In 1992, InfoTrends defined print on demand as "delivering what was needed, when it was needed and in the exact quantity required" (Pesko et al. 2009). Today, with the growing trend of distributed printing, one could add "in the locations needed". Both cost reductions and increased revenues can be achieved by POD (Figure 8). The development and estimate of the US print on demand market (Figure 9) shows a slight decline in the one-colour printing market, while four-colour printing is surging (Pesko et al. 2009).

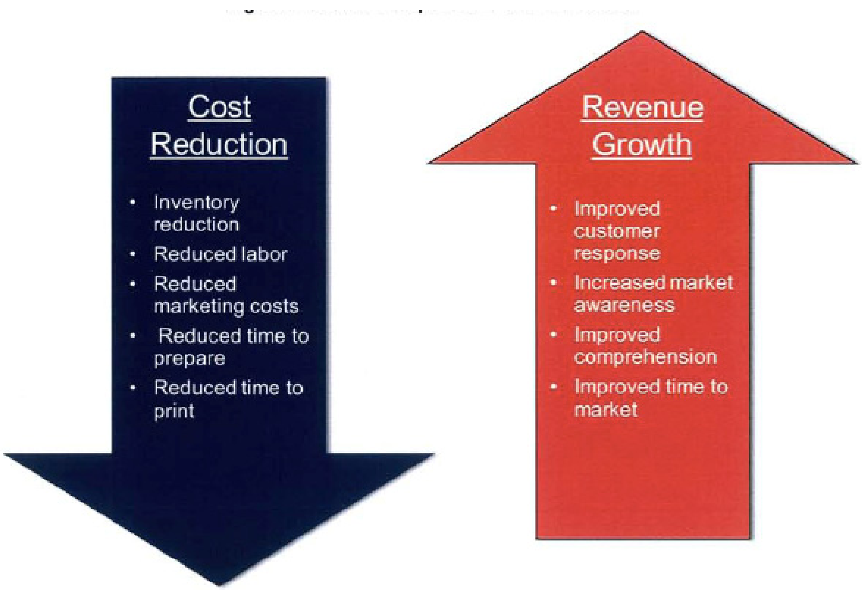


Figure 8. Basic principles of Print on Demand (POD) according to InfoTrends (Pesko et al. 2009).

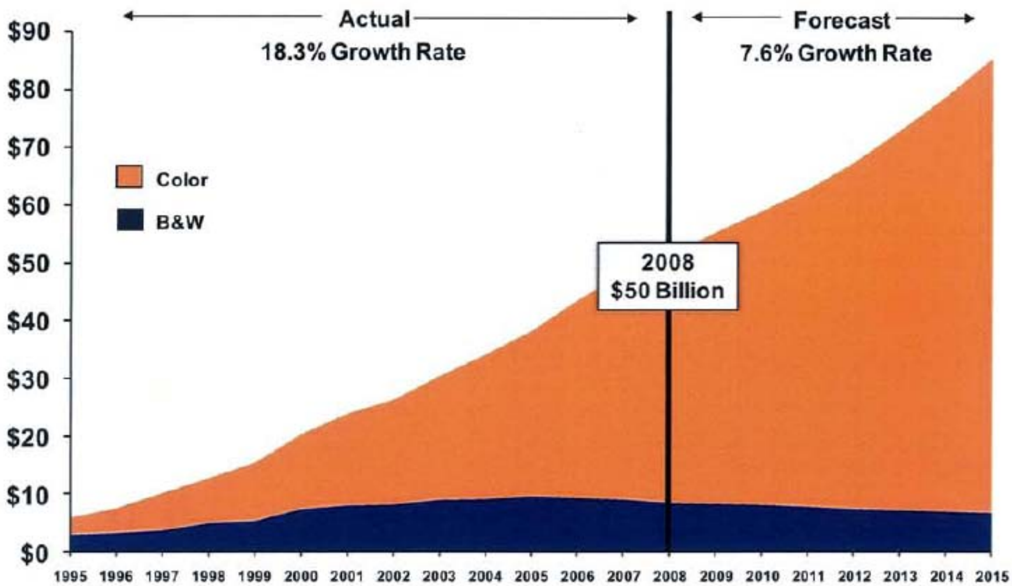


Figure 9. US print on demand market 1995–2015 (Billions of USD) (Pesko et al. 2009).

**Web to print** roughly means utilising the Internet in the preparation and workflow of print production. For example, a company can store sales brochures, product catalogues, price lists, posters, calendars and business cards on the web, and order printed versions according to demand. The products can be personalised (e.g. business cards) or versioned (e.g. sales brochures for a certain dealer) using a web interface. Digital printing offers an ideal production platform for the web to print environment (Xerox Finland 2009). The front end of a web to print system consists of the customer interface, which provides product options, pricing, web shop, account management and file/data upload. The back end system contains the front end management features, job tracking, online payment services, customer database and connection to other systems like delivery, order books and job tracking (Hiflex 2010). In a recent study, print buyers gained 14% savings using web to print services. The added benefits included shorter turnaround times, improved stock control, fewer errors and better brand management (Pesko et. al. 2009).

The larger web to print systems require expensive software applications, and are suitable for larger printing companies. Smaller printing companies can nowadays buy web to print services from specialised companies, without the need to invest in software. It is easy to combine a web to print application with highly automated digital workflows, which makes such applications very suitable for digital printing companies. MIS integration (Management information system) is also possible. This integration, combined with a suitable web interface, provides the customer with many services like job specification, pricing, scheduling, content upload, preflighting, job tracking, and payment. (Smyth 2008, Cleary 2009c.)

## 3.2 Transactional, promotional and transpromo

Direct mail (DM) and transactional documents (invoices, bank statements, etc.) have traditionally been produced by adding one-colour overprint with digital printing to the shells preprinted in offset. With the improved colour printing capabilities and quality of digital methods, everything can be printed digitally. In addition, targeted and personalised promotional messages can be added to the transactional product. This combination is called transpromo. (Brunner 2009, Smyth 2008.)

Transpromo provides a cost-effective way of utilising white space in invoices for four-colour promotional messages. It is a viable alternative for cases where DM is no longer considered effective enough (Anon 2009d). According to studies, only 7% of direct mailings are read, while 85% of invoices are read twice (Xerox Finland 2009). InfoTrends foresees strong growth in transpromo in the USA: the amount of printed impressions is predicted to grow from 1.7 billion in 2007 to 22.8 billion in 2012, showing a CAGR (compound annual growth rate) of 68% (Pesko et al. 2009).

Another emerging approach is **cross-media marketing** (also known as multi-channel marketing), which means the use of several media channels to convey promotional messages. Printed marketing messages, containing variable content personalised for the recipient, can be supported by personalised web pages and mobile messages. Compared to traditional DM, a cross-media approach has produced significantly better response and sales results (Xerox Finland 2009). According to a study by InfoTrends, the response rate of multi-channel campaigns, consisting of print, e-mail and web landing pages, was 35% higher than in a print-only direct mail campaign. The result was based on the feedback of over 200 marketing executives. In another InfoTrends study, the majority of the surveyed 200+ print service providers reported that multi-channel communications improved revenues, profits and customer acquisition and retention rates (Pesko et al. 2009).

## 3.3 Traditional graphic products

### 3.3.1 Newspapers

Digital printing offers good possibilities for newspaper production in two areas: personalised newspaper (incorporating the subscriber's personal content preferences) and distributed printing (printing small print runs at several locations near the customers). For example, a printer in Malta uses a Kodak Versamark for printing several British newspapers for local readers instead of flying the copies from the UK (Anon 2009e). These kinds of "specialist remote print centres" producing newspapers could be the way to replace the present "print and distribute" model with the new approach of distributed printing (Smyth 2008).

Up to now, digital newspaper production has been limited to monocolour electrophotography. Digital colour printing has been too slow and expensive (500 copies per hour of a 48-page newspaper at 3–4 € per copy). The new inkjet presses can produce over 1600 copies per hour at a cost of 1 € per copy. This will open up new opportunities for publishers and printers (Brown 2009).

### 3.3.2 Magazines

Digital printing is already used to produce short-run specialised magazines. It is estimated that magazine publishing and printing will remain quite strong in the coming decade (Smyth 2008). Digital printing is seen as a way to improve customer service by combining personalised and versioned sections with offset-printed ones (Anon 2008). Publishers could offer magazines on demand by providing a web interface via which readers could choose their own content, both editorial and advertising (Bennet 2008). There is also growing interest in developing and utilising e-readers for magazines and publications: five magazine publishers have started a joint initiative to study alternatives and develop common technical standards for different digital devices (Ovide & Adams 2009).

### 3.3.3 Books

Despite predictions to the contrary, printed books enjoy record sales, and digital printing is seen as an opportunity to secure the competitiveness of book printing. With the improvements in print quality, extended choice of paper grades and finishing automation and options, digitally printed books have gained wider acceptance (Smyth 2008, Holman 2009). A publisher can use a three-stage strategy for printing: digital for the launch, offset for the main edition and digital again for the end of the lifecycle (Anon 2009b).

Print on demand (POD) will reduce both the costs and risks of book publishing. Together with a distributed printing option, POD has a chance of providing an environmental advantage by decreasing the product transport needs and producing less waste (Holman 2009). New products have also been created using POD technology: photo books, school yearbooks, self-published titles, etc. (Smyth 2008). One example of a POD application is the Espresso Book Machine, the production platform for printing the book titles in the Google digital library (Anon 2009c, On Demand Books 2009).

Xerox considers photo books and related products a major growth area in digital printing (Xerox Finland 2009). InfoTrends predicts that the U.S. photo publishing market, consisting of photo books, photo calendars, photo cards and specialty prints, will grow from 0.7 billion USD in 2007 to 2.5 billion USD in 2013, resulting in a CAGR of 22% for the period (Pesko et al. 2009). Photobooks and other personalised products can yield far higher profits for the printer than the more standard printed matter (Eccles 2009).

## 3.4 Packaging

Digital printing is already used for producing labels, and it is gaining markets thanks to its quality and materials development. Both EP and IJ printing equipment manufacturers are actively developing label-printing equipment, e.g. HP Indigo (liquid EP), Xeikon 3300 (dry toner EP), Impika 6000 (water-based inkjet) and Agfa Dotrix (UV-curable inkjet). Digital printing offers fast turnaround and shorter run lengths, enabling special promotions, changing designs and personalisation (Smyth 2008, Chadwick 2009, Lewald 2008).

At Drupa 2004, StoraEnso and Xeikon presented a jointly developed automated production line for discbox sliders, CD and DVD packages made of paperboard (StoraEnso 2004). The Gallop, a digital printing and production line for cartons, was introduced at Drupa 2008. It was jointly developed by Stora Enso and Xerox, and consists of an iGen3 press, varnishing unit, embossing and foil-stamping unit and die-cutter. Targeted for the pharmaceuticals and cosmetics market, the Gallop is ideal for prototyping and short, personalised production runs of 2,000–20,000 pieces (Chadwick 2009). Digital printing is projected to take markets from both flexography and offset, as the print formats and production speed increase (Polischuk 2009).

The packaging sector will use new features like RFID tags, displays and indicators. Inkjet is considered to have fewer limitations in packaging applications, for example the ability to print on heavyweight and rigid materials and on uneven surfaces. Inkjet will also be used for flexible packaging and metal/glass packaging applications. (Smyth 2008.)

The development challenges of digital packaging printing have been related to the ability to print spot colours (PMS) and special effects like metallic inks and varnishes, and to the reduction of production costs (Chadwick 2009). Some digital presses already offer varnishing/spot colour options (e.g. HP Indigo, Kodak NexPress), and the first metallic inks have been introduced (Cox 2009). Online or near-line digital coating is possible with both EP and IJ. In some inkjet UV coating applications, the coating thicknesses can be varied to produce varying grades of gloss (Smyth 2008).

## 3.5 Other applications

In **wide-format printing**, inkjet has established itself as the dominant printing method, having claimed almost half of the traditionally screen-printed market. Many suppliers offer both roll-fed and flatbed printers, the largest of which are close to five metres wide. Many ink types can be used. Aqueous inks have a limited choice of substrates, and are less suitable for outdoor use. Dye-based inks in particular have lightfastness problems. Solvent-based pigment inks are suitable for outdoor use and many different substrates, but due to environmental and health issues related to solvent emissions, are being replaced by more environmentally friendly eco-solvent or latex inks. UV inks are also widely used, thanks to their wide selection of substrates and immediate drying. (Doumaux et al. 2008, Savastano 2009, Savastano 2007, Romano 2009, Robinson 2009)

Electrophotographic applications are dominant in **office document production**. There are signs of a shift from individual pieces of equipment towards workgroup devices, which integrate the functions of a printer, copier, scanner, etc. with some finishing options. This trend aims to reduce the number of equipment and to save both resources and the environment. With the introduction of new equipment like Xerox ColorQube 9200 and the Riso ComColor series, inkjet technology seems to be making a comeback in the office environment. (Esler 2009, Xerox 2009c.)

Digital printing, especially inkjet, offers good possibilities for producing **printed electronics**. The printing process is additive as opposed to the traditional subtractive masking and etching process where material is removed from the product. Printing can be used to deposit layers of metals, polymers and nanoparticle dispersions on various substrates, which enables the manufacture of both passive (resistors, capacitors, inductors) and active (e.g. transistors, diodes and OLEDs) elements. In addition, printing can be done directly onto the casing of devices. (Kunnari et al. 2009, Miettinen et al. 2008, Burrasca et al. 2008.)

It is estimated that the global market for printed and potentially-printed electronics will rise from 1.92 billion USD in 2009 to 57 billion USD in 2019. The most important product groups are photovoltaics, OLEDs and e-paper displays. Other applications under development include thin film batteries, thin film transistors, RFID tags and conventional electronic circuits. (EDSF 2009.)

Digital printing can also be used in **life-science applications**. Biosensors can be printed using special inks that contain enzymes, antibodies or DNA probes. These can be used to detect drugs, explosives or different chemicals (Smyth 2008). Organs could be printed using cell globules as ink, placing layers on a biodegradable sheet of paper. Cells and layers fuse together to form e.g. a blood vessel (EDSF 2009).

**Security printing** will also benefit from digital methods. More security features will be included in many printed products like ID and credit cards, passports, financial and official documents, tickets and packaging. The potential technologies include holograms, tags, invisible print, DNA taggant inks and laser-induced colour change inks. Since the security data often needs to be personalised, digital printing is the most promising production method for these applications. (Smyth 2008.)

## 3.6 Discussion on digital printing applications

According to the reviewed literature, digital printing is expected to gain markets in many product and application areas. In the traditional product segments, which are dominated by offset, flexography and screen-printing, digital printing is becoming a serious alternative, thanks to the improved print quality and wider choice of substrates. The following developments are reported in the literature:

- Wide-format inkjet has already conquered parts of screen-printing markets, the production of posters, banners, etc. for outdoor and indoor advertising, interior decoration, etc. Inkjet presses can handle a variety of flexible and rigid substrates, and the choice of inks covers various materials and applications.

- Electrophotography is getting stronger in short-run and on-demand book production, and the new inkjet applications are aiming at the same market. The key requirements are sufficient print quality (“offset quality”), the ability to use book paper grades, and the short-run and on-demand finishing capability. With on-demand printing, publishers can eliminate the common problem of excessive stocks.
- Distributed printing of newspapers is made possible with web inkjet presses, capable of high output on bulk paper like newsprint. Versioning, e.g. local advertising, may further increase the prospects for digitally printed newspapers.
- In packaging, especially label and folding boxboard printing, both inkjet and electrophotography are gaining markets dominated by offset and flexography. The digital methods offer short-run printing and variable data capabilities. Requirements for digital systems include high print quality, ability to use existing substrates, as well as application-specific demands, e.g. suitability for food packaging.
- In the printing of direct mail and other advertising material, the traditional combination of an offset-printed shell and added variable data one-colour printing with electrophotography or inkjet is also changing. Thanks to the increased quality of digital printing, the whole product can be printed with digital methods.

The new products and applications of digital printing include transactional, transpromo and other variable data and personalised products. The following indications can be observed in the surveyed literature:

- The transpromo market is predicted to grow significantly. The key issues are high productivity, medium to high print quality and strong data management capability. Web electrophotography with high-speed flash fusing as well as web inkjet are suitable methods, and are predicted to compete for the transpromo business.
- In the area of business-related printed products (brochures, adverts, stationery), web to print offers many advantages like versioning, variable data printing, on-demand production, etc. Although suitable for both me-

chanical and digital printing systems, web to print is considered to offer easier integration with a digital printing environment.

– Photo albums, calendars and other personalised photo products are a strongly growing sector. Apart from sufficient print quality, the system requires a web or standalone application for content upload and editing, and suitable finishing options.

The most important development areas from the printing industry point of view are presented in Table 8.

Table 8. Future developments in digital printing applications.

| **Application** | **Requirements** | **Potential methods** |
|---|---|---|
| Distributed and versioned printing of newspapers | High speed low cost 4/4 printing on news-print | Web IJ (EP) |
| POD and distributed printing of books | Medium to high quality monochrome and colour printing on standard book papers + binding | IJ, EP |
| Photobooks | High quality colour printing + bookbinding | EP, IJ |
| Transactional, trans-promo, DM | High speed, low cost, medium quality 4/4 printing on bulk paper | Web (and sheet) EP, IJ |
| Wide-format printing of posters, displays, outdoor advertising, etc. | High quality 4/0 printing on paper, textiles, plastics, laminates; good lightfastness and weather resistance | IJ (solvent, UV) |
| Labels | Medium to high quality 4–5/0 + varnish | IJ, EP |
| Packaging | High quality 4–5/0 printing + varnish, spot colours and special effect inks | IJ, EP |
| Security printing | High quality personalised printing with special inks and effects | IJ, EP |

**Summary: digital printing markets**

- Digital printing will continue to take existing short-run markets from offset (documents, publications, books), flexography (packaging) and serigraphy (posters, display).
- Products and applications that are based on variable data printing will grow significantly. These include transactional, transpromo, photobooks and other personalised products, and books on demand.
- Digital printing offers new opportunities for applications where versioning can create added value, e.g. versioned/personalised newspapers and magazines as well as marketing materials.
- Web to print, digital workflows and distributed printing enhance the attractiveness of digital printing.

# 4. Environmental performance evaluation

*"That which cannot be measured cannot be managed, and that which cannot be managed cannot be organizationally pursued!"*

*Jack Welch, CEO of General Electric*

In this chapter, different frameworks and approaches to the design and application of environmental indicators are presented. Indicators can be used for many different aspects of environmental performance evaluation, for example comparing different products, measuring the effect of process changes, reporting on the environmental achievements of a company, accounting the national environmental impacts, and developing environmental criteria for services. Each use requires its own approach. If the results are to be comparable, the indicators must be based on consistent data and similar data collection and calculation methods.

Most of the indicator frameworks are designed as tools for environmental management within companies and organisations. Thus, each organisation selects and adapts the indicators that are suitable and relevant to their own operations, products and services. Therefore, the indicator results cannot be directly compared to other organisations or products.

The indicator frameworks include the international standard ISO 14031, the sustainability reporting guidelines of the Global Reporting Initiative (GRI), the indicators used in environmental management accounting (EMA), and indicator sets proposed for the printing industry. Furthermore, the indicators used in earlier environmental studies of printed products, processes and the industry sectors are summarised. Finally, a set of indicators suitable for digital printing is presented. Ideally, the indicators should enable the environmental performance evaluation of processes, products and companies, and also enable comparisons and environmental benchmarking in the printing industry.

Eco-labels, for example the Nordic Swan label, are a popular tool for the environmental assessment of products, services and companies. The labels are excluded from this study. Further information can be found at the website of the Global Ecolabelling Network (GEN 2010), the EU Eco-label website (EU 2010) and the Nordic ecolabelling website (Miljömärkning Sverige 2010).

## 4.1 Environmental performance evaluation frameworks

Measuring environmental performance is one of the essential building blocks of environmental management. Both external and internal stakeholders of many organisations are showing growing interest in environmental performance. Supply chain members may require demonstrated compliance with the environmental management systems. Environmental metrics and indicators are needed to prove the results of the environmental activities for authorities, insurance companies and financial institutions. Indicators can be applied to processes, functions, products and production sites, but their scope can also be sectoral, national or global. (IFAC 2005.)

### 4.1.1 ISO 14031:1999 Environmental management – Environmental performance evaluation – Guidelines

The international standard for environmental management systems, ISO 14001:2004, requires that the key characteristics of the organisation's operations that can have a significant environmental impact are measured and monitored regularly (ISO 2004). The supporting standard *ISO 14031:1999 Environmental management – Environmental performance evaluation – Guidelines* gives guidance on the design and use of environmental performance indicators. The indicator categories are presented in Figure 10 (ISO 1999):

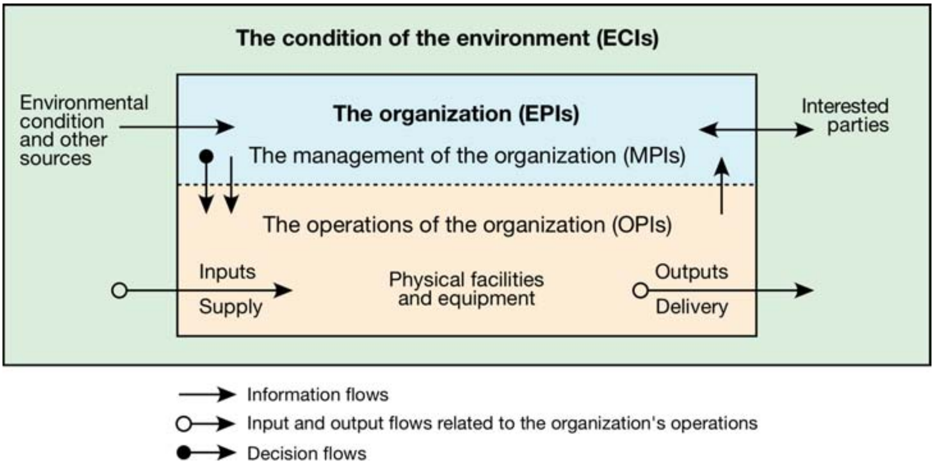


Figure 10. Interrelationships of an organisation's management and operations with the condition of the environment. ECI = Environmental condition indicator, EPI = Environmental performance indicator, MPI = Management performance indicator, OPI = Operational performance indicator (adapted from ISO 1999).

