Evaluating Environmental Sustainability of Digital Printing

Merja Kariniemi, Minna Nors, Marjukka Kujanpää, Tiina Pajula and Hanna Pihkola; VTT Technical Research Centre of Finland, Espoo, Finland

Abstract

Concern about climate change and the need to reduce greenhouse gas emissions has created pressures also for the digital printing industry. The previously published papers are based on assumptions of energy consumption on the press and during the pre and post press operations. We have collected the material flow and measured the energy consumption on different electrophotography printing presses from several Finnish printing houses. This enables us to present the results in reliable way.

This paper will focus on new, unpublished, results of the life cycle assessment case made for a 4-colour photo book printed with production scale electrophotography. The life cycle is studied from cradle to the customer, starting from the forest and covering the paper manufacturing, printing and distribution to customer. The life cycle inventory (LCI) phase results are concerning the main emissions to air and water. The impact assessment phase was left out. Furthermore, the carbon footprint information was seen important to evaluate properly.

The results are presented in a form to highlight the points were different actors in the value chain can affect the overall environmental load of the final product. The aim of this paper is also to provide guidance on improved environmental performance, focusing especially on energy and material efficiency in the printing phase.

Methods

Life cycle assessment is a method that provides detailed information about the environmental aspects and potential environmental impacts occurring during a life cycle of a print product. Carbon footprint is a fairly new application of life cycle assessment that concentrates only on greenhouse gas emissions. The carbon footprint is also a tool that is applied in product specific calculations. With the help of carbon footprint of a product the level of GHG emissions are evaluated and against it the actions to reduce these emissions are possible to measure systematic way.

Life cycle assessment

In the study, environmental performance of a photo book was evaluated based on life cycle assessment (LCA) methodology. LCA analyses the environmental aspects and potential impacts across the product life cycle from cradle to grave, including raw material acquisition, production, use, end-of-life treatment, recycling, and final disposal, by examining the physical chains of material flows. LCA assesses the environmental impacts of product systems in accordance with the stated goal and scope.

The four phases of LCA are the goal and scope definition phase, inventory analysis, impact assessment and interpretation. ISO 14040 -standard addresses some requirements for carrying out LCA [1]. In this paper, the life cycle inventory (LCI) and carbon footprint results are discussed.

The goal definition phase determines the goal of a study; the intended application, the reasons behind the study, the intended audience and if the results are intended to be used in comparative assertions in public. The scope includes information about the studied product system, the functions of product system, the functional unit, the system boundary, the allocation procedures, data requirements, assumptions, limitations, initial data quality requirements and type of critical review. [1]

Life cycle inventory (LCI) phase gives information about the inputs from the environment to the system and about the outputs to the environment from the studied system. Data for each unit process contain information about energy inputs, raw material inputs, ancillary inputs and other physical inputs; products, co-products and waste; emissions to air, discharges to water and soil, and other environmental aspects. After gathering the data, information is related to unit processes and to the reference flow of the functional unit. [1] In the life cycle impact assessment (LCIA) phase, the significance of potential environmental impacts is evaluated using the LCI results. LCIA involves associating inventory data with specific environmental impact categories and category indicators.

The scope, system boundary and level of detail of an LCA calculation depend on the subject and of the intended use of the study. Thus the depth of the study can differ depending on the goal of the particular study. As a consequence, the results of different LCA studies or carbon footprint calculations cannot be compared with each other without careful consideration of the system boundaries and assumptions related to calculations. [2]

LCA requires handling, equating and the balancing of large amounts of data. In order to make the data handling possible, a LCA calculation software KCL-ECO was utilized. In the software, different life cycle stages and processes along the life cycle are described in terms of modules and flows. The impact assessment was also calculated, but it was left out from this paper.

Carbon footprint

Carbon footprint calculation procedure is based on life cycle thinking and the Life Cycle Assessment (LCA) methodology. Carbon footprint (CF) refers to the quantity of greenhouse gases (GHG's) produced during a product's life cycle. Greenhouse gas emissions are converted into carbon dioxide equivalents using global warming potentials of 100 years. Carbon footprint case calculations in this study include all the greenhouse gas emissions that are mentioned by Intergovernmental Panel on Climate Change (IPCC) [3] and in PAS2050 (Publicly available Specification for the assessment of the life cycle greenhouse gas emissions of goods and services) [4]. However, the majority of the carbon footprint of fibre based print products is composed of carbon dioxide, methane and nitrous oxide.

