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Revision of European Ecolabel Criteria for printed paper products

Preliminary report

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ABBREVIATIONS

AHWG	Ad-hoc Working Group meeting
AOX	Adsorbable rganic Halogen
BAT	Best Available Technology
BPA	Bisphenol-A
BREF	Best Available Techniques Reference Document
CLP	Classification, Labelling and Packaging
CO_2	Carbon dioxide
CTP	Computer to Plate
DIBP	Diisobutyl phthalate.
DIPN	Diisopropylnaphthalene.
EDTA	Ethylenediaminetetraacetic acid
EMAS	Eco Management and Audit Scheme
EN	European Norm
EU	The European Union
EUEB	The European Union Eco-labelling board
EuPIA	The European Ink Industry's Association
FSC	Forest Stewardship Council
GMO	Genetically modified organism
INGEDE	Internationale Forschungsgemeisccchaft de-inking-Technik (International Association of the De-inking Industry)
ISCC	(International Sustainability and Carbon Certification),
ITX	Isopropylthioxanthone
IPPC	Integrated Polution Prevention and Control
ISO	International Standardisation Organisation
LCA	Life Cycle Assessment
NGO	Non-governmental organizations
NOx	Nitrogen Oxides
PEFC	Programme for the Endorsement of Forest Certification
PAH	Polycyclic aromatic hydrocarbons.
PBT	Persistent Bioaccumulative Toxic
PVC	Polyvinyl chloride
PUR	Polyurethane
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RSB	Roundtable on Sustainable Biomaterials
RSPO	Round Table on Sustainable Palm Oil
RTTS	Round Table on Responsible Soy
SETAC	Society of Environmental Toxicology and Chemistry
SO_2	Sulphur Dioxide
VOC	Volatile Organic Compound
vPvB	Very persistent, very bio-accumulative

1 SCOPE AND DEFINITION

1.1 Introduction

This project aims to revise the existing EU Ecolabel criteria for printed paper product products. The Commission Decision of 16 August 2012 establishes the ecological criteria for the award of the EU Ecolabel for printed paper (Commission Decision 2012/481/EU[1]). The criteria and the related assessment and verification requirements were established, for the first time, in 2012 while the Decision currently in force is valid until 31 December 2018.

This preliminary report intends to provide the background information for the revision of the EU Ecolabel criteria for printed paper products. The study has been carried out by the Joint Research Centre (JRC- Seville) with technical support from LEITAT. The work is being developed for the European Commission's Directorate General for the Environment.

The process of developing or revising Ecolabel criteria is a dynamic process, where the involvement of stakeholders is essential. For this reason, they are involved in a consultation process on draft technical reports and criteria proposals and in working group meetings. This document provides the background information for the criteria amendment ahead of the first Ad-hoc Working Group meeting (AHWG), scheduled to take place in December 2018.

This report consists of:

- **Introduction**: This section describes the goal and content of the document.
- **Previous considerations**: This part gathers previous decisions and discussions before this revision process, which should be taken into account.
- **Scope definition**: This section shortly describes the current definition for printed paper product.
- **Stakeholder's questionnaire**: It summarizes the key outputs from the questionnaire sent to registered stakeholders, and containing questions about scope and criteria revision.
- **Market analysis**: This part comprises the main market data for the printing sector, at global and European level. It includes data on production, trade, geographical distribution, as well as market trends and forecasts.
- **Technical analysis:** It analyses the technical aspects of the different printing technologies, the main production operations, applications and innovations.
- **Life Cycle Assessment (LCA):** LCA evaluates the potential environmental impacts of printed paper products while considering their whole life cycle, i.e. from raw materials to end-of-life. The section includes a screening LCA based on literature review and performed LCA case studies.

1.2 Previous considerations

The main outputs from previous documents and statements regarding the printed paper product group have been taken into account.

[1] Commission Decision No 2012/481/EU of the European Parliament and of the Council of 16 August 2012 establishing the ecological criteria for the award of the EU Ecolabel for printed paper, available online at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012D0481

The European Commission Statement from 2009[2] highlights the following key points for a future EU Ecolabel revision for printed paper products:

- If the printers and publishers wish to have a broader base on environmental certified paper grades to produce EU Eco-labelled printed paper products.
- The suitability of the assessment and verification of criterion 2a should be reconsidered against chemicals like nanomaterials.
- Criterion 1 should reflect a more horizontal approach concerning the equivalency of schemes to certify the sustainability of substrate fibres.

From the previous revision, establishment of the current criteria of 2012, the following criteria were discussed and they were finally excluded:

- <u>Transports:</u> Requirements on transports were discussed, but the concluded that they were not steerable by the most of the printing houses. Therefore, no criteria on transports were proposed.
- <u>Chemical products:</u> During the criteria development, it was discussed whether it is possible to set criteria on the chemicals production step as is done for the production of paper. The outcome advocates that it is beyond the frame of this project to develop such criteria. As regards the paper production, EU Ecolabel criteria are already set for graphic paper. The possibility of developing criteria for the production of the chemicals might be taken into consideration when the criteria for printed paper products are revised.
- <u>Energy:</u> The LCA studies showed that the energy use during printing has some but not the major impact on the environment. The majority of the small printing houses not actively consider energy savings or renewable energy sources. Therefore, the energy requirements are drawn up flexible. It was judged, that it is not possible to set limits to the energy use in printing in this first generation of criteria because the printing houses are far too heterogeneous.

In addition, other EU Ecolabel paper product groups have been analysed to identify synergies or possible overlaps.

1.3 Existing EU Ecolabel definition for printed paper products

The current EU Ecolabel printed paper products scope under revision is based on the final use/destination of the product.