The selected indicators should fulfil several of the following features (ISO 1999):

- relevant to the environmental policy and the important environmental aspects
- appropriate to the management activities, operations or the environment
- useful to and representative of the environmental performance criteria
- understandable to internal and external stakeholders
- easily obtainable, measurable and informative
- adequate in relation to data quality and quantity
- responsive to changes in environmental performance.

The data presented by indicators can be direct, relative or indexed. Indicators can also be aggregated and weighted, but this must be done and explained carefully to maintain verifiability, consistency, comparability and understandability (ISO 1999).

### 4.1.2 Environmental indicators of the Global Reporting Initiative

Over the past ten years, corporate social responsibility (CSR) has evolved into an important issue in business. All but one of the world's 100 largest companies produces some form of sustainability reporting. In the printing industry, only few companies have adopted CSR, but new media technologies and the responsible sourcing practices of big paper and print buyers will change the situation (Line 2009).

The Global Reporting Initiative (GRI) is a network-based organisation of business, civil society, labour and professional institutions that has developed a sustainability reporting framework and guidelines. The GRI reporting framework defines the principles, application and indicators that can be used by organisations to measure and report their economic, environmental, and social performance. The third version of the Sustainability Reporting Guidelines, known as G3, was published in 2006. An additional component of the framework is the set of Sector Supplements, outlining sector-specific indicators (GRI 2009a). The development of the sector supplement for the media industry was started in 2009 in collaboration with several media organisations; it is expected to be published in 2011. (GRI 2009b.)

G3 guidelines contain detailed instructions on how to define the content and quality of the report, set the reporting boundaries, issue statements of strategy, governance and management approach and choose the indicators. There are three categories of indicators: economic, environmental and social. The social category is further divided into four sub-categories: human rights, labour, product responsibility and society. (GRI 2009a.)

The environmental indicators of the G3 are summarised in Annex 3. *Core indicators* are considered generally applicable for most organisations, while *additional indicators* represent new practices or are relevant to some organisations (GRI 2009a). The indicators are classified under the headings Materials, Energy, Water, Biodiversity, Emissions, effluents and waste, Products and services, Compliance, Transport and Overall (GRI 2006).

### 4.1.3 Environmental Management Accounting

Conventional management accounting systems have several limitations that prevent the effective collection of environmentally related data. This limitation can hamper decision-making due to missing or inaccurate information (IFAC 2005). Environmental management accounting (EMA) is a branch of environmental accounting that identifies, measures, analyses and interprets information about the environmental activities of a company. EMA provides information for internal use in a company, and includes both monetary and physical indicators. Monetary environmental management accounting (MEMA) deals with e.g. expenditure on cleaner production, fines for breaching environmental laws and value of environmental assets, and its information is expressed in monetary units. Physical environmental management accounting (PEMA) deals with material and energy flows that have environmental impacts, and the information is expressed in physical units (kilograms, joules, etc.) (Schaltegger et al. 2003).

The physical side of EMA consists of tracking all physical inputs and outputs of the organisation. The accounts of energy, materials, water, wastes and products flowing in and out of the organisation can be called a *materials balance*, an *input-output balance*, a *mass balance* or an *eco-balance*. A schematic illustration of the materials balance factors is presented in Figure 11. Depending on the intended use, a materials balance can be collected for a production process, a product, a selected input material or an entire organisation or site. Accounting activity covers all steps including procurement, delivery, stocks, use, dispatch, waste collection, recycling, treatment, and disposal. This type of accounting is called materials flow accounting. (IFAC 2005.)

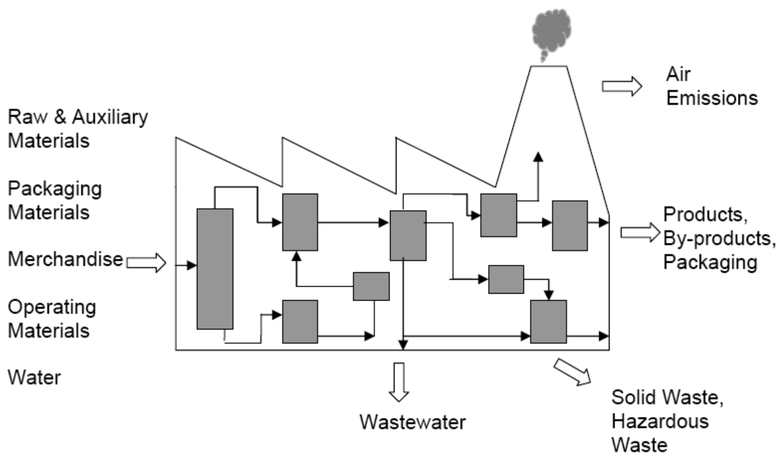


Figure 11. Components of materials flow accounting (IFAC 2005).

Environmental performance indicators (EPIs) can be monitored over time, are comparable between sites and companies, and consist of two variables, an absolute measure and a reference measure. EPIs should fulfil different information needs and reflect the significant environmental aspects of the company. Defining the type and source of collected data and its application, calculation comparison and communication of results are required for a successful EPI system. Indicators should be relevant, understandable, target oriented, consistent across the company, comparable over time and with other units, provide a balanced view and applicable for longer periods. Indicators can be absolute or relative. Absolute indicators, e.g. material consumption in kg or quantity of wastewater in $m^3$, are important from an ecological point of view, while relative indicators, like water consumption per staff member per day, give information about the environmental performance of the company in relation to its size, output or number of employees. A generic set of indicators is presented in Annex 3 (UN 2001).

Monetary information can also be relevant to EMA. It can be used to calculate EPIs that incorporate monetary data, and to establish environment-related expenses and earnings. Monetary data can be collected for a whole organisation or site, or for a specific material, a production line or a product. It is also possible to extend the system boundaries to include parts of the supply chain, e.g. customers and suppliers. Environment-related cost categories can be modified to the needs of each organisation. (IFAC 2005.)

### 4.1.4 Selecting the suitable environmental indicator framework

All three indicator frameworks reviewed above are designed as organisational tools and contain the same basic elements: energy, materials, emissions and wastes. Companies applying the ISO 14001 Environmental Management System could benefit most from the indicator framework of the ISO 14031 standard (ISO 1999), whereas companies that issue Corporate Social Responsibility (CSR) reports following the Global Reporting Initiative (GRI) guidelines should use the G3 Environmental Performance Indicators (GRI 2006). Companies that implement Management Accounting could expand their approach to cover Environmental Management Accounting (EMA) and use the respective guidelines for indicators (UN 2001, IFAC 2005).

ISO 14001, CSR reporting and EMA are mainly used by large companies. ISO 14001 is the most relevant in the printing industry – about 20 Finnish printing companies have a certified ISO 14001 system (Antikainen 2009). However, most of the printing companies are small, and do not implement any of the above systems and frameworks. Indicator systems could be tailored for SME printing companies according to the internal and external needs of the company in question. Suitable indicators from the presented literature can be selected, combined and modified. The established practices of the printing sector and its past research should also be considered.

### 4.1.5 Other metrics and indicators

There are many other measurements and indicators that can be used to evaluate a certain aspect of environmental performance. The most common ones are collected in Table 9. These single digit indicators are simple and easy to communicate, but they have two major shortcomings: first, they only measure one aspect of environmental performance, ignoring the rest, and secondly, the assumptions, system borders, calculation and valuation methods may vary considerably from case to case, which makes both communication and comparisons difficult. For example, carbon footprint (CF) has become extremely popular because of the growing concern and public awareness about climate change, but the carbon footprints of similar products may show very different results. The suitability of these indicators depends on the particular application and need, and also the availability of standardised assessment methods.

Table 9. Summary of other environmental indicators.

| **Indicator** | **Explanation** | **Unit** | **References** |
|---|---|---|---|
| Ecological footprint | Measures the biologically productive land and water requirements to sustain the population at present levels of consumption, technology, and resource efficiency | Global hectares (gha) | Ulvila and Pasanen 2009, Wiedmann 2009, WWF 2008, Global Footprint Network 2009 |
| Carbon footprint | Expresses the total amount of greenhouse gas (GHG, e.g. carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$)) emissions, calculated as carbon dioxide equivalents, caused directly or indirectly by an activity, a company, an industry sector, a nation, etc. | Kg $CO_2$e | BSI 2008a and b, Wiedmann 2009, ISO 2010 |
| MIPS (Material Input per Service unit) | Expresses the use of natural resources (materials) for producing a service or a product | Kg | Ritthoff et al. 2004, SLL 2009 |
| Water footprint | Measures the total volume of fresh water that is used directly and indirectly to run and support the business | L | WFN 2009, Toland 2009 |
| LCI/LCA indicators | A combination of several indicators, obtained from a life cycle inventory or assessment using the chosen impact categories and valuation methods | Various | ISO 14040 |

**Life cycle assessment (LCA)** is a method for calculating the environmental impacts of products and services over their entire life cycle. The methodology is specified in two international standards, ISO 14040:2006 and ISO 14044:2006.

LCA consists of four phases: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation. (ISO 2006b and c.)

LCA consists of four phases: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation. In the impact assessment phase, different impact categories are selected to characterise the environmental impacts. For example, one impact category could be *acidification*, and the amount of acidifying emissions (SO2, NOx, etc.) could be used as an environmental indicator. (ISO 2006c.)

Different impact assessment methods used in connection with LCAs (e.g. CML, EcoIndicator 99, EDIP) have different impact categories. A recent method called ReCiPe 2008 has 18 midpoint category indicators (e.g. climate change, water depletion, human toxicity) and three endpoint indicators (damages to human health, ecosystem diversity and resource availability). (Goedkoop et al. 2009.) In addition to the environmental indicators listed above, there are numerous **macro-level sustainability indicators** that have environmental components. For example, the Happy Planet Index combines human wellbeing and environmental impacts (Ulvila & Pasanen 2009). These sustainability indicators with a wider scope are excluded from this study.

The following section presents information on the printing industry and its initiatives. By combining the indicator frameworks of the abovementioned systems with the practices of the printing industry, a suitable indicator framework for digital printing can be developed.

## 4.2 Environmental indicators of printing

The environmental impacts of printing have been studied since the early 1990s. The most important studies have been summarised in Annex 4. Some studies (e.g. Juntunen et al. 1994 and Dalhielm and Axelsson 1995, Springer 1998a/b) have concentrated on typical or specific printed products, while others (Enroth 2006, Larsen et al. 2006) have evaluated specific printing methods. With the advent of new forms of digital media, some studies have compared printed products with digital ones (Hirschier and Reichart 2003, Moberg et al. 2007, Moberg et al. 2008).

This chapter presents the indicator systems proposed for the printing industry and summarises the earlier studies and other relevant aspects of indicators. Finally, the indicators for digital printing are discussed and a proposal for a set of indicators is presented.

### 4.2.1 Functional unit

Numerous indicators have been used to describe the environmental load of printing. The functional unit against which environmental data is presented varies from case to case. The easiest choice has been the weight of paper acquired, since paper in industrial printing operations is usually purchased by the tonne. A better alternative is to use the weight of printed products, which takes paper wastage into account. However, the main aspect of paper as an information carrier is its surface area, not weight. A good functional unit is the area of paper used in the final product, either in square metres or standard-sized sheets, e.g. A4s. This eliminates the role of paper basis weight (g/$m^2$), and facilitates comparisons between products and product groups.

Further functional units could be time, e.g. per week or month, turnover or number of copies produced (Envirowise 2004, Pohjola 2005, Enroth 2006). These may be practical within a single company. Katajajuuri and Loikkanen (1999) have used the amount of bytes transferred in the value chain as the functional unit for digital printing.

For commercial printers using a variety of paper grades and product types and sizes, one tonne of products printed or shipped to the customer is the most common choice (Pohjola 2005, Enroth 2006, Larsen et al 2006). According to anecdotal evidence, smaller printing companies, including digital printers, often do not keep track of surface area or product weight in their production output records. Number of prints (clicks) calculated to A4 pages, the widely used production output unit of both cut-sheet and web digital printers, could be used, along with the data obtained from printing equipment logs. Thus, two functional units could be recommended for digital printing: tonne of printed products and thousand/million duplex A4 pages (monochrome or colour, as the case may be).

### 4.2.2 Proposed sets of environmental metrics

Comprehensive sets of indicators have been proposed by Envirowise (2004), Pohjola (2005) and Enroth (2006). The indicators cover the areas of energy and water, materials, waste, emissions, packaging and transports. In addition, Pohjola and Enroth propose economic and social indicators. These three sets of indicators are summarised in Table 10. It can be noted that while there are differences in the selection and emphasis, the main indicators are more or less identical: energy, materials (paper and chemicals), emissions (VOCs, $CO_2$), waste (total, hazardous) and transports. This selection of core indicators can be seen to fulfil the requirements of ISO 14031 and also meet most of the demands of the GRI and EMA (see section 4.1 above). The additional economic and social indicators can be used to complement the core indicators in the environmental management of a company.

Table 10. Summary of the proposed environmental indicators for printing.

| **Source** | **Envirowise (2004)** | **Pohjola (2005)** | **Enroth (2006)** |
|---|---|---|---|
| **Functional unit** | Various, e.g. surface area of products ($m^2$) | Amount of used paper (tonnes) | One tonne of products |
| **Energy and water** | Net energy used (kWh)<br>Water consumption ($m^3$) | Consumption, electrical energy (kWh)<br>Consumption, heat energy (kWh)<br>Consumption, fabrication water ($m^3$) | Use of energy (MWh)<br>Non-renewable energy (MWh) |
| **Materials** | Total material yield (%, product area per purchased paper area)<br>Net chemical use (litres)<br>Total ink use (litres)<br>Solvent used for ink mixing (litres)<br>Net packaging use (kg) | Paper waste (tonnes)<br>Amount of solvents (litres)<br>Amount of chemicals (litres) | Total materials (printing paper) (kg)<br>Non-renewable materials (film, metal, mineral oils in inks, UV inks, toners, etc.) (kg)<br>Printing paper not accepted by environmental labelling criteria (kg)<br>Hazardous materials (kg) |
| **Emissions** | VOC concentration ($mg/m^3$)<br>Effluent quantities discharged ($m^3$) | $CO_2$ from energy production (tonnes)<br>$CO_2$ from transports (tonnes) | $CO_2$ emissions (kg)<br>$NO_x$ emissions (kg)<br>$SO_2$ emissions (kg)<br>VOC emissions (kg) |
| **Waste** | Total solid waste disposed (tonnes) | Amount of hazardous waste (tonnes)<br>Amount of assorted waste (litres) | Total amount of waste (kg)<br>Landfill waste (kg)<br>Hazardous waste (excluding electronic waste) (kg)<br>Electronic waste (kg) |
| **Transport** | Fuel efficiency (miles/litre) | Acquisition and delivery transports (km)<br>Waste transports (km)<br>Personnel transports (km) | Transports to the company (kg $CO_2$)<br>Product delivery (kg $CO_2$)<br>Business travel (kg $CO_2$) |
| **Economic** | | Energy costs (€)<br>Water costs (€)<br>Disposal costs of hazardous waste (€)<br>Waste disposal costs, paper (€)<br>Waste disposal costs, other (€)<br>Transport costs (€) | Cost of environmental work (€) |
| **Social** | | | Proportion of environmentally conscious customers (%)<br>Proportion of customers satisfied with the company's environmental performance (%) |

Energy consumption consists of electrical energy, heat energy and gas (usually propane). Total energy consumption is used as one of the basic indicators. Pohjola proposes a separate indicator for electricity and heat energy. Enroth's indicators include the proportion of energy produced from non-renewable sources. Water consumption includes all uses, such as process, cooling, rinsing, personnel, etc. These indicators are also suitable and essential for digital printing.

Paper is the most important material for the printing process. In the printing processes, usually 5–30% of purchased paper ends up as waste (reel-ends, make-ready waste, surplus copies, trimming waste, etc.). Other material categories are printing inks, solvents and other chemicals. Additional indicators suggested by Enroth are the amount of paper not fulfilling the environmental labelling criteria and the amount of non-renewable materials. For digital printing, paper consumption is an essential indicator, too. Another important indicator is the consumption of toners/inks. Consumables like fuser oil, imaging oil, OPC belts/drums, inkjet printheads, etc. may be included but are less important.

Emission indicators concentrate on VOCs and $CO_2$ (other greenhouse gases are much less significant in this context). Carbon dioxide is an important environmental aspect of energy production and transport, while VOC is the key emission in the mechanical printing processes, liquid toner electrophotography and solvent-based inkjets. For dry toner electrophotography, particle and ozone emissions should be included, at least until they have been proven to be insignificant.

Waste fractions include recyclable waste, like paper, hazardous waste and landfill waste. The latter two include both waste from the printing process as well as the waste from the printing plant. Transport indicators can include deliveries of materials to the plant, deliveries of products to the customers, waste transports, staff transport and business travel. Economic and social indicators reflect the other two areas of sustainability.

### 4.2.3 Other indicator frameworks

Sobotka (2009) proposes an overall rating scale for the sustainability of digital printing systems. The rating factor is calculated by evaluating and weighting nine different factors according to defined criteria (Table 11). Each factor has specified criteria for calculating the score. For example, deinkability is measured using the INGEDE method 11 (INGEDE 2007), and the score calculated according to the guideline of Technischen Kommission Deinking (INGEDE 2008), 100 points being the maximum. A score of 71–100, representing good deinkability, would yield 30 points, a score of 5170 points (enough deinkability) 20 points and a score of 0–50 points (deinking possible) 10 points. Air emissions would be evaluated according to relevant standards and limit values for emissions as follows (colour/b&w printers): TVOC 20/15 mg/h, benzene ≤0.05 mg/h, styrene 2.0/1.5 mg/h, ozone 3.5/2.0 mg/h and dust 4.0 mg/h (Sobotka 2009).

Table 11. Proposed environmental rating scale for digital printing systems (adapted from Sobotka 2009).

| **Factors** | **Max points** | **Rating coefficient** |
|---|---|---|
| Deinkability (INGEDE method 11) | 30 | 1 |
| Recyclability of printer components | 20 | 0.8 |
| Energy consumption | 30 | 1 |
| Paper waste in production | 20 | 0.5 |
| Air emissions (limit values for TVOC, benzene, styrene, ozone, dust) | 20 | 1 |
| Toner and ink formulation (harmful substances, container recycling) | 20 | 1 |
| Suitability for recycled/certified paper grades | 20 | 0.4 |
| Noise | 10 | 0.5 |
| $CO_2$ emissions | 20 | 0.5 |

While the information provided in the referred article is very limited, Sobotka's approach is an excellent contribution to assessing and developing digital printing at the systems level, i.e. equipment, process and materials. This approach shifts environmental responsibility from printing companies to systems developers, who in most cases design not only the equipment but also inks and other consumables. The proposed factors cover all relevant aspects of digital printing, although the weighing factors could be reviewed. Also, the specified deinkability test may not be relevant in this case (for more on deinking, see section 5.5).

Enroth and Widing propose a Design for Environment checklist for the evaluation of the environmental impacts of printed products already in the design stage (Enroth 2001). Assessment is based on the count of "sour faces" (☹) based on the choices made. For example, digital printing awards one, mechanical printing with CTP two and mechanical printing with film-based platemaking three sour faces. There are altogether 14 criteria with alternative choices, grouped into Production circumstances, Printing paper, Printing ink, Finishing and Transport (Enroth 2001). The checklist does not use indicators or provide numerical information on the environmental impacts, and thus can be considered as an indicative tool for the design stage – especially if updated to reflect present production processes and practices. For the same reason, it is not useful for this study. However, the abovementioned preference for digital printing is an interesting detail; it is not clear from the report how this was justified.

### 4.2.4 Indicators used in earlier studies

Short summaries of published studies on the environmental performance of mechanical and digital printing are presented in Annex 4. The indicators used in these studies are quite consistent, and the reports contain a reasonable amount of numerical data. Using the same indicators for future studies would enable continuity and different types of comparisons. The main issues related to this study and digital printing are listed below.

Physical indicator systems similar to those presented in section 4.2.2 above have been used in most studies, for example the Finnish study "Eco-balance of printed communication", carried out by VTT Research Centre of Finland (Juntunen et al. 1994, Pösö et al. 1993). The framework presented and applied in the studies of Enroth (2001 and 2006) has also been used in the environmental indicator project of several Swedish newspapers (MINT 2009). Similar physical indicators are also used in the studies of Peltonen (2008) and Viluksela (2007 and 2009).

Environmental aspects of lithographic and digital printing were compared in a study carried out at the Rochester Institute of Technology (Kadam et al. 2005). Similar print jobs of 500 and 3000 copies were printed on a sheet-fed offset and liquid-toner electrophotography press. A mass balance approach was used to analyse the inputs and outputs of the two processes. The results were related to “the short run” and to “the long run”, i.e. no common functional unit was used. Three interesting indicators were introduced:

- Resource Utilisation Efficiency (%) expresses the percentage of resource (paper and ink) used in the final product.
- Lost Material Value (LMV, dollars) expresses the value of resources lost in producing the product, and is calculated by multiplying the quantity of wasted (lost) materials by their unit prices.
- Environmental cost (dollars) expresses waste disposal costs, and is calculated by multiplying waste quantities by the costs of corresponding waste disposal methods.