Even though the LCA methodology is standardized by ISO (ISO 14040 and 14044) [1,5] the carbon footprint calculation procedure needs separate guidelines to cover carbon specific features. Internationally accepted consistent methods for calculating carbon footprints are under development. PAS2050 can be regarded the most credible and internationally recognized guidance for the time being since ISO standardation work is still on-going. Additionally a paper industry specific guidance is published by the Confederation of the European Paper Industy (CEPI). The ten toes of the CEPI carbon footprint framework [6] highlight the main stages of the paper product's life cycle that should be addressed in the carbon footprint calculation.

The PAS 2050 is based on life cycle thinking referring to the ISO 14040 series (LCA standards). According to the PAS specification, all GHG emissions arising from fossil sources shall be included in carbon footprint CF calculations. Biogenic carbon is excluded except where it arises from land use change, is non-CO2 (e.g. methane) or is stored in a product. Emissions are converted to CO2equivalent emissions.

The PAS specifies requirements for identifying the system boundary, the sources of GHG emissions associated with goods and services that fall inside or outside the system boundary, the data requirements for carrying out the analysis, and the calculation of the results. It is one of the intentions of the PAS to allow for the comparison of GHG emissions between goods or services, and to enable the communication of this information. However, it does not specify requirements for communication.

CEPI has launched a framework for issues that should be taken into account when calculating carbon footprint for paper products [6]. Like the PAS, it is based on life cycle inventory approach. The framework looks at direct and indirect emissions, carbon sequestration in forests and in products, the value of bio-energy and the concept of avoided emissions. It is based on ten key elements, which are called the ten toes of the Carbon Footprint. However, the framework allows different choices to be taken by individual companies and does not guide in methodological problems like how to calculate carbon sequestrated in forests.

The development of ISO standards for carbon footprints (ISO 14067 Carbon footprint of products – Part 1: Quantification and – Part 2: Communication) started in January 2009, and the targeted publication is in 2011. It is expected that once published the ISO standard will become the most important and globally referred guidance.

Since methodologies still develop and there is no accepted way to e.g. include carbon sequestration and forest carbon balance in the calculations, we have decided to follow the most recognized guidelines PAS 2050. This means that the biogenic carbon has a role when it causes non-CO2 emissions (e.g. methane) or is stored in a product (books). Apart from these two exceptions the biogenic carbon is regarded neutral.

LCI and carbon footprint of photo book

The goal of the study was to examine the environmental impacts of a generic case concerning digitally printed photo book. The scope of the study was cradle-to-customer, in which end of life is excluded from examination. The decision to limit the study to cradle-to-customer approach only was made because there is no data available concerning the end of life of photo books. Table presents the case study assumptions for digitally printed photo book. The case study does not present any specific Finnish electrophotographic printed photo book, but provides an example of a photo book that could be manufactured in Finland. The basic assumptions of the case study were defined together with the paper and printing industry representatives.

For a digitally printed photo book a cradle-to-customer study was done. The case study covers the life cycle of print products from cradle to customer: pulp and paper manufacturing (including harvesting and raw material manufacturing), print manufacturing, distribution of final products from printing house to consumer (home delivery), but excluding the end of life from the examination. Infrastructure (buildings, machinery, and other devices) and supporting functions like sales and marketing etc. are not included in the calculations. Transports are included covering the manufacturing of main raw materials and products Transportation of raw materials and products was included covering the whole life cycle of the product, from cradle to customer. Emissions from transports were calculated mass based (as ton-kilometers), based on information acquired from KCL EcoData database, The Finnish Environment Institute (SYKE), a paper recycling company and a Finnish logistics company. The transportation distances and modes of transport are estimates but they reflect common situations in Finland. Back haulages were included, assuming that after transporting the product, the vehicle drives half of the distance with empty load.

The emission factor for Finnish electricity from grid is 250 kgCO_2eq/MWh.

Table 1. Case study assumptions for a photo book.