The monetary indicators are closely related to those included in the framework of Pohjola (2005), and can be very useful for comparative studies and also for environmental performance evaluation in companies. Monetary information may be more useful than physical in certain cases. The resource utilisation efficiency indicator presents materials efficiency as a percentage figure, which may be more concrete in some cases. Although these indicators measure the same impacts as the physical indicators, they can provide additional value in environmental management.

## 4.3 Indicators for digital printing

Environmental indicators of printing can serve several quite different needs:

- measuring environmental performance against environmental plans and targets as part of the site- or company-level management system
- reporting environmental status and progress to stakeholders
- providing data for specific external purposes, e.g. environmental benchmarking in the printing industry or regulatory reporting
- studying the environmental aspects and impacts of the different stages and functions of production processes in order to identify and quantify the potential for improvement, to establish baseline data, to highlight best practices, etc.

Different needs require different approaches, data sources and resources. For the purpose of internal management and development, the organisation must consider the benefits of the indicators versus the resources needed for obtaining them. A simple set of key indicators calculated with easily available and reliable data is better than a more elaborate approach that cannot be implemented properly. This applies especially to SME printing companies, which are numerous in the printing industry (Graafinen teollisuus 2009). Small printers do not have adequate resources to develop and run data collection and analysis activities related to environmental indicators.

Based on the information presented earlier in this and the previous chapters, and taking into account the different needs and availability of information in printing companies of different size and activities, a new three-level system of environmental indicators is proposed. A detailed proposal of the three levels of indicators for digital printing is presented in Annex 5. The three levels and their characteristics are as follows:

**Basic level indicators**

- cover the main environmental issues at company level
- relatively few in number

- consist of physical and monetary EPIs (mainly OPIs)
- data is easy to obtain
- suitable for small companies with limited resources.

**Intermediate level indicators**

- provide more detailed information on the environmental performance of the company and process levels
- a larger collection of physical and monetary EPIs (OPIs and selected MPIs)
- require dedicated data collection
- suitable for companies implementing environmental management.

**Advanced level indicators**

- a large number of indicators, selected and adapted for both continuous and project-type use
- provide comprehensive information on the different aspects of environmental performance and sustainability
- require extensive data collection, both continuous and ad hoc
- suitable for companies with solid environmental management competence and resources
- also suitable for research and development studies and projects.

**Summary: Environmental performance evaluation**

- There are various frameworks to provide guidelines for selecting indicators, e.g. ISO 14031 standard, the reporting guidelines of the GRI and the recommendations of Environmental Management Accounting. For the most part, the indicators suggested in the different frameworks are quite similar. These guidelines are suitable as such for larger organisations, but can also provide ideas for smaller ones.
- Most indicator frameworks are designed as environmental management tools for use within an organisation. Indicators can also be related to products, processes, projects or nations.
- The environmental performance of digital printing can be evaluated using indicators developed for the printing industry and/or used in earlier studies.
- The number and scope of indicators for digital printing depend on the needs as well as the resources available. A new three-level system of environmental indicators is proposed for digital printers, ranging from a few essential company-level indicators at the basic level to a versatile set of indicators for the company at the advanced level.

# 5. Environmental aspects of digital printing

*"Our digital presses offer you an environmentally friendly, accomplished and professional print service. A huge benefit from using our digital technology is that our presses don't rely on plates, meaning our customers/clients can view a pre-press proof of the final result. This is in addition to the significantly reduced carbon footprint which digital printing offers..."*

*PureDigitalPrint website*[4]

Although CTP (computer-to-plate) and new printing plate technologies have decreased the environmental impacts of conventional offset printing, the digital methods skip the platemaking process altogether. This, added to simple make-ready, minimal use of cleaning agents and the claims of low or no emissions, leads to the assumption that digital printing methods may have environmental advantages over the traditional methods (Katajajuuri & Loikkanen 1999).

While a life cycle approach is required to evaluate the environmental impacts of printing (Figure 12), this chapter concentrates on the print production stage and recovery stages of digital printing and its products. A general overview of the environmental impacts of printing can be found in Enroth (2006) or Viluksela (2007).

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[4] http://www.puredigitalprint.com/.

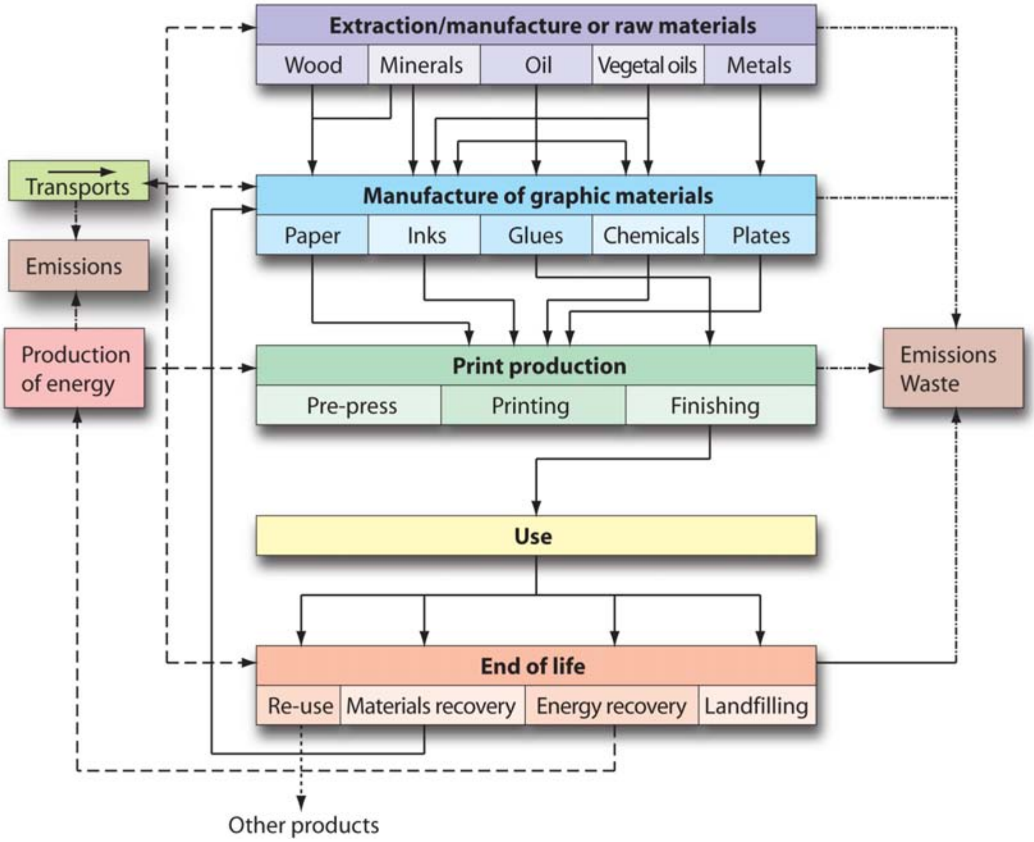


Figure 12. The main stages in the life cycle of printed products (applied and modified from ISO 2002 and Kärnä 2002).

According to the printing industry consultant Andrew Tribute, the main environmental issue of digital printing is deinkability. The advantages are on-demand production, low paper wastage and generally well-organised supplier-operated recovery and recycling of used consumables (Tribute 2009). Ebner et al. (2009) have found a different order of importance: paper consumption and the use phase electricity consumption are major contributors to the life cycle energy and greenhouse gas emissions of office imaging equipment (Figure 13).

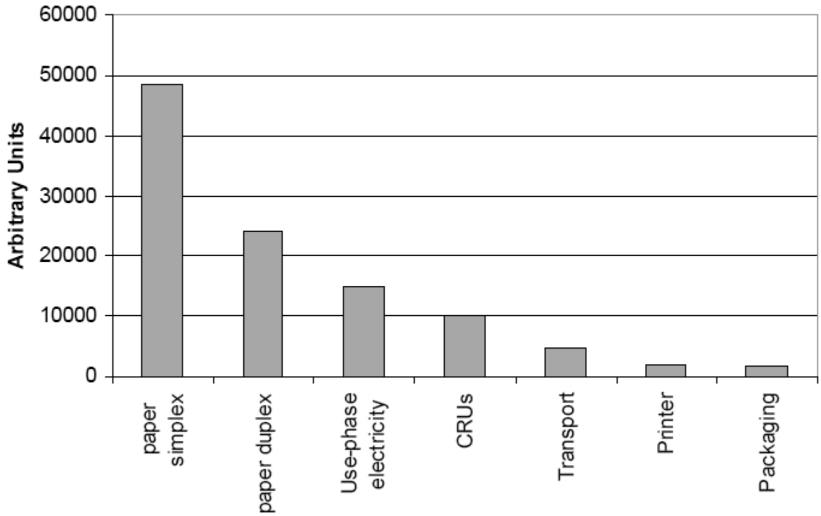


Figure 13. Relative energy and greenhouse gas impacts for different aspects of typical office imaging equipment. CRU = customer replaceable units, i.e. all service items designed to be replaced by the customer (Ebner et al. 2009).

As a whole, the published research on the environmental impacts of digital printing is quite limited. This chapter summarises the literature under the headings of energy, materials, emissions, waste and recyclability. Numerical data from the published environmental studies of both mechanical and digital printing are also presented, if available.

## 5.1 Energy efficiency

Up to the end of 2009, the only published life cycle assessment dealing with digital printing concentrated on electrophotographic toner. Ahmadi et al. (2003) studied the environmental impacts of toner manufactured by the older mechanical method in order to obtain the baseline for comparing future technologies under consideration. A summary of the findings is presented in Figure 14. The consumer use stage had the highest energy use and related emissions, which suggested that efforts should be directed to reduce the energy consumption of electrophotographic devices.

Two Finnish studies highlight the high electricity consumption of electrophotography when compared to offset. Katajajuuri and Loikkanen (1999) found that monocolour electrophotography consumed two to three times more electricity than offset, and in four-colour printing, the difference was even larger. However, this study was based on data from equipment manufacturers, and excluded platemaking. In a more recent study, electrophotography was found to consume two to three times more energy and printing inks (toners) per one tonne of printed products when compared to sheet-fed offset (Viluksela et al. 2008).

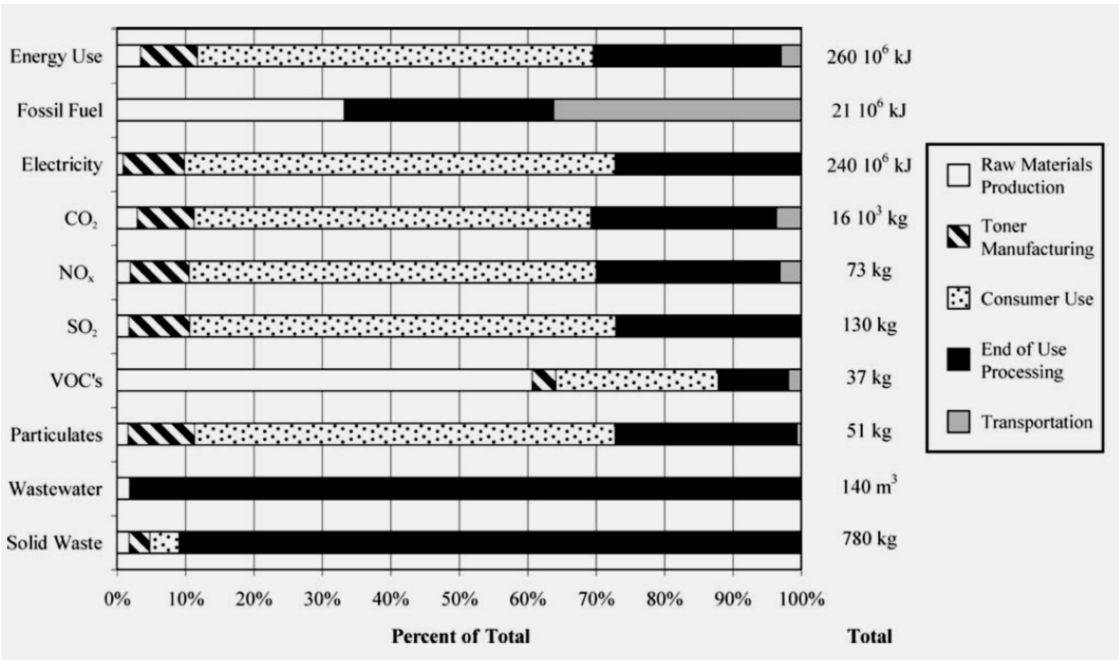


Figure 14. Energy use and emissions as a percentage of the total for the system processes. The functional unit is one megatonne of toner (Ahmadi et al. 2003).

In EP printing, fusing is one of the important sub-systems contributing to energy consumption (Azadi et al 2008). New toners that require lower fusing temperatures are reported to reduce the energy consumption of electrophotography (Gbadamosi 2009, Smyth 2008). Many press manufacturers state that the new equipment and toners are “eco-friendly”. For example, Xeikon claims that their new electrophotographic press 8000 “guarantees a significant reduction in raw materials, as well as energy and water savings” when compared against offset. Scientific proof, however, has not been published.

Another comparison of the electricity consumption and output figures of selected sheet-fed offset and electrophotographic presses is presented in Table 12.

Little information on offset printing is available, since press specifications usually do not indicate their electricity consumption. Furthermore, the information is only indicative, because data sources are not consistent, the production output of offset presses estimated in the table may be lower than in real life, and the Heidelberg press has extra features (fifth printing unit, varnish unit, dryer), leading to a higher than normal energy consumption. However, the comparison supports the indication that electrophotography is not as energy-efficient as offset.

Table 12. Energy consumption comparison of selected sheet-fed offset and electrophotographic presses.

| **Press type** | **Sheet-fed offset 4/0** | **Heidelberg SM 105-5L** | **Xeorx iGen4 (Sheet-fed)** | **Oce ColorStream 10 000 (Web)** |
|---|---|---|---|---|
| Energy consumption kW | 60 | 138 | 13.8 | 46 |
| Est. production output s/h* | 10 000 | 12 000 | | |
| Sheet size | 70 x 100 | 70 x 100 | | |
| Production output A4/min | | | 110 | 336 |
| Production output A4/h | 112 233 | 134 680 | 6 600 | 20 160 |
| **Energy consumption Wh/A4** | **0.53** | **1.02** | **2.1** | **2.3** |
| Data source | Christiansen (2008) | Heidelberg (2008b) | Xerox (2009b) | Océ (2009b) |

* Estimated from practical experience.

The printing company-level energy consumption figures of earlier studies indicate a similar difference: companies using mechanical printing methods consume 500–1200 kWh/tonne of printed products (Juntunen et al. 1994, Enroth 2006, Larsen et al. 2006) while the digital EP printing facility consumed 2900 kWh/tonne (Peltonen 2008). Corresponding company-level energy figures are not available for inkjet printing.

It must be pointed out that many other factors, in addition to the printing process, contribute to the total energy consumption of a printing plant. In the study of Haanpää (2010), it was found that production equipment in a digital printing plant consumed about half of the total daily electricity. Other significant activities that used electricity were the IT hardware and its cooling as well as the ventilation and air humidification of the production premises. The study also revealed that at night, when there is no print production, the electricity consumption remained quite high even tough heating of the building was not included in the figures (Haanpää 2010). In any case, further studies and perhaps more technical development are required to justify the claims that digital printing provides environmental and energy efficiency advantages.

Energy efficiency is also included in equipment marketing: Océ has published the comparison presented as Figure 15 in its marketing material (Océ 2009c).

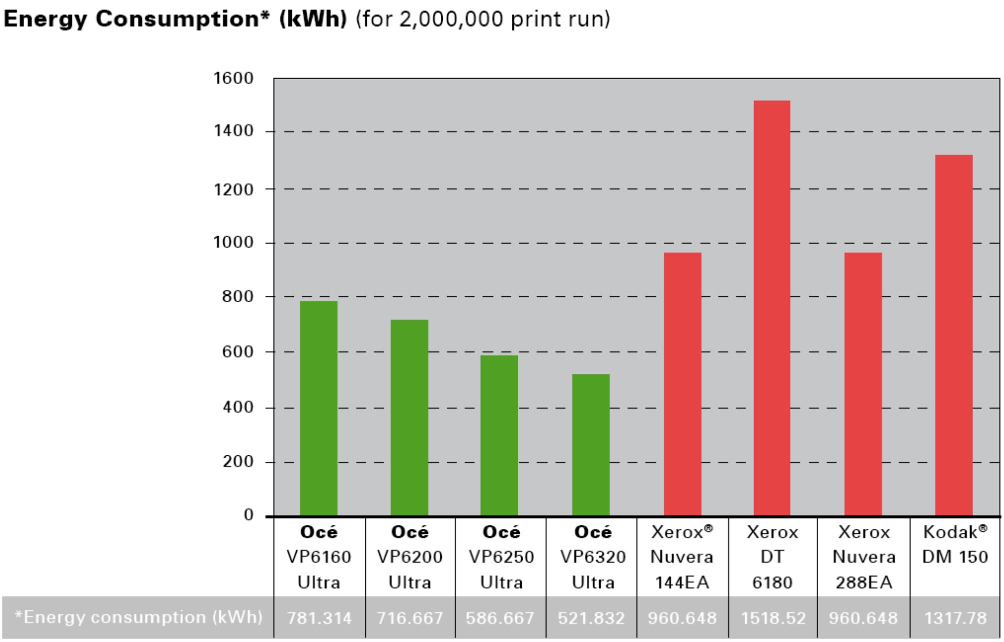


Figure 15. Energy consumption comparison of monochrome EP printers from an Océ marketing brochure (Océ 2009c).

Xerox claims that its new Emulsion Aggregation (EA) toner-manufacturing technology consumes 25% less energy in the manufacturing stage, compared to the traditional melt-mixing and pulverising method. In addition, 40–50% less EA toner is required for printing, reducing the fusing energy needs. Furthermore, alternative resins can be used to reduce the fusing temperature. All these developments lead to a 60–70% reduction in the energy consumption per page (Xerox 2006, Xerox 2007). The data available from the Product Safety Data Sheets of Xerox, available on the Xerox web pages, confirms that the new Emulsion Aggregation toners seem to have improved energy efficiency (Figure 16). This comparison does not take into account factors like the inline finishing equipment or print resolution of the printers, which may explain why the iGen presses differ from the rest of the equipment. Haanpää (2010) measured the energy consumption of the iGen3 presses during production and stand by stage. The measured values were clearly higher than the values given in the PSDS and the only difference was that the measured device had also the in feed unit in it (Haanpää 2010).

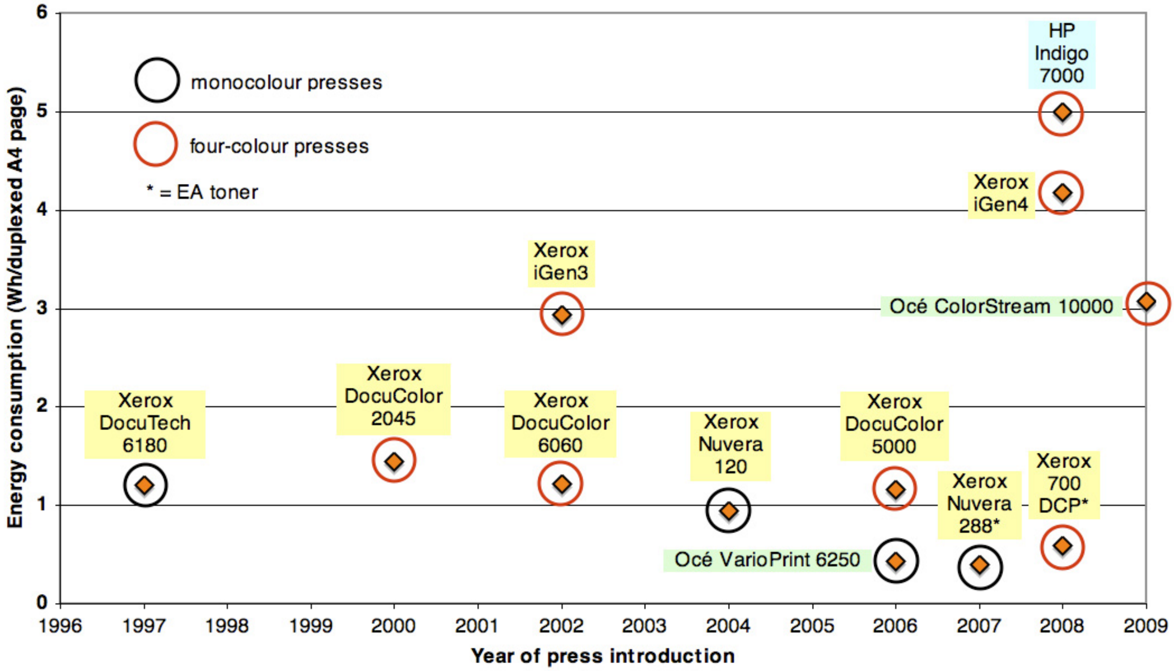


Figure 16. Energy consumption (watts per duplexed A4 page) of selected Xerox electrophotographic printers. Data taken from the Product Safety Data Sheets of Xerox equipment (Xerox 2009b), and product specification data from HP and Océ.

Energy consumption data from several digital printing manufacturers has been collected from product data sheets and brochures, and is presented in Figure 17, calculated as watts per duplexed A4 page. Direct comparisons between machines and technologies are difficult because the data sources are not consistent and are based on manufacturer data. Furthermore, the energy consumption in the other lifecycle stages, e.g. ink/toner manufacture, must not be forgotten. With these limitations in mind, two general observations can be made: colour printing seems to consume more energy than monochrome, and inkjet presses seem to be more energy efficient than corresponding EP presses.

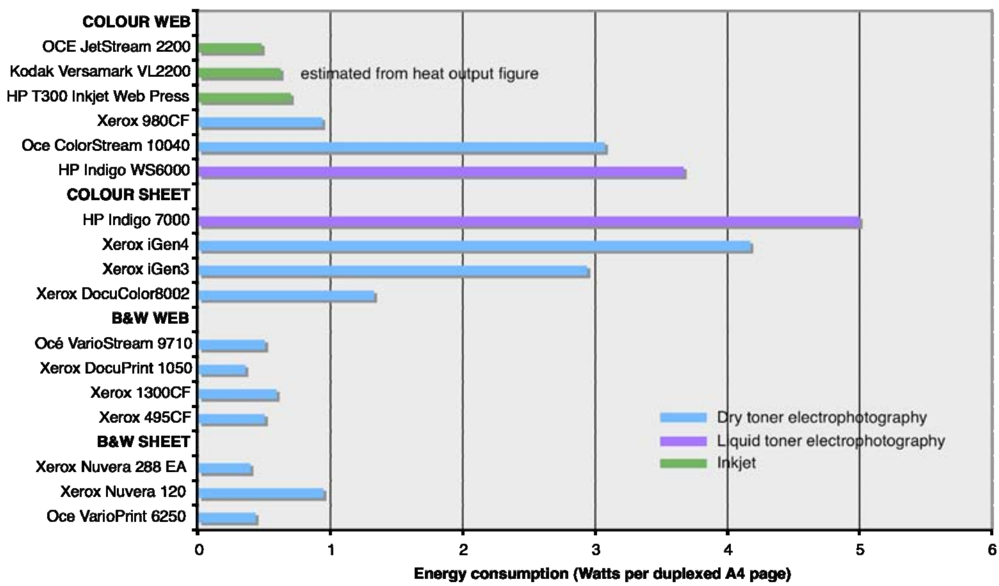


Figure 17. Examples of the printing stage electricity consumption of digital presses. Data obtained from the data sheets and brochures of equipment manufacturers. Note: Due to the varied sources, the data is only indicative.

Energy consumption of print production with mechanical methods has been reported in several studies (Pösö et al. 1994, Jepsen & Tebert 2003, Enroth 2006, Larsen 2006, MINT 2008). Energy consumption, comprising both the printing process and the printing plant, typically ranges from 500 to 2000 kWh/tonne of products. The lower figures are related to products printed on low grammage paper (newspapers and magazines). Corresponding data from the digital printing methods is not available.

## 5.2 Materials efficiency

As has been pointed out by Ebner et al. (2009, see Figure 13), paper consumption represents a major environmental concern in office printing. Digital printing has the technical prerequisites for better materials efficiency than mechanical printing methods. This advantage is based on the simple make-ready and masterless technique, enabling on-demand printing and eliminating unnecessary copies (overprints). (Kadam et al. 2005, Canonico 2009.)

In the study of Peltonen (2008), the studied EP printing facility consumed 1170 kg of paper and board and 26.8 kg of toner and 13.9 kg of packaging materials for one tonne of digitally printed products. Bearing in mind the claims of the quick make-ready and minimal waste of digital printing methods, the paper consumption is higher than one would expect. This is mainly caused by the overrun for the finishing process. Water consumption for air humidification was 0.35 $m^3$/tonne (Peltonen 2008). Water and chemicals consumption was found to be significantly smaller in electrophotography than in sheet-fed offset (Viluksela et al. 2008). At another digital printing plant, paper waste was estimated at 18%, out of which almost 8% resulted from the make-ready of the printing presses (Hopponen 2010).

In electrophotography, new toner technologies improve materials efficiency: chemically manufactured toners decrease toner consumption by 40–50% (Xerox 2006) and lead to smaller carbon dioxide emissions (Figure 18, Fuji Xerox 2010). In addition, the single-component toner made by Océ is said to reduce toner consumption (Océ 2009). In the inkjet side, Agfa claims that UV ink consumption is lower than solvent ink consumption (8–10 ml/$m^2$ vs. 12–14 ml/$m^2$, respectively) (Agfa 2007).

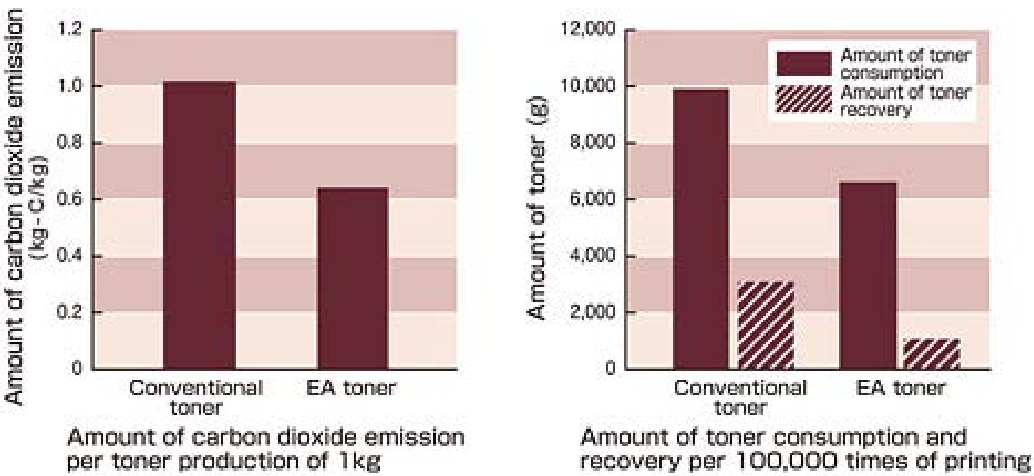


Figure 18. Comparison of energy and resource consumption between EA (emulsion aggregation) and conventional toner (Fuji Xerox 2010).

Paper and ink consumption of print production with mechanical methods has been reported in the studies of Pösö et al. 1994, Jepsen & Tebert 2003, Larsen 2006 and MINT 2008. Paper consumption is typically in the range of 1100–

1300 kg per tonne of products. Ink consumption is about 10–40 kg/tonne of products. The considerable variation is due to the product type and number of colours (e.g. text-only book vs. full-colour advertising) and the paper grade used. Data from digital printing is insufficient for comparisons.

In HSWO, the role of paper in energy efficiency of the printing process has been extensively researched (Table 13, PrintCity 2008). A similar approach could be worthwhile in digital printing as well, combining the effects of paper, inks/toners and drying/fusing.

Table 13. Paper properties affecting energy consumption in heatset printing (PrintCity 2008).

| Paper impact on energy use | Paper properties | "Add on" changes in paper properties | Typical magnitude of change | Average savings with "add on" |
|---|---|---|---|---|
| Drives and | Basis weight | Lower basis weight | - 20% | 22% |
| web path | Bulk | Higher bulk | + 25% | but only |
| | Porosity, B:sen | Higher porosity | + 60% | about 10 Wh |
| | Roughness, PPS | Higher roughness | + 55% | per printed roll |
| | Friction | Lower friction | - 30% | |
| | Tensile stiffness | Higher tensile stiffness | + 25% | |
| Printing nips, web | Ink setting | Slower ink setting | - 15% | 18% |
| release from | Ink demand | Lower ink demand | - 20% | 40 kWh |
| blankets | Porosity | Higher porosity | + 60% | per printing nip |
| | Roughness | Higher roughness | + 55% | |
| Drying and | Moisture content | Lower moisture cont. | - 35% | 24% |
| cooling | Ash content | Higher ash content | + 30% | savings in total |
| | Ink demand | Lower ink demand | - 20% | energy for |
| | Grammage | Lower paper weight?* | - 20% | drying and |
| | Porosity | Higher porosity?** | + 40% | cooling*** |
| | Roughness | Lower roughness | - 40% | |
| | Coated/Uncoated | Coated paper | Coated | |

* *Lower weight without higher ink demand*
** *Higher porosity without higher ink demand*
*** *See pages 12-13 for the impact of dryers with integrated oxidisers.*

## 5.3 Emissions to air

Air emissions present both environmental and health concerns. Some research has been carried out concerning the emissions of office printers, but very little independent information is available on production printing equipment. Some information is available from equipment manufacturers, e.g. some include emission data in their PSDSs (product safety data sheets). The main emissions from digital printing, VOCs, particles and ozone, are discussed below.

### 5.3.1 VOC emissions

Volatile organic compounds (VOCs) are chemicals that can produce photochemical oxidants by reactions with nitrogen oxides in the presence of sunlight (UNECE 1991). VOCs are emitted from natural sources, motor vehicle exhausts and various industrial processes, e.g. solvent use. VOCs play a significant part in many environmental phenomena like stratospheric ozone depletion and ground level ozone formation. VOCs also have direct toxic and carcinogenic health effects. VOCs contribute to the greenhouse effect by accumulating in the troposphere and absorbing infrared radiation from the sun or the earth. VOCs are removed from the troposphere either by dry and wet deposition or by chemical reactions. The life span of VOCs ranges from days to years depending on the removal mechanism. VOC emissions can be controlled by product reformulation, process modifications and end-of-pipe techniques. All of these approaches have been used in the printing industry. (Derwent 1995, Atkinson 1995, Passant 1995, EU 2007.)

VOC emissions of digital printing have been addressed in a couple of studies. Kagi et al. (2007) studied the emissions of two office-scale laser printers and one inkjet printer in 2002. In chamber tests, laser printers were found to emit xylene and styrene, while the inkjet printer emitted pentanol. The peak concentrations of the older printer were considerably higher than those of the newer one (3000 vs. 25 $\mu g/m^3$ of o-xylene and 400 vs. 240 $\mu g/m^3$ of styrene). The peak concentration of pentanol of the inkjet printer was 270 $\mu g/m^3$. The source of the VOCs was found to be the toner and the ink, respectively. (Kagi et al. 2007.)

In a comparative study of sheet-fed offset vs. liquid ink electrophotography, Kadam et al. (2005) measured VOC emissions both in the breathing zone of the press operator and above the printing press. The VOC emissions, expressed as the concentration of n-hexane, were 74 $mg/m^3$ in the breathing area of the digital press and 483 $mg/m^3$ above the press. For the sheet-fed offset press, the peak concentration in the breathing zone was 120 $mg/m^3$ during press cleaning and 7.2 $mg/m^3$ outside the breathing zone. (Kadam et al. 2005.)

In the 1990s, VOC emissions were in the range of 10 kg/tonne of printed products (Juntunen et al. 1994). According to more recent reports, typical VOC emissions are 0.1–5 kg/tonne of products (Jepsen & Tebert 2003, Enroth 2006, Larsen 2006, MINT 2008). Corresponding data from digital printing is not available.

### 5.3.2 Emissions of particulate matter

Particulate matter (PM) consists of airborne solid particles and/or droplets that vary in size, composition and origin (WHO 2004). Particles are usually characterised by their aerodynamic size: coarse particles (> 2.5 μm in aerodynamic diameter), fine particles (0.1–2.5 μm, known as $PM_{2.5}$) and ultrafine particles (< 0.1 μm or 100 nm). Particles originate from agricultural and industrial processes and transport. Particulate matter causes health problems. The smaller the particles, the deeper they can penetrate and be deposited in the human pulmonary system. The smallest particles can be transferred from the lungs to blood circulation. PM-related health effects can be both short and long term, and include lung inflammatory reactions, adverse effects on the cardiovascular system, reduction in lung function and reduction in life expectancy. (WHO 2004, Samet et al. 2006.)

The EU limit value for $PM_{10}$ is 50 μg/$m^3$ as a 24-hour average, and the same value is specified in the Finnish air quality legislation (Ilmatieteen laitos 2009, L 711/2001).

In the study of Kadam et al. (2005), low amounts of particulate matter were discovered during printing on a sheet-fed offset press and a liquid ink electrophotographic press. Total particulate matter was found to be < 0.8 (offset) and < 0.9 (electrophotography) mg/$m^3$, and respirable particulate matter was < 0.3 mg/$m^3$ for both presses, both less than 10% of the US permissible exposure limits (Kadam 2005). However, compared to the Finnish daily air quality limit of 50 μg/$m^3$ for $PM_{10}$ (particulate matter under 10 μm in size), the results raise some concerns. (Kadam et al. 2005.)

Emissions of particulate matter were also measured in the study of Kagi et al. (2007). It was found that particle emissions depend on the printer type. During laser printing tests in an office room, the concentration of particles under 100 nm increased, especially with the older laser printer. As the size of toner particles is about 10 μm, the study concluded that particle emissions were not directly generated from the toner (Kagi et al. 2007).

Further studies of particle emissions of laser printers have been carried out at Queensland University of Technology. He et al. (2007) investigated 62 printers and found out that 40% of the printers did not emit particles. 27% of those that did emit particles were classified as high emitters. Printers from the manufacturer HP, which represented over 50% of the total number of printers, were found in all subgroups (non-emitters, low level emitters, middle level emitters, high level emitters). The mean particle size was 35–94 nm, and there was a dependence between particle emissions and toner coverage. The highest emission rate was close to the level of cigarette smoking in residential houses (He et al. 2007).

In more recent tests, it was confirmed that a laser printer can release high amounts of particles, and that colour laser printers emit more particles than one-colour printers. However, the mechanism of particle release is not the same for every printer. For example, the relationship between particle emissions and toner coverage or number of printed pages is not similar between printers, and the emission source of the particles has not yet been identified. (Wensing et al. 2008.)

### 5.3.3 Ozone emissions

Tropospheric (lower atmosphere) ozone causes negative effects in humans and plants. The human health issues are related to both short and long term pulmonary problems like lung inflammatory reactions, lung function reduction and increased mortality (WHO 2004). The effects on plants include decreased growth due to disturbed photosynthesis as well as cell death. Ozone may have a significant role in climate change as it reduces the plants' ability to remove carbon dioxide from the atmosphere (Sitch et al. 2007). There are no EU limit values for ozone, but Finnish legislation specifies the target value for ozone concentration at 120 $\mu g/m^3$ as the highest daily 8-hour average (Ilmatieteen laitos 2009, L 783/2003).

Apart from the indirect formation of ozone through the reactions of VOCs, ozone can also be emitted from certain types of electrophotographic printers. Kagi et al. (2007) found that ozone concentration in an office room rose from 1.5 ppb to 6 ppb during printing with an older type of laser printer, but on a newer printer, there was no increase. Similar results were obtained from a chamber test. The tested office inkjet printer did not emit ozone. Modern electrophotographic printers are equipped with ozone filters, which must be replaced at certain intervals (Xerox 2009b). In its marketing literature, Océ compares the ozone emissions of its printer with those of its competitors (Figure 19).

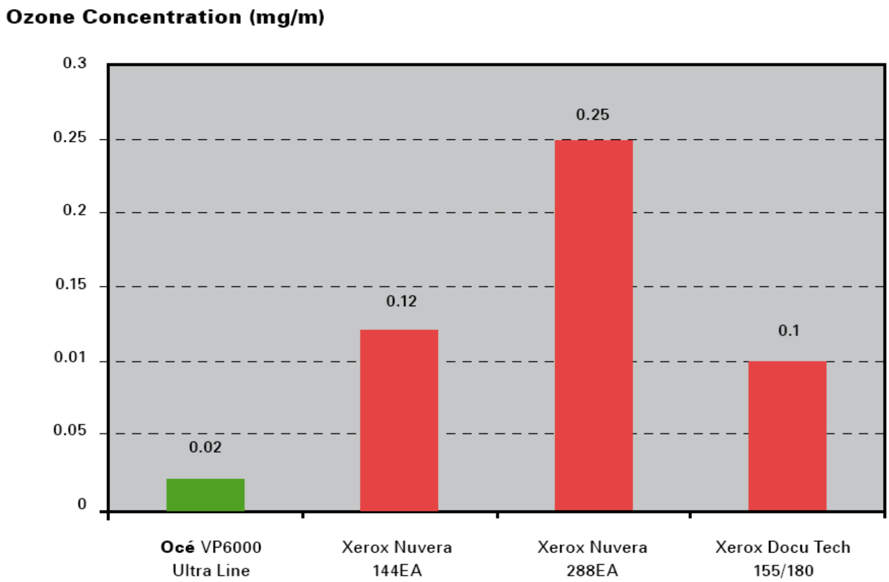


Figure 19. Comparison of ozone concentrations presented in Océ's marketing material (Océ 2009c).

### 5.3.4 Availability of emission data

Xerox publishes Product Safety Data Sheets (PSDS) for all its digital printers on its website. Most of the PSDSs contain information on TVOC (total volatile organic compounds), particle and ozone emissions. A complete data set includes both *concentration* (mg/m$^3$) and *emission* (mg/h) figures of all three emission groups. However, few of the PSDSs include the complete data – the emission data is mostly missing. According to Xerox, the emission rate is the most important factor. It is the function of the machine, while the concentration figure is the function of the room. Concentration figures are measured according to the latest testing standards, e.g. ECMA 328. (ECMA 2009, Xerox 2009b, Kulmala 2010.)

Two sample PSDSs were obtained from Océ. One contained the ozone concentration figure only, and the other included dust and ozone emissions as well as the ozone concentration. Using the obtained emission data, it seems to be very difficult to compare the emissions of digital printing equipment. Companies that are purchasing printing equipment should demand better information from the manufacturers.

The noise data is included in all of the obtained data sheets. According to the PSDSs of Xerox and Océ, the noise levels of digital printing equipment range from 62 to 82 dB when running. Web presses seem to have higher noise output than sheet presses.

### 5.3.5 Greenhouse gas emissions

According to ISO 14064, greenhouse gases (GHGs) are a "gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds [...] GHGs include carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride ($SF_6$)" (ISO 2006). The Guide to PAS 2050, How to assess the carbon footprint of goods and services, defines the term carbon footprint as the amount of greenhouse gas (GHG) emissions caused by a particular activity or entity (BSI 2008b). Annex A of PAS 2050:2008, Specification for the assessment of the life cycle greenhouse gas emissions of goods and services, contains a list of all GHGs (BSI 2008).

Carbon footprinting of products, services and companies has become popular in the wake of the climate change movement. Many different versions of carbon calculation exist in the printing industry, too. An international standard, ISO 14067 – Carbon footprint of products, is under development. In November 2009, the Technical Committee of the International Organization for Standardization (ISO) responsible for graphic standards development (TC 130) decided to form a task force to develop standard methods for carbon calculation and reporting. The European paper and printing industry federations, CEPI and Intergraf, have published carbon footprinting guidelines. (ISO 2010, Dewitz 2009, CEPI 2007, Intergraf 2010.)

A study carried out by HP (Canonico et al. 2009) presented an estimate of the global carbon footprint of printed products in the year 2020. The study was based on various estimates of GHG emissions of print media and projections of the print media volume. It was assumed that paper accounts for 70% of the global warming potential (GWP) of all printed product groups. Emission factors were taken from two sources: the EcoInvent database (Swiss Center for Life Cycle Inventories) and the Paper Calculator of the Environmental Defence Fund (EDF). According to Canonico et al., the EDF data is more inclusive, and gave results that were two to three times higher than EcoInvent. The calculated results using the

EcoInvent data (Figure 20) add up to about 340 MMt $CO_2$e (the figure is not given in the report but estimated from the graph). The six largest product groups account for more than 80% of the total GHG emissions. (Canonico et al. 2009.)

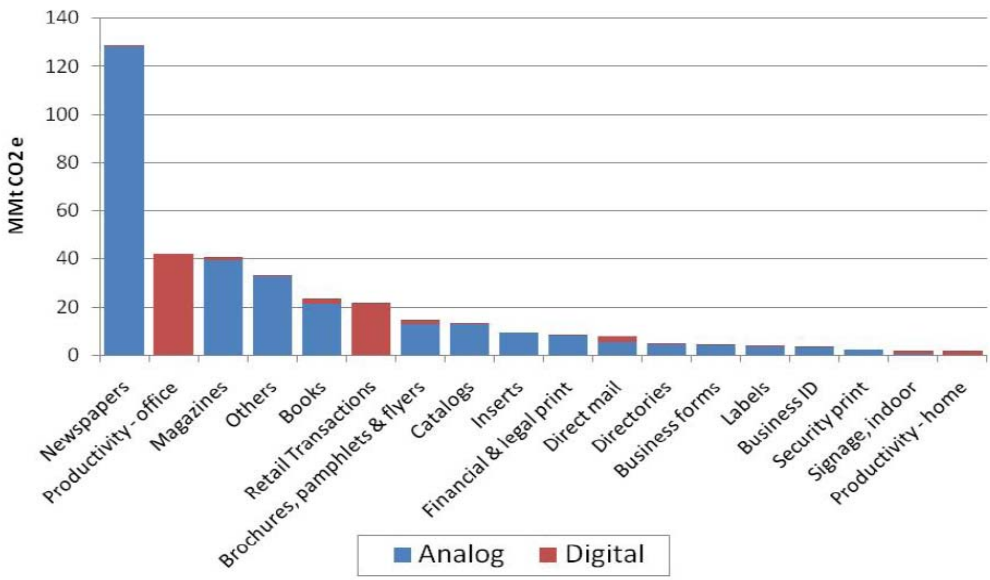


Figure 20. Global Printing Carbon Footprint – Estimate for 2020, modelled using EcoInvent database (Canonico et al. 2009).

According to Canonico et al., digital printing offers considerable abatement potential for GHG emissions. The first improvement comes from targeting the print content (personalising, customising, regionalising), i.e. using fewer pages to communicate. The second advantage is minimising overruns using a print-on-demand approach. The third benefit is material and energy savings from the simple make-ready of digital printing processes. The fourth improvement takes place in the office, where duplexing, user control and digital workflows reduce the paper consumption. By implementing all the steps listed above, the total global carbon footprint of printing would decrease by 114...251 MMt$CO_2$e. The lower figure is based on EcoInvent data and the higher on EDF data. Compared to the total estimated carbon footprint presented in Figure 20, the reduction is in the range of 34% (estimated from the graph and the data). (Canonico et. al. 2009.) The results of Canonico et al. are very interesting. However, it is difficult to evaluate their significance without the background data being available.