Print product	Photo book, hard cover, glue binded, size A4
Printing	Electrophotography (EP), 4-color printed
Paper	Cover: 1300 gsm board + 150 gsm coated fine paper + laminate Inner sheets: 150gsm coated fine paper End papers: 150gsm uncoated fine paper Board for back: board, excluded from the calculations due to negligible contribution
Weight and dryness	500g (35-45 pages) and 800g (80-90 pages) / book, dryness 96%
Pagkaging	Corrugated board box 120g, plastic wrapping 14g
Geographical aspects	Paper production, printing and delivery in Finland
Distribution	Delivery to home
Storage at home	50 years

Figure 1 shows the system boundary of the studied system. A cradle-to-customer approach was applied, meaning that the life cycle was studied from raw material extraction until the customer receives the photo books with the direct mail. The paper mills were assumed to be integrated with pulp mills. Data for paper manufacturing was derived mainly from the KCL Ecodata database. The LCI-data concerning printing phase was collected from four Finnish printing houses [7,8,9]. Additional information was also received from printing press manufacturers and toner manufacturers. The distribution of the photo book was assumed to happen as home delivery with direct mail. In this case study, the studied system is divided to different components of the book. In addition to that, printing and transportations are examined separately.

Toner production was derived from Ecoinvent 2.1. database and the data mainly stands for toner production for office laser jets. However, data was verified by a component manufacturer and thus it was assumed that the data is accurate to be used for high speed digital printing too. Toner production includes the raw materials of toner and the actual manufacturing of toner powder. In this study, a circulation of empty cartridges and refilling them is excluded due to lack of data, but it should be noted that cartridge circulation may lead to increased environmental impacts and emissions.

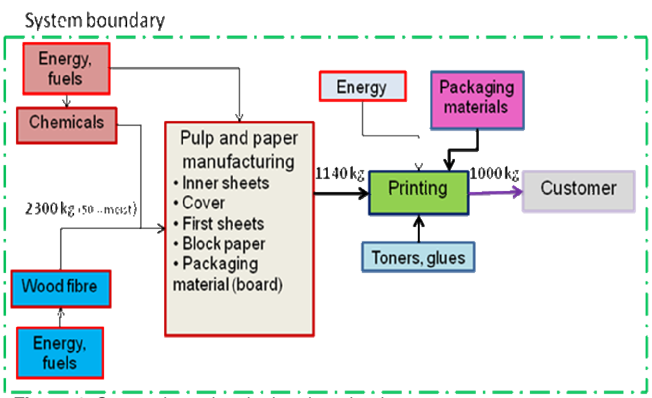

Figure 1. *System boundary in the photo books case.*

Life cycle inventory results

The potential contribution of the digitally printed photo book product system to environmental burden is mostly connected to the manufacturing of the different types of paper and cardboard used for the book. The impact profiles from the different fibre materials are similar, but the overall amounts of impacts differ in compliance with the different amounts of materials needed for the book. The delivery to consumers also has a very relevant role in the overall impacts. Life cycle inventory results that were calculated include emissions to air (NO_x, SO_2 and TSP) having influence on particular matter formation and emission to water (COD, N_{tot}, P_{tot}, TSS) having influence on freshwater eutrophication.

According to our calculations delivery to home has clearly the biggest contribution on the emissions to air. Inner sheet manufacturing has a clear impact on emissions to air too. Printing phase has a contribution of about 12% on NO_x emissions, 15% on SO_2 emissions and 20% of total TSP emissions. The origin of these emissions is mainly from the purchased energy used in the printing phase. The biggest emissions to water originate from wood free paper production for inner sheets. Packaging materials have also a clear contribution on emissions to water. Printing phase, on the other hand, has a minor contribution on emissions to water.

Carbon footprint results

The cradle-to-customer carbon footprint of a photo book ton is 2013 kg CO_2eq./t of photo book. It has to be remembered that the end of life was excluded from the study. Inclusion of end of life treatment would most probably increase the emissions due to decomposition in landfills, but on the other hand fibres can be recycled and virgin fibre production could be partly replaced (Pajula, Nors VTT symposium).

Figure 2 presents the carbon footprint of a photo book, showing the shares of each component and printing. It can be seen that the paper used in the book has a total share of 44%. Delivery to customer produces roughly 20% of the cradle-to-customer greenhouse gas emissions. Printing phase has a contribution of about 21% of the total cradle-to-customer greenhouse gas emissions.