In a study by Chalmers University of Technology, carbon footprints were calculated for two digitally printed products and one printed in sheet-fed offset, and the results are presented in Figure 21. Product A, a document (A4, 152 pages + cover, 40 copies) printed on a sheet-fed HP Indigo (liquid toner electrophotography) produced 0.5 kg $CO_2$e per copy or 43 g per printed $m^2$. Product B, a perfect-bound book (A5, 190 pages + covers, 54 copies), printed on a web-fed Indigo, produced 0.3 kg $CO_2$e per copy or 42 g per printed $m^2$. Product C, a booklet (A4, 24 pages, 8 000 copies) printed in sheetfed offset produced 0.2 kg $CO_2$e per copy or 109 g per printed $m^2$. (Bengtsson and Heimersson 2009.)

The Chalmers study contains the first published CF data on digital printing. However, the results of the sample print jobs can only be regarded as indicative. The example cases are printed with LEP (liquid toner electrophotography), which is a marginal method in terms of market volume. Furthermore, the CF results per copy and per $m^2$ are slightly inconsistent. Comparisons are not relevant due to the differences in the print jobs in question. However, the significance of paper production and transport to the carbon footprint is clear: in the examples, paper production caused around 80% and transport about 12% of the carbon footprint.

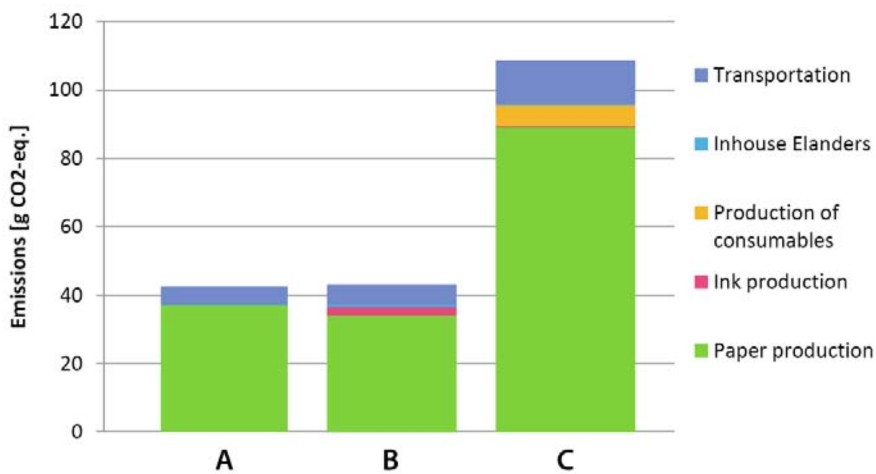


Figure 21. Carbon footprints of two digitally printed products (A, B) and one sheetfed offset printed product (C) in g $CO_2$e per one $m^2$ of printed products. A: 152-page A4 booklet on 100 g/$m^2$ G-print, B: 190-page A5 perfect-bound book on 80 g/$m^2$ Munkern Premium, C: 24-page booklet 0n 170 g/$m^2$ MultiArt Silk (LumiSilk) (Bengtsson and Heimersson 2009, modified).

If the carbon footprints are expressed in kg $CO_2$e/tonne of products, a more popular way of presenting results, the corresponding figures are as follows: A – 860 kg $CO_2$e/tonne, B – 1050 kg $CO_2$e/tonne, C – 1282 kg $CO_2$e/tonne. The results can be compared to a Finnish study where the carbon footprint of a typical publication printed on dry toner EP was in the range of 1010–1500 kg $CO_2$e/tonne (Nors et al. 2009b).

## 5.4 Waste output

In the comparative study of Kadam et al. (2005), a digital press was found to generate much less paper and chemical waste than a sheet-fed offset press: paper waste was 5–20% for the digital and 35–75% for offset, and the chemical waste 0.2–1.1 g per impression for digital and 3.2–7.3 g per impression for offset. However, the study only consisted of two small print jobs (500 and 3000 copies), and the result cannot be generalised. In a Finnish study, a digital printing plant generated 174 kg of waste per one tonne of digitally printed products, out of which 136 kg was paper waste (Peltonen 2008).

Due to the smaller number of materials, digital printing produces less waste fractions, especially chemical-related, than traditional printing methods. The equipment supplier usually takes care of the collection, handling and recycling of the consumables. Detailed information on how the consumables are processed and recycled is not available (Peltonen 2008). Electrophotographic presses have many replacable consumables (ink cartridges, OPC drums and belts, charging coronas, etc.). In this respect, inkjet is a better method (Romano 2009). According to a Finnish study, EP generated significantly less hazardous, metal and landfill waste than sheet-fed offset (Viluksela et al. 2008).

## 5.5 Recyclability of digitally printed products

Increasing materials recovery and recycling has become a priority in the EU. The target for the paper recovery rate at the European level for 2010 is 66% (ERPC 2008). As the volume of digitally printed products increases, recyclability becomes increasingly important. At present, the following printing technologies pose deinking problems with the flotation method (Tribute 2009, ERPC 2009, Cox 2009b):

- water-based flexographic inks
- UV-curable offset, inkjet, etc. inks, coatings and varnishes
- liquid electrophotography toners
- aqueous inkjet inks
- phase change (hotmelt) inks.

The results from the evaluation of deinkability carried out by the ERPC (European Recovered Paper Council) are presented in Figure 22. Deinkability has been measured according to the INDEGE 11 method of the International Association of the Deinking Industry (INGEDE 2007), which is based on flotation deinking.

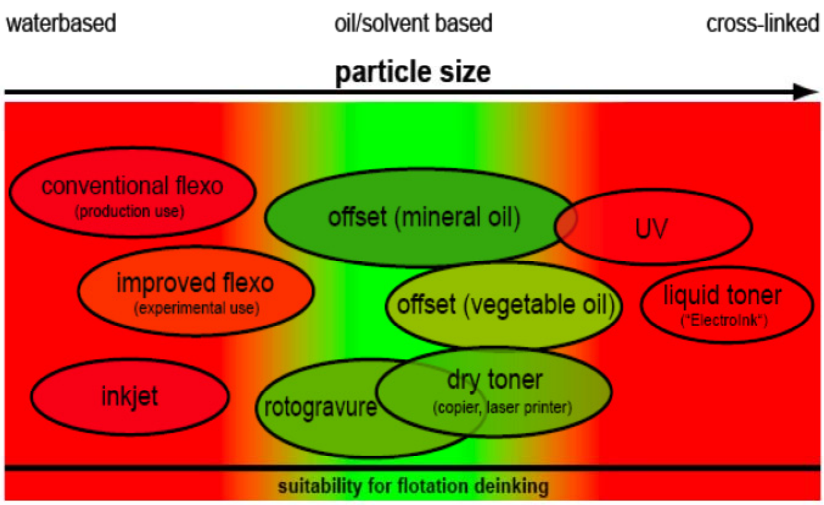


Figure 22. Deinkability of different printing techniques (ERPC 2009).

The size of dry toner particles after pulping is 40–400 μm, and the main deinkability problem is specks (visible contaminants). The deinkability of dry toner electrophotographic prints depends on toner formulation and fusing technology: polyester resin seems to be better than the older styrene acrylate copolymer, and indirect fusing, soft roller nip fusing and IR fusing show good deinkability (Elegir & Bussini 2008). Ultrasound treatment has produced good results in breaking the large toner particles into smaller ones and improving deinkability (Saari 2008).

Water-based inkjet inks lead to poor deinkability when using the INGEDE 11 test. Water-based dye inks can be bleached with reductive bleaching to improve the result, while pigment inks are not bleachable (Hanecker & Strauss 2008). HP's new approaches to inkjet ink formulations have shown to improve deinkability using flotation; e.g., the use of coagulants or lower pH eliminates water-solubility, and the ColorLok ink design is claimed to make the ink stay on the paper surface, leading to better deinkability (Lane & Macias 2008).

Other deinking methods have also shown promising results. According to the latest research data from HP, good deinkability can be achieved with the appropriate deinking chemistry: various ElectroInk and inkjet ink–media combinations scored well within the targets of the deinkability score card (ERPC 2008) of the European Recovered Paper Council (Ng et al. 2009). Nyman (2009) found that enzymatic deinking produces good results with inkjet prints on chemical pulp-based paper.

The digital printing equipment manufacturers and INGEDE have different opinions on the deinkability of digital prints. During Drupa 2008, HP claimed that the latest version of ElectroInk 4.0 is as deinkable as dry toners, after which INGEDE issued a press release stating that the claims were incorrect (INGEDE 2008). Digital printing equipment manufacturers also question the relevance of the single-step laboratory test of the INGEDE 11 method, claiming that it does not reflect the industrial conditions of two-loop deinking (Cox 2009b).

Another area of disagreement between deinkers and digital printing equipment manufacturers is the share of poorly deinkable digital prints in the total volume of recovered paper. According to INGEDE, a 10% share of present inkjet prints could make the whole batch undeinkable, and even 5% could create problems. Digital printing equipment manufacturers think that there is no problem up to a share of 10%. Now, the share of total digital print in the total deinked paper is around 5%, and the share of inkjet is minimal. It will take time before the volumes are significant, and by then, the deinking problems will have been solved. (INGEDE 2009, Cox 2009b, Tribute 2009.)

INGEDE and ERPC would like to see all inks modified so that the existing flotation deinking method could be used. The method has been optimised for hydrophobic oil-based inks, and does not work well with water-based inks. European deinkers use closed loop water systems, which are particularly sensitive to dye-based inks. Inkjet printing equipment and ink manufacturers point out that other methods, e.g. bleaching, could be used. This approach is also mentioned by Carré and Magnin (2004), who report that inkjet printed fibres can be discoloured with peroxide of hydrosulphite bleaching. A promising development is also the bonding agent of the HP Inkjet Web Press, which is said to produce ink particles of a size suitable for flotation deinking (Cox 2009b, Tribute 2009). In contrast to flotation deinking, the washing method is more effective in removing small ink particles, and thus provides better results with inkjet and flexo prints. Washing is more widely used in USA than in Europe (Nyman 2009).

HP, Infoprint, Kodak and Océ have established their own organisation, the Digital Print Deinking Alliance (DPDA), to carry out research on printing, paper and chemicals in order to develop cost-effective and practical deinking and recycling practices and to enhance the sustainability of the industry (Tribute 2009, Cox 2009b, Lane & Macias 2008).

## 5.6 Environmental challenges of digital printing

The analysed literature gives only a fragmentary picture of the environmental performance of digital printing, and there is not much published research to support the claims of the environmental advantages offered by digital printing methods.

However, based on the available data, some general and preliminary conclusions can be made. The advantages of digital printing, compared to mechanical printing methods, are:

- *Lower waste output.* However, the impact of consumables waste, usually taken care of by equipment suppliers, is not known.
- *Lower use of water and chemicals.* The consumption of chemicals (other than inks/toners) is minimal, and water is used mainly for air humidification.
- *Lower paper waste.* However, in some cases the paper waste has been found to be on a par with the waste generated by mechanical printing methods.

The areas where the environmental performance of digital printing should be improved are:

- *Reducing the energy consumption of the printing process.* Toner fusing in EP and ink drying in IJ are the key development areas.
- *Reducing the ink consumption levels.* This area requires more research, e.g. comparisons between inks and technologies, the effect of paper properties, the techniques of pre-coating, bonding agents, etc.

- *Solving the deinkability problems of liquid ink electrophotography and inkjet.* Development of the printing processes and deinking technologies are underway to solve this problem.

These three issues seem to be connected with each other. Reducing the need for ink would lead to lower energy consumption in ink drying/toner fusing. Suitable paper properties and the use of a bonding agent or coating could contribute to a reduced ink need, and also improve deinkability. All three issues are being addressed in ongoing R&D activities, and some improvements have already been reported, e.g. better energy efficiency with the chemical EP toners, and reduced IJ ink need with UV-curable inks. These developments are supported by the potential financial savings from improved energy and materials efficiency.

In the area of emissions to air (VOCs, ozone, particles), more research needs to be done to determine the environmental and health implications of digital printing. The emissions of different toners and inks and fixing/drying/curing systems should be studied to assess their environmental and health effects in production circumstances.

Based on the rather limited data available, the current environmental status of digital printing can be summarised in the form of a SWOT analysis (Table 14). The predicted market growth for digital printing applications will probably put additional pressure on equipment and ink/toner manufacturers to reduce energy and materials consumption and costs – this will lead to environmental improvements as well.

Public opinion that printed products are environmentally harmful may become stronger in the future and affect digital printing as well. Electronic invoicing and other digital media solutions may in the future become an environmentally preferable alternative to digitally printed products.

All in all, the environmental performance of digital printing will most likely improve in the future, both in absolute terms and in relation to mechanical printing methods. This trend will support the growth of digital printing markets and applications.

Table 14. Environmental SWOT analysis of digital printing.

| **Strengths** | **Weaknesses** |
|---|---|
| ▪ Good materials efficiency (paper, chemicals, water)<br>▪ Technology enables efficient workflows (variable data, print on demand, distributed printing, targeting)<br>▪ Production efficiency (no platemaking, simple make-ready) | ▪ Relatively high energy consumption<br>▪ Relatively high ink consumption<br>▪ Limited environmental efficiency in high volumes<br>▪ Deinkability (inkjet, liquid toner EP) |
| **Opportunities** | **Threats** |
| ▪ Ink and process development to solve deinking challenges<br>▪ New ink/toner technologies improve materials and energy efficiency (chemically manufactured toners, UV and hotmelt inkjet inks, bonding agent)<br>▪ Turning workflow advantages into business | ▪ Advances in competing electronic media (e.g. electronic invoicing vs. digitally printed invoices)<br>▪ Weaknesses are not improved sufficiently<br>▪ Strengths cannot be turned into business |

**Summary: Environmental performance of digital printing**

- Published research on the environmental performance of digital printing is very limited. Some data is available from the printing equipment manufacturers, but part of it is marketing-oriented.
- The main environmental challenges of digital printing seem to be high energy consumption, high ink consumption and the deinkability of some digital prints. Recent development has led to improvements in all of these areas.
- Digital masterless printing offers a number of workflow-based advantages that may help to reduce environmental impacts. For example, print on demand eliminates excessive stocks and improves materials efficiency, distributed printing reduces physical transport needs, and targeting, personalisation and versioning improve the efficiency of communication.
- More research is needed to improve and expand environmental knowledge in the various areas of digital printing.

# 6. Conclusions

*"Before we 'stop the presses', and acknowledge the extinction of newspapers, as many pundits suggest, let's take another look at the future of printing. In my view, within four years, newspaper production will become radically different from today's process. We'll enter an era of small print runs, highly decentralized printing units and above all, customized papers."*

*Frédéric Filloux*[5]

There is little published research on the environmental performance of digital printing. The analysed literature partly supports the claims that digital printing methods offer environmental advantages over mechanical ones. More research is needed to clarify several open issues.

The three main environmental challenges of digital printing, compared to mechanical printing methods, are

- improving the energy efficiency of the printing process
- reducing the ink consumption
- solving the deinkability problems, especially of liquid ink electrophot graphy and inkjet.

The advantages of digital printing, compared to mechanical printing methods, are

- lower waste output
- lower use of water and chemicals
- lower paper waste.

[5] The Future of Print Could be… Digital Presses. February 22, 2009: http://www.mondaynote.com/2009/02/22/the-future-of-print-could-be-digital-presses/.

## 6.1 Environmental characteristics of digital printing methods

The major difference of digital printing compared to mechanical methods is the masterless printing process. The elimination of masters (printing plates, cylinders, etc.) and the master preparation process (platemaking, etc.) brings direct and indirect environmental advantages. The major digital printing methods – electrophotography and inkjet – have their own environmental characteristics. These are summarised below.

### 6.1.1 Process and workflow advantages

Digital printing provides good opportunities to address and improve some of the structural disadvantages of mechanical printing methods and traditional production processes. On-demand production can reduce or eliminate overprints of newspapers, magazines and books. Distributed printing can reduce physical distribution needs. Personalisation and versioning can reduce unwanted printing and waste. Digital production techniques eliminate platemaking-related processes, materials and wastes and speed up make-ready and production start.

### 6.1.2 Energy consumption

Electricity consumption of production digital printers is higher than that of the mechanical printing methods, but the difference is shrinking due to recent technical developments in toner/ink manufacture and processing. Energy consumption of toner fusing in dry toner methods is considerably reduced with the use of new chemical toners that use lower-melting resins as binders. High-volume inkjet systems require ink drying or curing, e.g. hot air or UV radiation.

The available data from equipment manufacturers seems to indicate that inkjet has slightly better energy efficiency than dry toner and especially liquid toner electrophotography. However, the energy consumption of the printing house building as well as the manufacture of inks/toners and other supplies must also be taken into account.

### 6.1.3 Materials consumption

There is little information available on the materials consumption of digital printing. Since the ink and consumables supply is most often outsourced to the equipment supplier, printing companies do not record or monitor the consumption figures. The ink film thicknesses of dry and liquid toner electrophotography are 5–10 μm and 1–3 μm, respectively, while that of offset is 0.5–1.5 μm (Kipphan 2001). In the EP-SFO comparison, it was also noted that ink consumption is higher in electrophotography (Viluksela et al. 2008). The significance of ink consumption in relation to the total environmental impacts has not been established.

Chemical toners are reported to decrease toner consumption compared to mechanically manufactured toners (Fuji Xerox 2010). In wide-format inkjet, the move from solvent-based inks to UV inks is reported to decrease ink consumption from 12–14 $ml/m^2$ to 8–10 $ml/m^2$ (Agfa 2009). Typical offset ink need is about 1–2 $g/m^2$ depending on the paper properties. The above findings indicate that the ink demand of digital methods is higher than that of offset, but new techniques are improving the performance of digital printing. However, comparisons are difficult due to the different properties of inks.

Digital methods are generally considered to consume less paper than offset, thanks to the simple make-ready and ink transfer. However, there is no information available on paper waste due to printer calibration or technology-related runnability and printability problems. According to anecdotal evidence, the greatest cause of paper waste in a digital printing facility is workflow-related problems (wrong imposition, incomplete adjustments, insufficient checks of proofs).

Consumption of cleaning chemicals and water is much lower in digital printing than in the mechanical methods.

### 6.1.4 Emissions

The main emissions to air of digital print production consist of

- the VOC, particle and ozone emissions from the printing process
- the indirect $CO_2$ emissions of energy production
- the $CO_2$ and particle emissions of transport.

The major VOC emission sources seem to be solvent-based inkjet inks, liquid electrophotographic toners and dry toners used in connection with flash fusing. Some office electrophotographic printers create particle emissions. Ozone emissions from electrophotographic devices are captured with ozone filters. There is very little data on emission levels in production environments; further research is required to establish whether the air emission levels present health or environmental concerns.

### 6.1.5 Waste

Thanks to the smaller number of materials, digital printing produces less waste than traditional printing methods. The process is simple, reducing the amount of make-ready waste. However, especially in electrophotography, there are many replacable consumables (ink cartridges, OPC drums and belts, charging coronas, etc.). The equipment supplier usually takes care of the collection, handling and recycling of the consumables. Detailed information on how the consumables are processed and recycled is not available.

### 6.1.6 Recyclability

Tribute (2009) mentions the poor deinkability of inkjet and liquid toner electrophotography as the biggest environmental challenge of digital printing. Although dye inks, water-based inkjet inks and the ElectroInk of Indigo cause problems in traditional flotation deinking, which is designed for oil-based offset and rotogravure inks, there are reports of improved deinkability using neutral conditions, enzymatic deinking and new ink formulations. In addition, the share of inkjet-printed products in the waste stream is at the moment very small, and it will take years before this becomes a real problem, even with the predicted increase in inkjet applications. Digital printing ink manufacturers and the deinking industry have started to collaborate in order to find solutions to the challenges; for example, INGEDE organised an “European round table deinking of digital prints” in April 2010 as part of the PTS deinking symposium (INGEDE 2010).

## 6.2 Future development of digital printing

It is encouraging that environmental concerns are taken into account in different areas of the digital printing sector. The most prominent signals come from the digital printing equipment manufacturers: most if not all major equipment suppliers actively communicate their environmental principles and management activities, corporate social responsibility achievements and their new technology advances. However, environmental claims are seldom backed up by scientific proofs.

An excellent example of considering environmental impacts when designing new product applications is the research done at Tampere University of Technology. Kunnari et al. (2009) point out that the choices made in the early stages of design determine over 80% of the product's environmental load, and that developing new technology provides an opportunity to take environmental considerations into account right from the beginning. The LCA analysis of inkjet-printed electronics shows both advantages and disadvantages compared to the existing method of lithographic mask printing and etching.

### 6.2.1 Anticipated development issues

Much of the technical development in the future will probably take place in the area of new, functional and non-graphic products. Inkjet seems to be the most suitable method for many functional products such as printed electronics and biomedical applications. Inks combining the right functionality and jettability will be a focus of research and development. Environmental issues should be taken into account when developing new products and applications.

In the development of graphic applications, ink composition and drying technologies will also be on the agenda. Future inks should be based on renewable, biodegradable components, and the energy consumption and emissions of drying processes should be as low as possible. Alternatives to replace solvent inks include eco-solvent inks (containing less volatile or harmful substances), water-based and latex inks and UV-curable inks. There are many developments underway at the moment; for example, the new HP T300 web inkjet press uses water-based inks with hot air dryers (HP 2009), while Agfa employs UV inks in its Dotrix and wide-format applications (Agfa 2009).

Regarding paper for digital printing, there are two different trends. One is the improvement of the capability of digital printing techniques to print on existing paper grades like newsprint, uncoated woodfree and coated offset papers. This trend is dominant in applications where digital and mechanical printing are used side by side, e.g. newspapers and books. The potential techniques enabling the use of offset papers include special ink formulations and special coatings (primers) to eliminate problems with bleeding, show-through and smearing. In applications where both inkjet and electrophotography are used (e.g. transactional, home and office), the same paper grades should be suitable for both methods.

The opposite trend is the development of paper properties and grades to optimise the quality and performance of digital printing applications. This trend is encouraged and adopted by equipment manufacturers, e.g. HP. These properties and grades are required for special applications like photo printing, security printing and packaging.

In many mass product groups like transactional, transpromo, newspaper and book printing, costs are an important issue, and paper is a significant cost item. Many development activities will be addressing the economy of digital printing. Inkjet is considered to have better potential for reducing costs.

### 6.2.2 Sustainable and green products

Environmental, health, safety and sustainability issues are becoming increasingly important due to regulations like REACH and initiatives like CSR (Corporate Social Responsibility). Formulations of inks and other print-related chemicals will be developed to decrease the amount of harmful components and VOC emissions, and to replace inputs from non-renewable sources with renewable and biodegradable ones. Mineral oil-based products have already to a considerable extent been substituted by vegetable-based ones. The potential new materials include lactic acid from wood hydrolysates and corn starch, polyhydroxyalkanoates, biodegradable pigments from plants or marine algae and biodegradable inks based on water or biomass-derived green solvents (Smyth 2008). Digital printing systems use much less chemicals than mechanical ones, but the new developments could also benefit the digital methods.

### 6.2.3 Sustainability by equipment and system design

To promote green print production, digital printing and other production equipment could incorporate sustainability features: integrated energy meters to monitor and report on the electricity consumption, printer logs to collect information on materials consumption and waste output, etc. The equipment could also teach the operators to save resources. For example, the operators could be informed when it is better to switch off the printer rather than leave it in standby mode. The equipment could also help in the collection of indicator data at different levels (job, day, operator, material, etc.). This type of green technology would yield the greatest benefits to small digital printing companies with limited resources.

Another initiative worth developing further is the proposal of Sobotka (2009) for the use of a sustainability rating scale for digital printing systems (see section 4.2.3. A common evaluation framework with standardised test procedures and rating scales would ensure consistency and comparability of results.

## 6.3 Recommendations for research

The indicative findings of the study, based on the rather limited available data, are summarised in Figure 23. Many of the findings are based on information from equipment and materials suppliers or the trade press, and should be verified through independent scientific research. There is a clear need for additional research on the environmental issues of digital printing, both at the process and product level and at the printing company level. A summary of the most important research topics is presented below:

- Energy and materials consumption of different digital printing techniques
    - different toner compositions of EP
    - different solvents of liquid EP and IJ inks
    - different ink drying and toner fixing methods
    - share of energy consumption accounted for by the different printing system components, e.g. imaging, paper transport, ink drying, data communication
    - the role of paper and other substrates in energy consumption and ink/toner need
    - the effect of bonding agents on energy and materials consumption.
- Energy consumption of equipment in all production stages of digital printing
    - computers, servers, data communication
    - RIPs, printing equipment
    - inline and offline finishing equipment.
- Share of building services and facilities in energy consumption
    - the requirements of digital printing operations for space, ventilation, air humidity and temperature
    - possibilities of recovering heat output energy from digital presses.
- Environmental impacts of the manufacture, disassembly and recycling of digital printing and production equipment and supplies
    - computing equipment, printers, auxiliary equipment
    - consumables like toner cartridges, OPC belts, corona devices, etc.

- Air emissions from industrial scale digital printers
  - ozone, particulate matter, VOCs
  - effect of toner/ink composition and fusing/drying techniques.
- Waste output from digital printing
  - waste types and waste processing, e.g. toner and developer waste
  - role of materials, production technology and workflow problems in the creation of waste (paper, other materials).
- The role of paper and other substrates in the environmental performance of digital printing
  - paper characteristics vs. energy consumption, ink consumption
  - effect of bonding agents on paper choice and performance.
- Deinking of inkjet and liquid toner electrophotographic prints
  - effect of different techniques (e.g. flotation, screening, bleaching, enzymatic process)
  - effect of ink/toner formulations, paper properties, coatings, etc.
- Application of environmental management accounting and environmental performance indicators in digital printing processes and at companies
- Developing an environmental scorecard for digital printing along the lines of the proposal of Sobotka (2009) and the checklist for the design for environment (DfE) of printed products (Enroth 2001).

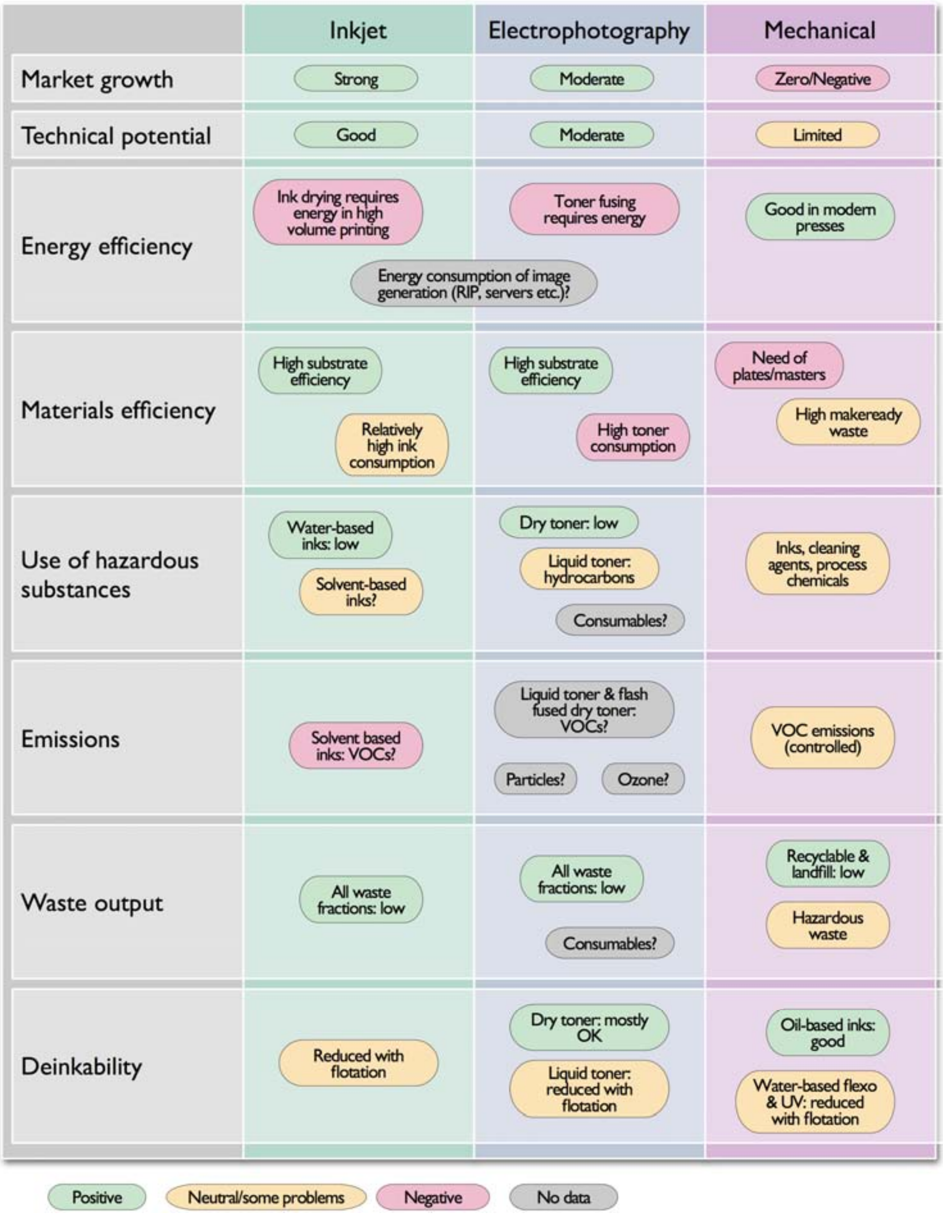


Figure 23. Indicative summary of study findings: Environmental aspects of digital versus mechanical printing.

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# Appendix A: Operational performance indicators proposed in ISO 14031

**Materials**

- quantity of materials used per unit of product
- quantity of processed, recycled or reused materials used
- quantity of packaging materials discarded or reused per unit of product
- quantity of auxiliary materials recycled or reused
- quantity of raw materials reused in the production process
- quantity of water per unit of product
- quantity of water reused
- quantity of hazardous materials used in the production process.

**Energy**

- quantity of energy used per year or per unit of product
- quantity of energy used per service or customer
- quantity of each type of energy used
- quantity of energy generated with by-products or process streams
- quantity of energy units saved due to energy conservation programmes.

**Services supporting the organization's operations**

- amount of hazardous materials used by contracted service providers
- amount of cleaning agents used by contracted service providers
- amount of recyclable and reusable materials used by contracted service providers
- amount or type of wastes generated by contracted service providers.

**Physical facilities and equipment**

- number of pieces of equipment with parts designed for easy disassembly, recycling and reuse

**Products**

- number of products introduced in the market with reduced hazardous properties
- number of products which can be reused or recycled
- percentage of a product's content that can be reused or recycled
- rate of defective products
- number of units of by-products generated per unit of product
- number of units of energy consumed during use of product
- duration of product use
- number of products with instructions regarding environmentally safe use and disposal.

**Services provided by the organization**

- amount of cleaning agent used per square metre (for a cleaning services organization)
- amount of fuel consumption (for an organization whose service is transportation)
- quantity of licenses sold for improved processes (for a technology licensing organization)
- number of environmentally-related credit risk incidents or insolvencies (for a financial services organization)
- quantity of materials used during after-sales servicing of products.

**Wastes**

- quantity of waste per year or per unit of product
- quantity of hazardous, recyclable or reusable waste produced per year
- total waste for disposal
- quantity of waste stored on site
- quantity of waste controlled by permits
- quantity of waste converted to reusable material per year

- number of hours per year a specific piece of equipment is in operation
- number of emergency events (e.g. explosions) or nonroutine operations (e.g. shut-downs) per year
- total land area used for production purposes
- land area used to produce a unit of energy
- average fuel consumption of vehicle fleet
- number of vehicles in fleet with pollution-abatement technology
- number of hours of preventive maintenance to equipment per year.

**Supply and delivery**

- average fuel consumption of vehicle fleet
- number of freight deliveries by mode of transportation per day
- number of vehicles in fleet with pollution-abatement technology
- number of business trips saved through other means of communication
- number of business trips by mode of transportation.

- quantity of hazardous waste eliminated due to material substitution.

**Emissions**

- quantity of specific emissions per year
- quantity of specific emissions per unit of product
- quantity of waste energy released to air
- quantity of air emissions having ozone-depletion potential
- quantity of air emissions having global climate-change potential.

**Effluents**

- quantity of specific material discharged per year
- quantity of specific material discharged to water per unit of product
- quantity of waste energy released to water
- quantity of material sent to landfill per unit of product
- quantity of effluent per service or customer.
- noise measured at a certain location
- quantity of radiation released
- amount of heat, vibration or light emitted.

Source: ISO 1999, paragraph A4.3.2.

# Appendix B: The environmental indicators of the sustainability reporting guidelines (G3) of the GRI (Global Reporting Initiative)

| Aspect | C/A | Code | Indicator |
|---|---|---|---|
| Materials | C | EN1 | Materials used by weight or volume. |
| | C | EN2 | Percentage of materials used that are recycled input materials. |
| | C | EN3 | Direct energy consumption by primary energy source. |
| | C | EN4 | Indirect energy consumption by primary source. |
| | A | EN5 | Energy saved due to conservation and efficiency improvements. |
| | A | EN6 | Initiatives to provide energy-efficient or renewable energy based products and services, and reductions in energy requirements as a result of these initiatives. |
| | A | EN7 | Initiatives to reduce indirect energy consumption and reductions achieved. |
| Water | C | EN8 | Total water withdrawal by source. |
| | A | EN9 | Water sources significantly affected by withdrawal of water. |
| | A | EN10 | Percentage and total volume of water recycled and reused. |
| Biodiversity | C | EN11 | Location and size of land owned, leased, managed in, or adjacent to, protected areas and areas of high biodiversity value outside protected areas. |
| | C | EN12 | Description of significant impacts of activities, products, and services on biodiversity in protected areas and areas of high biodiversity value outside protected areas. |
| | A | EN13 | Habitats protected or restored. |
| | A | EN14 | Strategies, current actions, and future plans for managing impacts on biodiversity. |
| | A | EN15 | Number of IUCN Red List species and national conservation list species with habitats in areas affected by operations, by level of extinction risk. |

| Aspect | C/A | Code | Indicator |
|---|---|---|---|
| Emissions, Effluents, and Waste | C | EN16 | Total direct and indirect greenhouse gas emissions by weight. |
| | C | EN17 | Other relevant indirect greenhouse gas emissions by weight. |
| | A | EN18 | Initiatives to reduce greenhouse gas emissions and reductions achieved. |
| | C | EN19 | Emissions of ozone-depleting substances by weight. |
| | C | EN20 | NO, SO, and other significant air emissions by type and weight. |
| | C | EN21 | Total water discharge by quality and destination. |
| | C | EN22 | Total weight of waste by type and disposal method. |
| | C | EN23 | Total number and volume of significant spills. |
| | A | EN24 | Weight of transported, imported, exported, or treated waste deemed hazardous under the terms of the Basel Convention Annex I, II, III, and VIII, and percentage of transported waste shipped internationally. |
| | A | EN25 | Identity, size, protected status, and biodiversity value of water bodies and related habitats significantly affected by the reporting organization's discharges of water and runoff. |
| Products and Services | C | EN26 | Initiatives to mitigate environmental impacts of products and services, and extent of impact mitigation. |
| | C | EN27 | Percentage of products sold and their packaging materials that are reclaimed by category. |
| Compliance | C | EN28 | Monetary value of significant fines and total number of non-monetary sanctions for noncompliance with environmental laws and regulations. |
| Transport | A | EN29 | Significant environmental impacts of transporting products and other goods and materials used for the organization's operations, and transporting members of the workforce. |
| Overall | A | EN30 | Total environmental protection expenditures and investments by type. |

C/A = Core / Additional indicator, source: GRI 2006.

# Appendix C: The generic indicators of environmental management accounting for an environmental performance indicator system

| | Absolute quantity | Relative quantity Eco-intensity |
|---|---|---|
| Production output (PO) | kg, litre | |
| Raw material input | kg | kg/PO |
| Auxiliary material | kg | kg/PO |
| Packaging | kg | kg/PO |
| Operating material | kg | kg/PO |
| Energy | kWh | kWh/PO |
| Water | $m^3$, litre | $m^3$/PO |
| Waste | kg | kg/PO |
| Wastewater | $m^3$, litre | $m^3$/POe |
| Specific pollution loads | kg | kg/PO |
| Air emissions | $m^3$ | $m^3$/PO |
| Air emissions loads | kg | kg/PO |
| Other denominators | | |
| Number of employees | number | |
| Turnover | money value | |
| EBIT (Earnings before interest and tax) | money value | |
| Production hours | time | |
| Workdays | days | |
| Building area | $m^2$ | |
| Management performance indicators | | |
| Number of achieved objectives and targets | | |
| Number of non-compliances or degree of compliance with regulation | | |
| Number of sites with environmental reports | | |
| Number of sites with certified EMS (Environmental management system) | | |
| Percentage turnover from EMS certified sites | | |
| Percentage turnover of green products (e.g. organically grown vs. conventional crops) | | |

Source: UN 2001.

# Appendix D: Summaries of environmental studies of printing

## Eco-balance of printed communication (Finland 1994)

| |
|---|
| **1.1 Objective**<br>To develop an eco-balance model for printed communication utilising both qualitative and quantitative data, to apply the model to the evaluation of environmental impacts, and to highlight the key areas for technical development leading to reduced environmental loads. |
| **1.2 Scope**<br>Seven product groups of printed matter: newspapers, magazines, books, forms, commercial printed products, package printing, others. Data collected from geographically and technically representative sample of printing companies, covering almost 25% of the printing industry turnover. Reports: 28 + 25 pages. |
| **1.3 Carried out by**<br>VTT (Eco-balance model implemented with KCL-ECO application) |
| **1.4 Geographical coverage**<br>Finland |
| **1.5 Time**<br>1993–1994 (data mainly from the year 1992) |
| **2 Indicators used**<br>Functional unit: one tonne of printed products<br>Indicators expressed as physical units (e.g. kg, MWh, l); about 50 different material categories, over 30 waste categories, emissions to water and air and energy consumption. |
| **3 Selected results**<br>Totals for the Finnish printing industry:<br>- Energy consumption: 1.3 MWh/t<br>- Material consumption: 1.3 t/t<br>- Recyclable waste: 184 kg/t<br>- Hazardous waste: 8.7 kg/t<br>- Landfill waste: 11.3 kg/t<br>- $CO_2$ emissions: 18.2 kg/tonne<br>- VOC emissions: 9.3 kg/tonne |
| **4 Comments**<br>The study provides an excellent framework for analysis and extensive baseline data for the printed matter product groups. However, the product-based approach has its limitations. For example, magazines were printed by both heatset offset and rotogravure, and it is not possible to obtain separate results for these two different printing methods. Number of reported indicators and results exceeds the other studies, and the sample for data collection was large. |
| **5 References**<br>Pösö et al. 1993, Juntunen et al. 1994 |

# Environmental profiling (Sweden 1996)

| |
|---|
| **1.1 Objective**<br>To identify the most environmentally harmful stages of print production, to acquire knowledge of the environmental impacts of the graphic sector and to propose improvement areas based on life cycle analyses. |
| **1.2 Scope**<br>Five different printed products: local telephone directory (CSWO), advertisement brochure (HSWO), large business directory (CSWO), printed envelope (flexo) and monthly magazine (HSWO). Report: 117 pages |
| **1.3 Carried out by**<br>Institute for Media Technology, Sweden (institutional research) |
| **1.4 Geographical coverage**<br>Specified on a case-by-case basis for each of the printing houses, Sweden |
| **1.5 Time**<br>1996 (data collection in 1993-95) |
| **2 Indicators used**<br>Functional unit: 1000 copies of the product in question at printing house gate. Physical ecodata on material, energy, product and process related waste and VOCs. LCA methods: EPS, eco-scarcity and impact category. Results shown as graphs without numeric data. |
| **3 Selected results**<br>The share of paper manufacture was approx. 80% of the total environmental impact. |
| **4 Comments**<br>The main value of the study was to develop an LCA application for printing. A separate analysis was done for the pre-press, papermaking and printing stages. The results are indicative, but no longer very valuable, because the effects of transport, consumption and disposal were not included in the study, but were only estimated. Number of reported metrics was not as extensive as in the Finnish study (Juntunen et al. 1994). |
| **5 References**<br>Dalhielm and Axelsson 1996 |

# LCA of a daily newspaper and a weekly magazine (Germany/Sweden/Canada 1998)

**1.1 Objective**

The objectives included (among others) the evaluation of the environmental impacts of newspaper and magazine production.

**1.2 Scope**

Forest use, manufacturing of pulp, newsprint, SC and LWC papers, newspaper printing (coldset offset) and magazine printing (rotogravure). Full-scale LCA with method development. Reports: 41 + 114 + 72 pages.

**1.3 Carried out by**

INFRAS (Switzerland) – Scientific consultants

**1.4 Geographical coverage**

Pulp and paper manufacture: Canada, Sweden, Germany; printing: Germany

**1.5 Time**

1998 (data collection 1996–97)

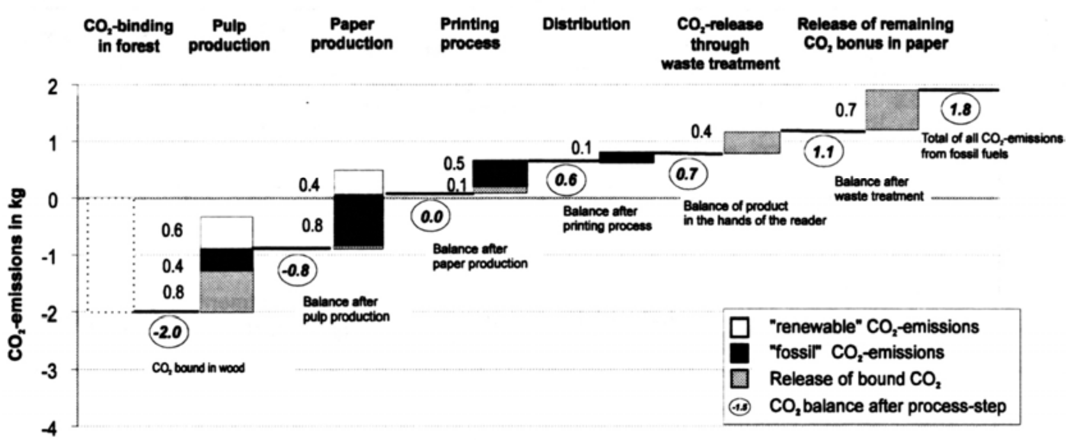
**2 Indicators used**

Environmental impacts were assessed using Eco-indicator 95 and CML methods. The results were expressed as mIPs (milli-indicator points). In some results, the functional unit of 1 kg of printed products was used.

**3 Selected results**

- environmental impacts of magazines are higher than those of newspapers
- energy production has a strong effect on environmental loads
- the use of DIP (deinked pulp) reduces environmental loads
- an interesting way of presenting $CO_2$ emission results, see figure below.

**$CO_2$-Balance for 1 kg of magazines**




**4 Comments**

The study provides interesting background information on the environmental loads of pulping, papermaking and printing. However, the study presents very little useful information for benchmarking or digital printing.

**5 References**

Springer 1998a and b

# Electronic print communication – environmental impacts and the need for environmental management (Finland 1998)

**1.1 Objective**

To evaluate environmental aspects of digital printing.