The figure shows that packaging materials (corrugated board and LDPE film) have a clear contribution on carbon footprint of a photo book. This is because every single book is packed separately and thus the amount of packaging materials used is relatively high. In the following table (table 3), carbon footprints are presented with and without packaging materials. In addition, carbon footprints of photo books are presented for two different-sized books; one weighting 500g (roughly 35-45 pages) and the other weighting 800g (roughly 80-90 pages). Comparison of these results to other calculations should not be done due to the system boundaries and assumptions.

Table 3. Carbon footprint of photo book with and without packaging materials. Delivery to customer is included in numbers. Carbon footprints calculated for two different-weighed photo books, 500g and 800g. [kg CO_2eq.]

Carbon footprint, cradle-to-customer	With packaging material	Without packaging material
Total, one ton of photo books	2013 kg CO_2 eq.	1745 kg CO_2 eq.
Total, one photo book, weight 500g	1000 g CO_2 eq.	870 g CO_2 eq.
Total, one photo book, weight 800g	1420 g CO_2 eq.	1280 g CO_2 eq.

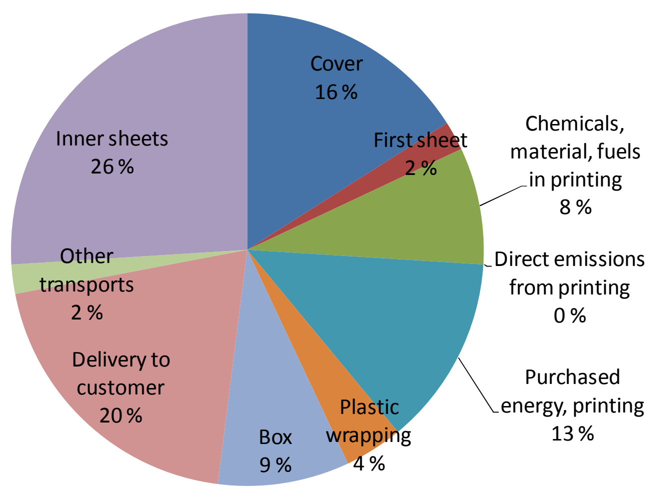

Figure 2. *Relative shares of each component of a photo book and a printing phase in cradle-to-customer carbon footprint.*

Calculating carbon storage according to PAS2050

PAS2050 allows to credit a carbon storage of a product from carbon footprint if "more than 50% of the mass of carbon (of biogenic origin) in the product remains removed from the atmosphere for one year or more following the production of the product". In this study it was assumed that a photo book is kept for 50 years in a book shelve and the carbon storage is calculated for that time. The results of carbon storage are shown in table 4. The calculation is just for the book, because the package is not stored as long.

Table 4. Carbon storage and carbon footprints with credited storage, calculated according to PAS2050. The book is kept for 50 years and then carbon is immediately released to the atmosphere.

Weight of the digitally printed photo book	unit	**500 g**	**800 g**
Cradle-to-customer carbon footprint (without packaging)	CO_2 eq.	870 g	1280 g
Carbon content of a photo book	CO_2	530 g	760 g
Carbon storage that can be credited from carbon footprint	CO_2	260 g	610 g
Carbon footprint according to PAS2050	CO_2 eq.	380 g	900 g

It should be noted that the carbon storage in this example is calculated for one book and it is assumed that after 50 years the book is destroyed immediately and the carbon is released back to the atmosphere. However, usually the situation is not that straightforward and the carbon in book might be released slowly to the atmosphere (e.g. when degrading in landfill). If multiple books are studied, it is probable that not all of them are stored for 50 years but some of them are stored only for a while whereas some of them might be stored for a very long time. In these cases, the weighting factor would be different.

Conclusions

The cradle-to-customer carbon footprint of a photo book ton is 2013 kg CO_2eq./t photo book. The GHG emission per one 500 gram photo book is about 1000 gCO2eq and per one 800g photo book about 1420 gCO_2eq. These emissions equal to the GHG emission that is caused by watching modern TV for about 27-38 hours in Finland. (A modern 32-37'' LCD TV set consumes 0.15 kWh_e/h [10] and only the electricity of watching the TV was included in this comparison). End of life was excluded from the study due to lack of data and due to the fact that end of life assumptions and allocations that would have to been made in order to carry out a full life cycle assessment would have increased the uncertainty remarkably.