**1.2 Scope**

Electronic publishing and printing chain. Quantitative part consists of one case, electrophotography, centralised and decentralised printing. Report: 59 pages.

**1.3 Carried out by**

VTT, Finland (Preliminary research)

**1.4 Geographical coverage**

Finland

**1.5 Time**

1997–98

**2 Indicators used**

Functional unit: amount of bytes transferred in the value chain. Environmental impacts: Total, $CO_2$, $NO_x$, $SO_2$, COD.

**3 Selected results**

Consumption for duplex monocolour A4 sheet:
- electricity 0.7...1.2 W
- toner 40...150 mg
- silicone oil 0.002...0.0025 ml

Based on the data from equipment manufacturers, digital printing consumes more energy than traditional methods (platemaking is excluded), and web digital consumes less electricity than sheet-fed.

*Indicative electricity consumption figures (Wh) for duplex A4 printed sheet, based on data from equipment manufacturers*

| Printing method | Traditional | Digital |
|---|---|---|
| **B&W (sheet-fed)** | 0.2...0.4 | 0.6...0.8 |
| **4-colour (sheet/web)** | 0.5...1 | 3...10 |

Paper manufacturing represents 60...80% of total environmental load. Excluding papermaking, the biggest environmental load comes from toner manufacture (40%), followed by printing and data provision, < 30% each.

**4 Comments**

A very interesting study. Many of the results still seem to apply. The case provides interesting results, but is naturally quite limited. This was a preliminary study, but apparently did not lead to further research. The following needs for further research were identified:
- electricity consumption of digital printing equipment, improving energy efficiency
- toner composition and related waste and health aspects
- deinkability of electronically printed products; development of deinking methods
- comparison of centralised and decentralised electronic printing solutions
- basic data collection from home and office printing
- recycling of electronics waste
- paper use trends as part of the communication methods of information society

These needs are astonishingly valid even today.
The amount of bytes cannot be considered to be a practical functional unit. The report gives two examples: 10 MB represents 200 monochrome pages, and 300 MB one 4-colour image. Using product tonnes as the functional unit would give completely different results.

**5 References**

Katajajuuri & Loikkanen 1998

# Life-cycle inventory of toner produced for xerographic processes (USA 2003)

**1.1 Objective**

To establish the boundaries of the life-cycle of toner particles, wastes and by-products produced, to determine areas that have high emissions, material consumption or energy use, to present the resulting data as a baseline for comparing the current system to alternative systems and technologies.

**1.2 Scope**

Dry toner electrophotography, mechanical toner manufacturing. Article: 10 pages.

**1.3 Carried out by**

Clarkson University (level of study not known)

**1.4 Geographical coverage**

USA

**1.5 Time**

Published 2003 (paper submitted 2001)

**2 Indicators used**

Physical units per one tonne of toner

**3 Selected results**

See section 5.1 on page 62.

Table 3
Material requirements and by-products of the system

| Material Inputs and Sources | Quantity (kg/mton) | By-product | Quantity (kg/mton) |
|---|---|---|---|
| Ethane from natural gas | 240 | Light organic products | 51 |
| Benzene from refinery | 530 | Residual organics used as fuel | 95 |
| NaCl from rock salt | 340 | Benzene/Toluene mixed stream | 47 |
| $FeSO_4*7H_2O$ from $TiO_2$ production | 510 | Chlorine gas | 210 |
| Carbon black feedstock from refinery | 44 | Hydrogen gas | 5.8 |
| $C_4$ fraction from steam cracking of ethane | 120 | Butanes and C5 fraction | 36 |
| Other toner fines from recovery facility | 117 | $Na_2SO_4$ salt | 260 |
| Total inputs | 1900 | Total by-products | 700 |

**4 Comments**

This study provides valuable information on dry toner manufacturing and its environmental impacts. Unfortunately, similar data is not available for chemical dry toner, liquid toner or inkjet ink manufacturing.

**5 References**

Ahmadi et al. 2003

# Best available techniques in the printing industry (Germany 2003)

**1.1 Objective**

Not indicated (Assumption: to analyse the eco-balance of printing processes, especially VOC emissions, and to propose BAT candidates for reducing VOC emissions.)

**1.2 Scope**

HSWO, packaging flexo and rotogravure, publication rotogravure. Report: 56 pages.

**1.3 Carried out by**

Ökopol – Institut für Ökologie und Politik GmbH (institutional research)

**1.4 Geographical coverage**

Germany

**1.5 Time**

2003 (includes data from earlier studies; time of data collection not clearly indicated – year 2000?)

**2 Indicators used**

Functional unit: per annum. Physical input-output figures of reference plants (typical printing plants of the German printing industry). Indicators per tonne of products can be calculated.

**3 Selected results**

HSWO: Energy consumption total 27,100 MWh/a, out of which:
- gas energy 13,700 MWh/a
- electric energy 13,400 MWh/a, of which
    - printing press 8,900 MWh/a
    - cooling 1,700 MWh/a
    - flue gas treatment 700 MWh/a

Energy consumption:
- HSWO plant 27,100 MWh/a (1.5 MW/tonne)
- package printing plant 3,320 MWh/a (0.34 MWh/tonne)
- publication rotogravure plant 67,500 MWh/a (0.78 MWh/tonne)

Fugitive VOC emissions:
- HSWO plant: 47 t/a (2.6 kg/tonne)
- package printing plant 96 t/a (9.9 kg/tonne)
- publication rotogravure plant 365 t/a (4.2 kg/tonne)

**4 Comments**

The German study was carried out as part of the preparation for the BREF document “Surface treatment using organic solvents” by the European IPPC Bureau. Results are said to represent typical levels of consumption and production. However, the focus is on VOC emissions, and there are fewer input and output categories than in the abovementioned Finnish and Swedish studies. The study presents some input and output factors, e.g. cleaning solvents and VOC emissions, in relation to one tonne of heatset ink used. This method of calculation is also used in the BREF. Due to the objective of the study, the data can be regarded as indicative, and is valuable for comparison purposes. The value for digital printing is minimal.

**5 References**

Jepsen and Tebert 2003

# Environmental aspects of lithographic and digital printing (USA 2005)

**1.1 Objective**

To identify environmental, health, and safety (EHS) issues of lithographic and digital printing processes, to provide technical information to printing companies for technological choices, to inform the printing industry about material usage and waste generation and to deliver a methodology for a comparative environmental assessment of two different printing technologies.

**1.2 Scope**

Two identical print jobs on a SFO and LEP press. Report: 57 pages

**1.3 Carried out by**

Rochester Institute of Technology (student thesis)

**1.4 Geographical coverage**

Rochester, USA

**1.5 Time**

2005

**2 Indicators used**

Functional unit: per 500 copies ("short run"), per 3000 copies ("long run"). Materials input-output figures, air quality measurements, monetary data (lost materials value, waste costs)

**3 Selected results**

| Chemical Type | Lithographic Press | | | | Digital Press** | | | |
|---|---|---|---|---|---|---|---|---|
| | Potential VOC Emission (g) | | Actual VOC Emission (g) | | Potential VOC Emission (g) | | Actual VOC Emission (g) | |
| | Short | Long | Short | Long | Short | Long | Short | Long |
| Inks | 238.32 | 330.98 | 11.92 | 16.55 | 180.60 | 1115.24 | 12.82 | 79.18 |
| Imaging agent | N/A | N/A | N/A | N/A | 2.76 | 16.60 | 0.196 | 1.18 |
| Imaging oil | N/A | N/A | N/A | N/A | 245.5 | 1882.00 | 17.43 | 133.62 |
| Fountain solution | 93.17 | 112.94 | 93.17 | 112.94 | N/A | N/A | N/A | N/A |
| Coating solution | 13.8 | 82.8 | 13.8 | 82.8 | N/A | N/A | N/A | N/A |
| Platemaking bath solution | 108.95 | 108.95 | 108.95 | 108.95 | N/A | N/A | N/A | N/A |
| Cleaning solution applied with rags | 824.41 | 824.41 | 412.21 | 412.21 | N/A | N/A | N/A | N/A |
| Cleaning solution applied without rags | 37.10 | 37.10 | 37.10 | 37.10 | N/A | N/A | N/A | N/A |
| Total (g) | 1315.75 | 1497.18 | 677.15 | 770.55 | 428.87 | 3013.84 | 30.45 | 213.98 |

* Potential VOC emission is the maximum VOC emission that the chemical can produce if it's allowed to dry completely at high temperature for long periods, whereas the actual VOC emission represents the emission value corresponding to the normal press operating conditions.

** Potential VOC Emissions = Actual VOC Emissions if Emission Factor is assumed to = 1. As shown in Appendix A, actual VOC Emissions are calculated using an Emission Factor = .071, as calculated by HP.

Table 6. Potential and Actual VOC Emissions*

**4 Comments**

A very interesting study, but the results are not easily interpreted (e.g. the potential and actual VOCs table above). The case approach and small sample data limits the usefulness of the results.

**5 References**

Kadam et al. 2005

# Applications of an environmental modelling system in the graphics industry and road haulage services (Finland 2005)

**1.1 Objective**

To develop a modelling framework to identify and analyse environmental, financial and process factors, to determine the environmental performance and costs, and to identify the potential alternatives to improving environmental performance cost-effectively.

**1.2 Scope**

Modelling system applied to the graphics industry and road haulage services

**1.3 Carried out by**

Helsinki University of Technology (part of a doctoral dissertation)

**1.4 Geographical coverage**

Finland

**1.5 Time**

Published 2005 (research 1999-2000)

**2 Indicators used**

Functional unit: amount of used paper (tonnes). Large collection of physical and monetary indicators; see section 4.2.2 on page 53.

**3 Selected results**

The research concentrated on developing the modelling and accounting systems; no numeric data was included.

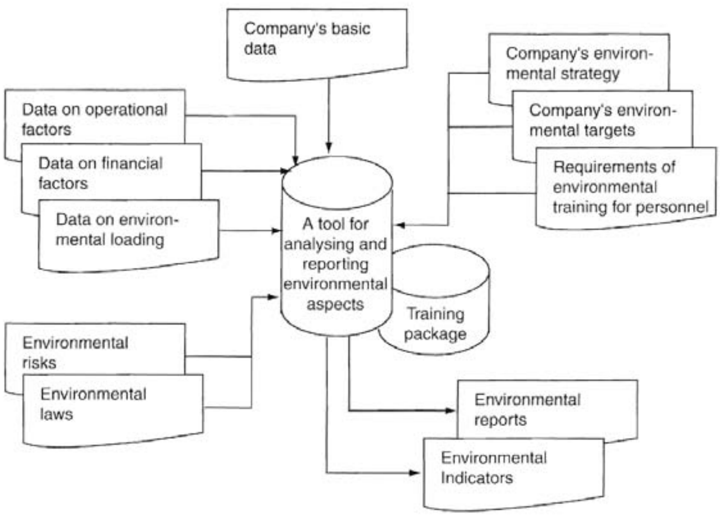



*Figure 5. The structure of an Environmental Internet System*

**4 Comments**

The strength of the model is in combining environmental and financial data. The system requires comprehensive data collection procedures, and is therefore suitable for companies with adequate resources. An Internet application was developed to implement the model.

**5 References**

Pohjola 2005

# Tools for eco-efficiency in the printing industry (Sweden 2001)
# Tools for sustainability management (Sweden 2006)

**1.1 Objective**

To provide the printing industry with environmental tools that contribute to eco-efficiency and sustainable production.

**1.2 Scope**

Mainly CSWO, HSWO, RG. Reports: 135 + 134 pages.

**1.3 Carried out by**

KTH, Sweden (licentiate and doctoral theses)

**1.4 Geographical coverage**

Sweden + international

**1.5 Time**

2001 and 2006 (data collection between 1999–2005)

**2 Indicators used**

Functional unit: one tonne of printed products.

**3 Selected results**

Indicator framework (presented in section 4.2.2 on page 53), Eco-design checklist (section 4.2.3 on page 55).

Table 13 Mean values in 2002 for the gravure printers studied (19 companies) and heatset offset printers (9 companies). (Paper VI)

| | | GRAVURE | HEATSET OFFSET |
|---|---|---|---|
| Production in 2002 | Tonnes/company | 140,000 | 54,000 |
| Paper Waste | Tonnes/tonne product | 0.13 (12%) | 0.21 (17%) |
| Use of Energy | MWh/tonne product | 0.89 | 0.61 |
| Consumption (loss) of VOC | Kg/tonne product | 1.9 | 3.0 |
| Hazardous Waste | Kg/tonne product | 1.1 | 3.5 |
| Share of companies with certified Environmental Management Systems (ISO 14001 and/or EMAS) | % | 32 | 44 |

**4 Comments**

Licentiate and doctoral theses of Maria Enroth, partly based on the same articles. Include various studies and approaches: industry-specific indicators, EMS implementation, Eco-design, Sustainability strategies. Useful as a background document for the environmental issues in the printing industry. Contains adequate indicator data for comparisons. No direct content for digital printing.

**5 References**

Enroth 2001, Enroth 2006

# Ecolabelling of printed matter (Denmark 2006)

**1.1 Objective**

To create a basis for criteria and methodology development within eco-labelling of printed matter based on a life cycle perspective.

**1.2 Scope**

70 sheet-fed offset printing plants. Report: 143 pages.

**1.3 Carried out by**

Institute for Product development, Dept. of Engineering and Management, Technical University of Denmark (part of a doctoral thesis).

**1.4 Geographical coverage**

Denmark and Southern Sweden

**1.5 Time**

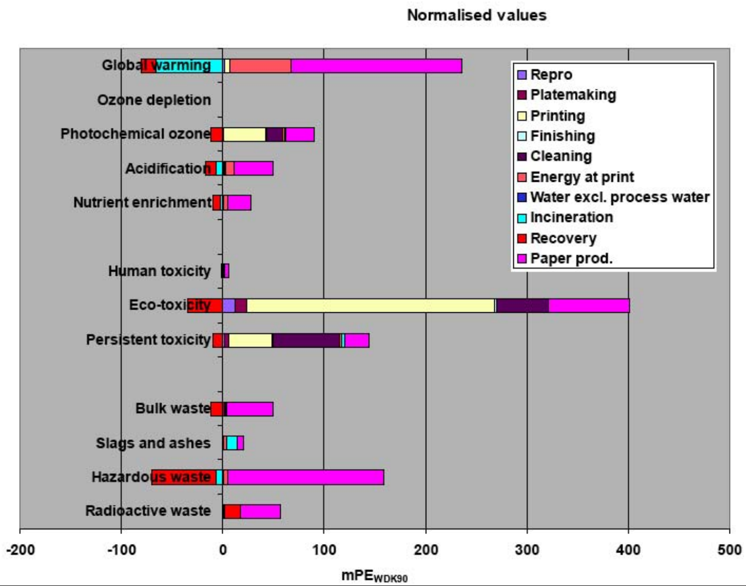
2006 (data collected 2003–04)

**2 Indicators used**

Functional unit: one tonne of SFO-printed products. Extensive physical eco-balance data (avg. - min - max). EDIP method used for the LCA, results expressed in mPE (milliperson equivalent).

**3 Selected results**

- Recycled paper has 16% less environmental impacts than virgin paper.
- Replacing the biocide benzalkonium chloride with another (Kathon) could reduce the environmental impact by 69% (see graph, Eco-toxicity)
- Changing volatile aliphatic cleaning agents to vegetable oil-based ones reduced environmental impact by 26%




**4 Comments**

An extensive study with various scenarios and sensitivity analyses. The extent of chemical data was larger than in earlier studies, and resulted in a different environmental profile. Provides good baseline data for both offset and digital printing studies.

**5 References**

Larsen et al. 2006

# Screening environmental life cycle assessment of printed, web-based and tablet e-paper newspaper (Sweden 2007)

**1.1 Objective**

To describe the potential environmental impacts of three studied product systems; to identify data gaps and areas where more information is needed.

**1.2 Scope**

Printed newspaper, web-based newspaper and tablet e-paper newspaper. Report: 106 pages.

**1.3 Carried out by**

Royal Institute of Technology (KTH) and STFI-Packforsk; a screening LCA study

**1.4 Geographical coverage**

Sweden

**1.5 Time**

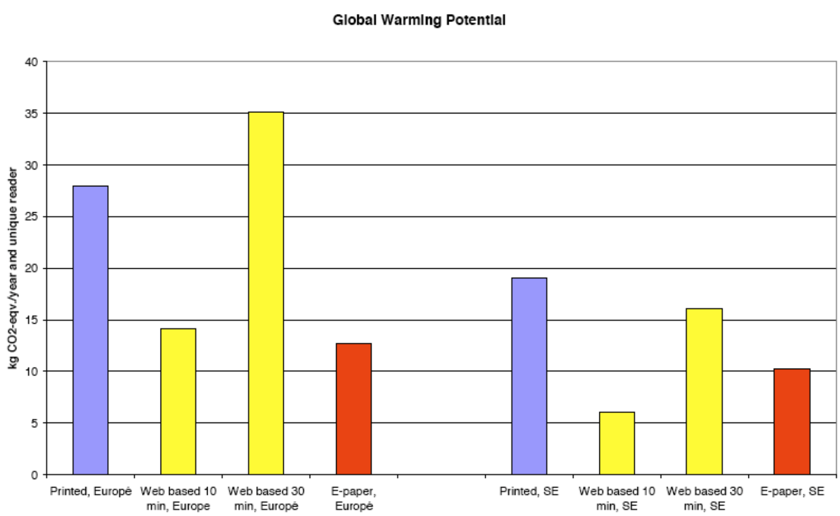
2007 (updated preface added in 2009)

**2 Indicators used**

Functional unit: yearly consumption of newspaper for a unique reader. **Printed newspaper:** 131 newspapers/year (312 newspapers/year and 2.4 unique readers/newspaper), **Web-based newspaper:** 913MB and 61 hours of reading, **Tablet e-paper newspaper:** 1830 MB and 183 hours of reading. Weighting methods: Eco-indicator 99 HA and Ecotax 02 min and max.

**3 Selected results**

*Figure: "Comparison between printed newspaper, web-based newspaper (reading time 10 and 30 minutes) and tablet e-paper newspaper. The comparison regarded global warming potential, and the systems were compared within the European and Swedish scenarios."*




**4 Comments**

An interesting study. The identified data gaps include the manufacturing of tablet e-readers, the energy consumption of data processing and transfer, and the processing of e-waste.

**5 References**

Moberg et al. 2007

# Effects of a total change from paper invoicing to electronic invoicing in Sweden. A screening life cycle assessment focusing on greenhouse gas emissions and cumulative energy demand (Sweden 2008)

**1.1 Objective**

To assess the consequences of a complete transition from all paper invoicing to all electronic invoicing in Sweden.

**1.2 Scope**

All invoices in Sweden. Screening LCA. Report: 82 pages.

**1.3 Carried out by**

Royal Institute of Technology, commissioned by Itella Ab.

**1.4 Geographical coverage**

Sweden

**1.5 Time**

2008

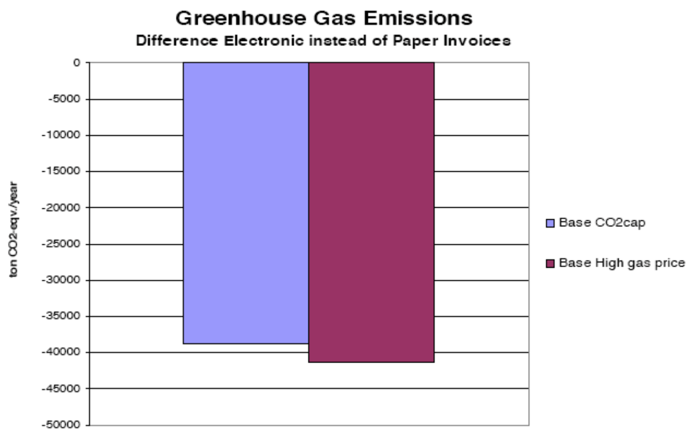
**2 Indicators used**

Functional unit: The distribution of 1.4 billion invoices, whereof 70% B-to-C and 30% B-to-B.

**3 Selected results**

Changing from paper invoices to electronic invoices was found to be beneficial. Changing all invoices in Sweden from paper to electronic would lead to total energy savings of around 1 400 TJ/year and reductions of greenhouse gas emissions amounting to 39 000 to 41 000 tonne $CO_2$e/year, depending on the electricity mix used.

*Figure 14. Potential consequence in terms of greenhouse gas emissions if all invoices in Sweden were changed from paper to electronic. Base scenario, with two different electricity mixes.*




**4 Comments**

Another interesting study from the Royal Institute of Technology. 67% of the paper invoices were assumed to be preprinted in offset, and all of the invoice data printed with EP. The printing stage energy consumption of paper invoices was assumed to be 5 Wh/A4 sheet and 11 Wh/invoice, and toner consumption 25 g/1000 pages.

**5 References**

Moberg et al. 2008

# Environmental sustainability in the Finnish printing and publishing industry (Finland 2007)

**1.1 Objective**

To analyse environmental sustainability in the printing and publishing industry in order to identify further areas of research, to identify drivers for encouraging or forcing printers and publishers to engage in environmental work and to compare environmental technology used by Nordic printers with the BAT.

**1.2 Scope**

Printing industry and its stakeholders, Finland. Licentiate thesis, 129 pages.

**1.3 Carried out by**

Helsinki University of Technology

**1.4 Geographical coverage**

Finland

**1.5 Time**

2007

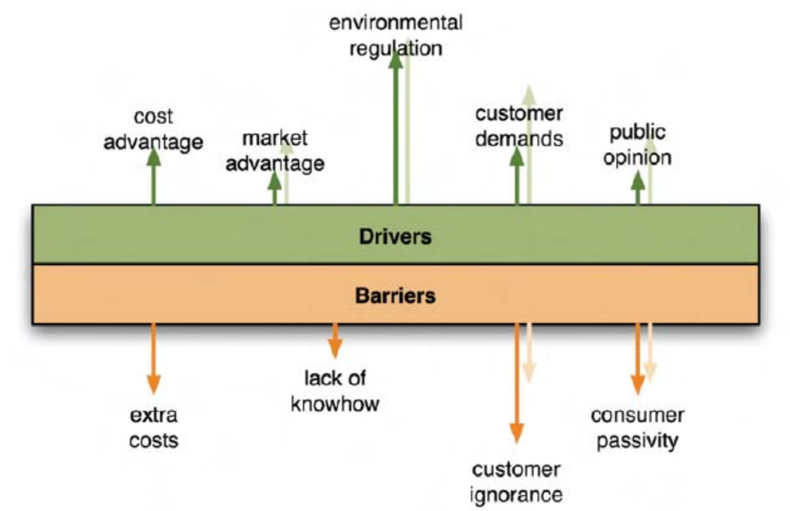
**2 Indicators used**

Functional unit: tonne of printed products. Physical environmental data.

**3 Selected results**

Legislation is the most important driver for environmental work, followed by demands from customers. Most of the decisions that determine the environmental impacts of printed products are made by print buyers and graphic designers, who do not necessarily know the consequences of their decisions.

*Drivers and barriers of environmental action in the printing and publishing industry. Light arrows indicate the anticipated changes in the future.*




**4 Comments**

The survey results suffer from low response rates.

**5 References**

Viluksela 2007

# Environmental aspects of digital printing (Finland 2008)

**1.1 Objective**

To define the environmental effects caused by digital printing.

**1.2 Scope**

Digital printing facility, EP, Finland

**1.3 Carried out by**

KCL/Metropolia (B.Sc. thesis)

**1.4 Geographical coverage**

Finland

**1.5 Time**

2008 (data from years 2006 and 07)

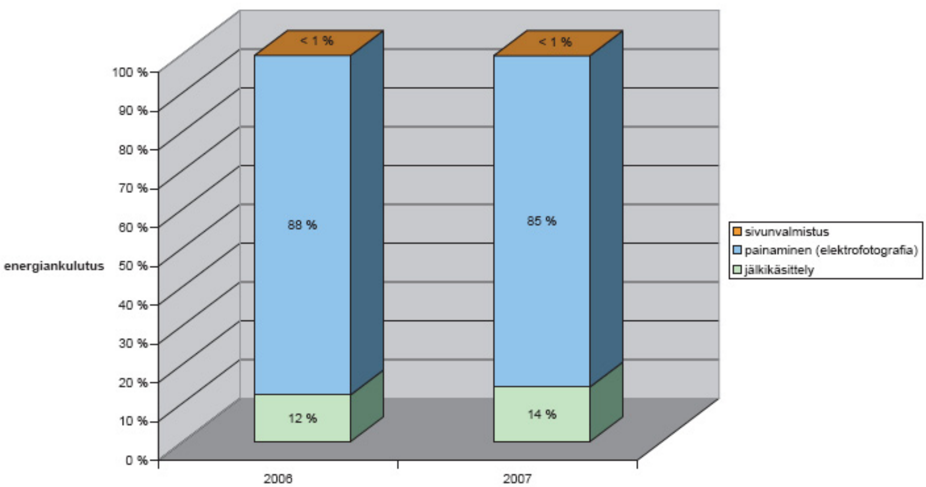
**2 Indicators used**

Functional unit: one tonne of digitally printed products. Physical eco-balance data.

**3 Selected results**

Energy consumption 3.3 MWh/tonne
Toner consumption 27 kg/tonne
Paper waste 195 kg/tonne
Hazardous waste 0.8 kg/tonne

*Figure: Share of the process stages of total energy consumption. Orange = prepress, blue = printing, green = finishing.*




**4 Comments**

This is the first study to assess the eco-balance of a digital printing plant at an annual level. Thus, the results are valuable as baseline data. Indicator results have been included in Chapter 5 of this report.

**5 References**

Peltonen 2008

# Changes in sustainability due to technology development in selected printing processes (Finland 2008)

**1.1 Objective**

To discuss the relationship between technology changes and the environmental performance of the printing houses.

**1.2 Scope**

SFO, CSWO, HSWO, EP. Article: 11 pages.

**1.3 Carried out by**

KCL (with Metropolia), part of a large research project

**1.4 Geographical coverage**

Finland

**1.5 Time**

2008

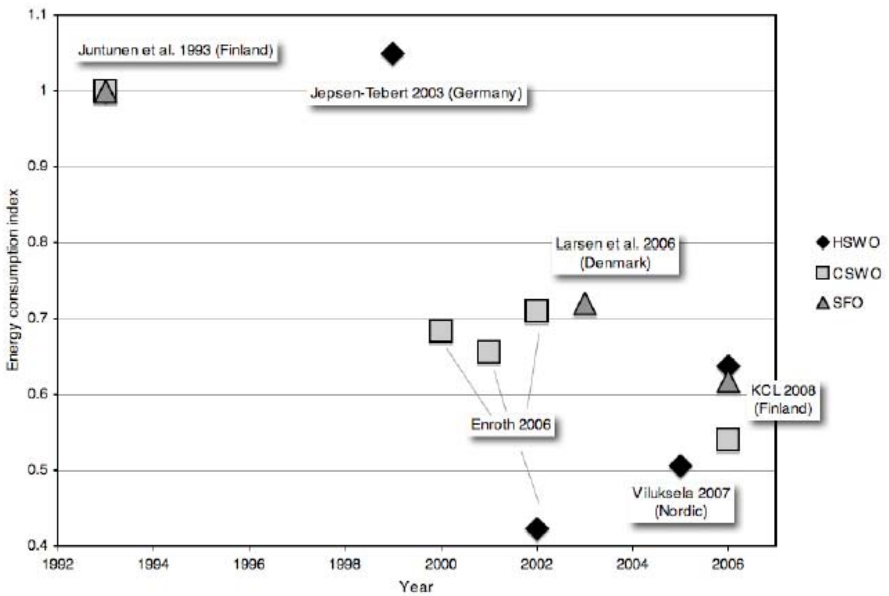
**2 Indicators used**

Functional unit: tonne of printed products. Indexed physical units.

**3 Selected results**

In the past 15 years, development of technology has improved the environmental performance of the printing industry. The SFO/EP comparison results are presented in Chapter 6.

*Figure: Energy consumption index of printing processes, calculated as total energy consumption per one tonne of printed products (Finnish ecobalance study from year 1993 = 1).*




**4 Comments**

Extensive literature study to find out the development happened in the environmental sustainability of printing and to find out the places of future development.

**5 References**

Viluksela et al. 2008

# Development of a green scorecard to identify research projects for eco-efficient print engines (USA 2009)

**1.1 Objective**

To identify and quantify the most important challenges of environmental impacts to the manufacturers of printing equipment and services, including the impact of supplies such as toner and paper.

**1.2 Scope**

Office imaging equipment. Article: 6 pages.

**1.3 Carried out by**

Xerox.

**1.4 Geographical coverage**

–

**1.5 Time**

2009

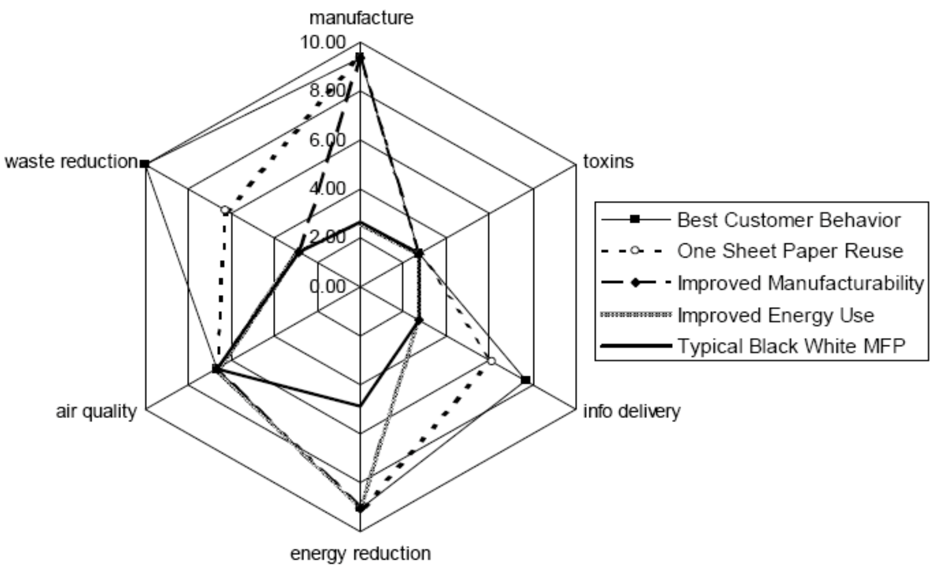
**2 Indicators used**

Functional unit: Info-unit, the amount of information on a single A4 impression, typically 5–6% area coverage per colour.

**3 Selected results**

See Figure 13 on page 62.

*Figure: Radar chart of scorecard scores for 5 different scenarios (arbitrary units).*




**4 Comments**

The green scorecard is not explained in detail. The approach seems somewhat similar to Sobotka's proposal (Sobotka 2009), although the purpose is different: the green scorecard is used identify and prioritise sustainability research projects at Xerox, while Sobotka's rating scale would be used to assess the sustainability of digital printing systems.

**5 References**

Ebner et al. 2009

# Reducing the greenhouse gas emissions of commercial print with digital technologies (USA 2009)

| |
|---|
| **1.1 Objective**<br>To examine the global carbon footprint of printing for the year 2020, and highlight the abatement potential enabled by digital technology. |
| **1.2 Scope**<br>All printing methods and products. Article: 6 pages. |
| **1.3 Carried out by**<br>HP |
| **1.4 Geographical coverage**<br>Global. |
| **1.5 Time**<br>2009 (projection to 2020) |
| **2 Indicators used**<br>Carbon footprint as an absolute value. |
| **3 Selected results**<br>In 2020, digital printing can reduce overruns of newspapers by 20%, magazines by 50%, books by 30% and others by 20%. Digital printing can reduce setup (make-ready?) losses in newspaper and magazine printing by 5% and in other printing by 20%. By targeting content and distribution, digital printing can reduce [the quantity of] newspapers, magazines and catalogues by 10%. Improved print management in offices can lead to 25% reduction in office printing. All these lead to a CF reduction potential of 114...251 million metric tonnes of $CO_2$e globally. |
| **4 Comments**<br>A heroic attempt to quantify the global CF of printing. Unfortunately, much necessary data and background information is left out of the 6-page article. The carbon footprint reductions through digital printing are partly justified, but realising the potential requires major productivity and cost-efficiency improvements from digital printing manufacturers. |
| **5 References**<br>Canonico et al. 2009 |

# Carbon footprint of printed matter. Development of a carbon footprint calculator for Elanders Sverige AB (Sweden 2009)

**1.1 Objective**

To develop a carbon footprint calculator for Elanders; to investigate the implementation of carbon footprint tools in the printing industry from a research perspective.

**1.2 Scope**

Operation of Elanders Sverige AB (EP, SFO, HSWO)

**1.3 Carried out by**

Chalmers University of Technology (M.Sc. thesis)

**1.4 Geographical coverage**

Sweden

**1.5 Time**

2009 (data from 2008)

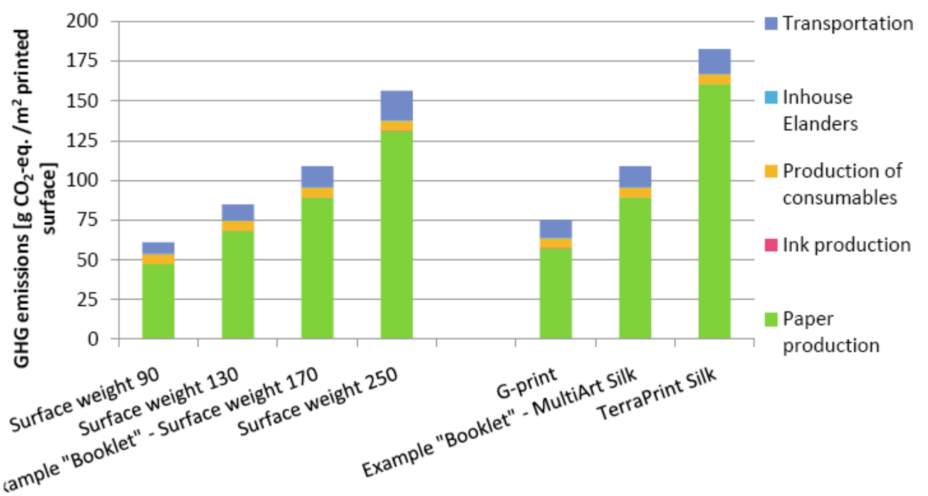
**2 Indicators used**

Functional unit: one $m^2$ of printed matter. Inventory analysis includes physical input-output data.

**3 Selected results**

See section 5.3.5 on page 74.

*Figure: Example from sensitivity analyses: the impact of paper basis weight and paper grade on GHG emissions*




**4 Comments**

An interesting study with extensive numerical inventory data, e.g. GHG emissions for various paper brands. Some data on digital printing (dry and liquid toner EP) is included. The functional unit used makes some of the numerical data useless, e.g. GHG emissions from electricity used, Indigo sheet-fed: <0.0001 kg $CO_2e/m^2$.

**5 References**

Bengtsson & Heimersson 2009

# Energy flow measurements in digital press (Finland 2010)

**1.1 Objective**

Adapting an energy flow measurement method to digital printing houses and to find out in detail where the energy is used in printing

**1.2 Scope**

Digital web presses, prepress and postpress devices. Report 49 pages

**1.3 Carried out by**

VTT / Metropolia (B.Sc. thesis)

**1.4 Geographical coverage**

Finland

**1.5 Time**

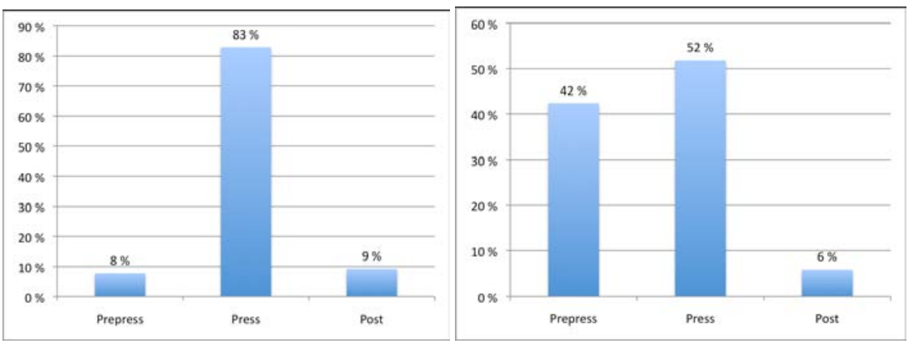
2010 (measurements 2009)

**2 Indicators used**

Functional unit: energy requirement (kW) and energy consumption/1000 sheets (kWh)

**3 Selected results**

*Figure: The proportion of energy consumption in prepress, press and post press. Left – digital printing press-room. Right – the IT-operations are also included to the figure of prepress.*




**4 Comments**

An interesting study with new information about how the consumed energy is divided in the printing house. The measurements were done only for short time, but they give good indication.

**5 References**

Haanpää 2010

# Applications of electrophotography and the environmental impacts of digital printing (Finland 2010)

**1.1 Objective**

To define the environmental effects caused by digital printing.

**1.2 Scope**

Digital printing facility, EP, Finland

**1.3 Carried out by**

VTT/Metropolia (B.Sc. thesis)

**1.4 Geographical coverage**

Finland

**1.5 Time**

2010 (data from years 2008 and 09)

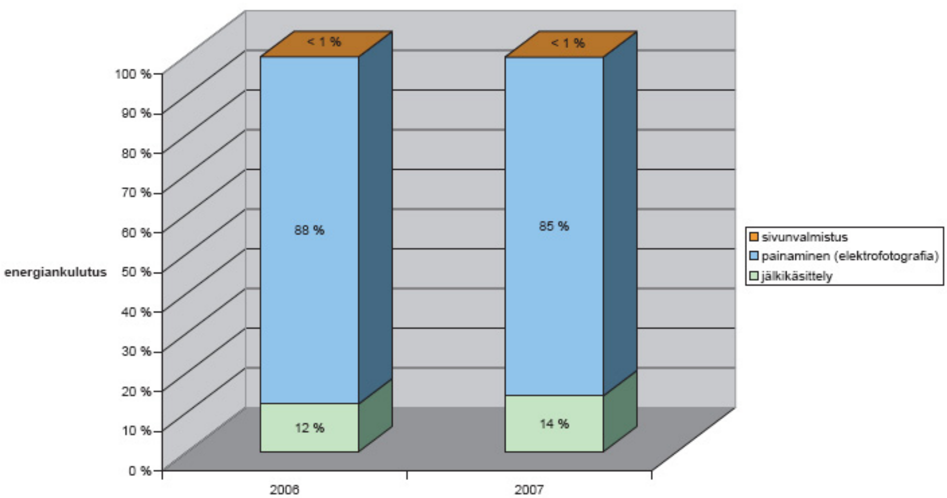
**2 Indicators used**

Functional unit: thousand copies of digitally printed products. Physical eco-balance data.

**3 Selected results**

Energy consumption 1 664 kWh /24 hours
Toner consumption 6,4 kg/1000 products
Paper 219,4 kg kg/1000 products
Silicon oil 0,4 kg/1000 products

*Figure: Share of the process stages of total energy consumption. Orange = prepress, blue = printing, green = finishing.*




**4 Comments**

This study promotes the results obtained by Peltonen 2008.

**5 References**

Haanpää 2010

# Applications of electrophotography and the environmental impacts of digital printing (Finland 2010)

| |
|---|
| **1.1 Objective**<br>To define the environmental effects caused by digital printing. |
| **1.2 Scope**<br>Digital printing facility, EP, Finland |
| **1.3 Carried out by**<br>VTT/Metropolia (B.Sc. thesis) |
| **1.4 Geographical coverage**<br>Finland |
| **1.5 Time**<br>2010 (data from years 2008 and 2009) |
| **2 Indicators used**<br>Functional unit: thousand copies of digitally printed products. Physical eco-balance data. |
| **3 Selected results**<br>Energy consumption 1 664 kWh / 24 hours<br>Toner consumption 6,4 kg / 1000 products<br>Paper 219,4 kg kg / 1000 products<br>Silicon oil 0,4 kg / 1000 products |
| **4 Comments**<br>This study promotes the results obtained by Peltonen 2008. |
| **5 References**<br>Haanpää 2010 |

| **Category** | **Basic level** | **Intermediate level** | **Advanced level** |
|---|---|---|---|
| **Applied to** | **Company** | **Company, process, product** | **Company, process, product, project** |
| Supply and delivery | Total delivered products (tonnes)<br>Total delivery distance (km) | Total vehicle transport distance (km)<br>Fuel consumption (l/km) of vehicles<br>CO2 emission (g/km) of vehicles | Vehicles in fleet with pollution-abatement technology<br>Number/km of business trips saved through other means of communication<br>Number/km of business trips by mode of transportation. |
| Products | Product output ($10^6$ of A4, tonnes) | Defective products (% of total)<br>Eco-labelled products (% of total) | Eco-designed products (% of total)<br>Environmental savings from eco-design activities<br>Products with instructions concerning recycling (% of total) |
| Wastes | Paper waste ($10^6$ of A4, kg)<br>Mixed waste (kg) | Ink/toner waste (kg)<br>Hazardous waste (kg) | Consumables waste (kg, number)<br>Paper/mixed/hazardous waste eliminated due to initiatives |
| Emissions | $CO_2$ emissions (kg) by source<br>• Energy production<br>• Transport | VOC emissions (kg)<br>Particle emissions (kg)<br>Ozone emissions (kg)<br>GHG emissions (kg $CO_2$e) | Emissions (kg) of ozone-depleting substances<br>Emission reductions achieved by process development activities<br>Carbon footprint |
| Effluents | | Waste water (l) | Quantity of specific material discharged to waste water<br>Effluent and noise reductions achieved by process development activities |

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Pentti Viluksela, Merja Kariniemi & Minna Nors

Title

# Environmental performance of digital printing

## Literary study

Abstract

The objective of this literature study is to summarise the present situation and future prospects of digital printing technologies and markets, to review the existing publicly available information on the environmental impacts of digital printing, and to present suitable indicators for assessing the environmental performance of digital printing.

Digital printing methods have developed considerably in recent years, both in terms of quality and productivity. New products based on the variable data printing capability of digital printing have been introduced. Digital methods have also taken market share from mechanical printing methods in the on-demand and short-run production of traditional products. The market share of digital printing will continue to increase in the future.

There is little published research on the environmental impacts of digital printing. The analysed literature indicates that digital methods have a higher energy and ink/toner consumption than mechanical methods, but their chemicals and water consumption and waste output are lower. Paper consumption and emissions to air are difficult to assess due to the lack of data. More research is needed to obtain a better and more reliable understanding.

Environmental indicators used in earlier studies of printing can be used for digital printing as well. These include physical and monetary input and output figures like energy and materials consumption, emissions and waste output. The suitable functional units are the weight and the surface area of products, e.g. tonne of printed products or million duplex printed A4 sheets.

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Fax +358 20 722 4374

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Digital printing technology has developed considerably in recent years. Electrophotography and inkjet are gaining ground by enabling new products as well as taking markets from the traditional printing methods. The environmental performance of the digital printing is marketed to be more sustainable than of the traditional printing methods.

This literature survey looks at digital prining methods and digitally printed products from the environmental standpoint. The report also presents some methods for assessing the environmental performance of digital printing operations at the company level. Furthermore, main environmental indicators, such as energy and materials consumption, are presented.

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