The previous results in the research has brought in a point of view where the end of life has a significant impact on results in the printed products such as magazines or newspapers when they are disposed to landfill [2, 11]. Consequently, the consumer choices concerning the end of life phase of print products are very significant and should be clearly communicated. Thus, it can be recommended that after use, consumer should not dispose book to landfill but recycle it or dispose it to the energy recovery. If photo book was recycled with other household paper waste, covers should be separated and recycled with board waste and inner sheets with newspapers and magazines. In order to give more precise arguments of end of life, more research is needed, concerning especially recycling rates and deinkability of digitally printed products.

In addition to the GHG emissions, the life cycle inventory phase brought in information concerning also other emissions to air and the emissions to water was calculated. Printing phase has a contribution of about 12% on NO_x emissions, 15% on SO_2 emissions and 20% of total TSP emissions. The origin of these emissions is mainly from the purchased energy used in the printing phase. Printing phase has only a minor contribution on emissions to water.

Discussion

The environmental sustainability can be influenced by technology development, but the main impact is still on how the technology is adopted to the industry and how it is used. Work process has a strong influence on the sustainability and economics of the printing house. It needs to be remembered, that the whole value chain has already done several improvements to the process. To further improve the eco-efficiency of the print products, the development should be done together with the whole value chain and focused on the critical areas and communicated to the public in the correct way.

As the main material in printing is paper, a finger is often pointed at the paper mills when the environmental sustainability of printing is talked about. The different kinds of paper manufacturing processes have been and still are under strong research to improve the energy efficiency of paper making processes.

The information concerning energy consumption should be available and measurable for all machinery in the prepress, press and postpress rooms. In the printing houses the energy consumption should be made visual in real time to the operators. When the energy consumption is visualized and divided to machines the places for obvious energy savings can be found. In many print houses the consumption figures of paper material already exist but the information about the energy consumption should be included to guide towards optimal operations in machines

According to our measurements the digital printing presses consume almost as much energy on the stand by position as they do while printing [6]. The printers tend to keep the machines on stand by the whole night to ensure the perfect print quality from the first copy in the morning. Machine manufacturers should focus more on the quality of the first copy. The image of digital printing as a sustainable printing method is based on the idea that every copy printed is used.

The constant humidity and temperature conditions in the printing houses need also to be considered when thinking what a printing house can do to reduce environmental impacts. Air conditioning, warming and cooling did use energy according to our measurements more than was expected. Operating the printing presses needs always a supply of fresh air. The air conditioning is kept usually the same all the time, even some savings would be possible during the night time if the presses are turned off.

When the energy consumption of the servers is also calculated to the printing process the share of the prepress functions can be almost as high as the actual printing. The digital processing of the data needs to be as non-bearing as possible. Even tough the computers are faster and more efficient the software used should minimize the data handling in prepress.

The overall energy and material efficiency of a printing house is even more significant in the future. Evaluation and measuring with accurate data the energy and materials related to specific devices would be helpful to printers. This way they could find out the critical places in the process or in the work habits were to reduce emissions

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Author Biography

Merja Kariniemi received her M.Sc. degree in Graphic Arts Technology from Helsinki University of Technology in 1997. During 12 years she worked at KCL in different research and expert positions and in customer related positions. KCL was a research company of the Finnish paper industry. Since the merging of KCL and VTT in 2009 Mrs. Kariniemi has worked as a Senior Research Scientist at VTT. Now she is working in a national level printing and paper industry consortium project called Lean Development with Renewable Resources

Minna Nors, received her M. Sc (Tech.) degree on year 1995 in Graphic Arts Technology from Helsinki University of Technology, where she worked one year. In 1997-2003 she worked at Stora Enso Oulu mill in printing laboratory and laboratory manager positions. She joined KCL in 2003 working in different research and customer related positions until 2009. Currently she is Project Manager of the Lean Development with Renewable Resources –project and works as Research Scientist at VTT Sustainability assessment.

Marjukka Kujanpää received her M.Sc. degree in Energy Technology from Lappeenranta University of Technology in 2008. Since then she has done research on the field of Life Cycle Assessment and carbon footprinting. After graduation she worked as a project engineer at LUT and in autumn 2008 she joined the Sustainability assessment team at KCL. Since merging of KCL and VTT in 2009, she has worked as a research scientist at VTT.