EU Ecolabel for printed paper products (Commission Decision 2012/448/EC)

"The product group 'printed paper' shall comprise any printed paper product that consists of at least 90% by weight of paper, paperboard, or paper-based substrates ,except for books, catalogues, pads, booklets or forms that shall consist of at least 80% by weight of paper or paperboard of paper-based substrates. Inserts, covers and any printed paper part of the final printed paper shall be considered to form part of the printed paper product"

[2] Summary of the meeting of the Regulatory Committee established under Article 16 of Regulation (EC) N° 66/2010 of 25 November 2009 of the European Parliament and of the Council on the EU Ecolabel

(2) Fixed inserts to the printed paper product (not intended to be removed) shall fulfil the requirements of the Annex to this Decision. Inserts that are not fixed to the printed paper (such as flyers, removable stickers) but sold or provided with it, shall fulfil the requirements of the Annex to this decision only if the ecolabel is intended to be placed on them.

(3) The product group 'printed paper' shall not include printed tissue papers, printed paper products used for packaging and wrapping, folders, envelops and ring binders.

1.4 Feedback from scoping questionnaire

A questionnaire was sent out to stakeholders registered for participating in the revision process. Its aim was to identify possible issues of relevance for the revision at this early stage. Diverse questions about the scope and the specific criteria were answered, and the results are interpreted and presented in the following paragraphs.

A total number of 35 stakeholders participated in this early stage of the revision process. The diverse types of stakeholders, who have reacted to the call, were classified as industry, competent bodies of the EUEB members, buyers, NGOs, government, and others. As can be seen in Figure 1, the most representative type is industries (43%) involved in the printed paper supply chain, followed by competent bodies of the member states (20%) and other types (28%), such as universities and consultancies.

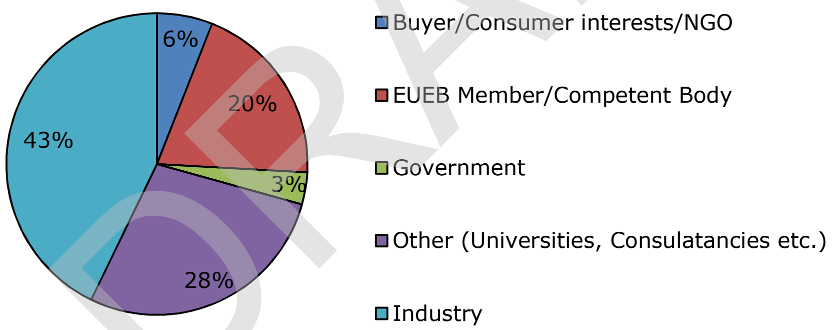


Figure 1. Classification of stakeholders by interest or type of organization

In a next step, the report divides industry branches according to their position at the printed paper supply chain into three different groups, Industry- Supplier (i.e. Paper substrate, printing equipment or chemicals), Industry- Intermediate (i.e. Printing house) and post-production involved industries, such as waste management companies. Figure 2 points out the shares by group and suggests the printing houses and their suppliers are the key groups.

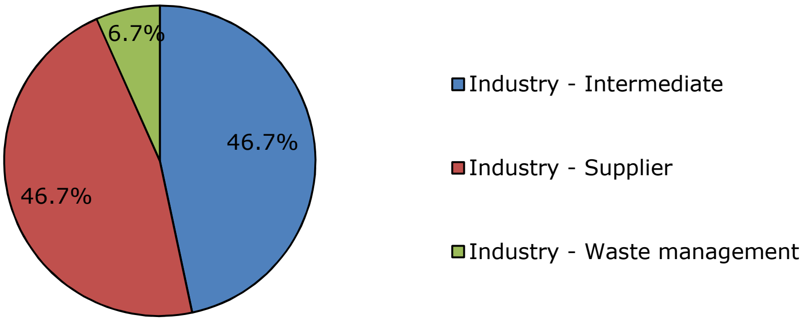


Figure 2. Classification of industries by type of industry

1.4.1 Questionnaire results - Scope

This section reflects the replies to scope-related questions. First, the stakeholders were asked about difficulties they face to include products to the current scope and secondly whether they have any difficulties to understand the scope. The results are pointed out in Figure 3 and Figure 4.

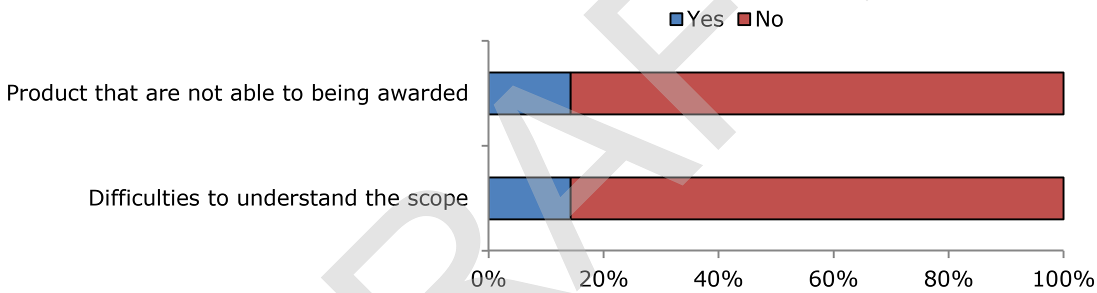


Figure 3. Difficulties encountered during the certification procedure

Figure 3 shows 80% of the stakeholders not to face any difficulties to include products in the current scope. However, it is reasonable to further analyse the results in Figure 3, considering the stakeholders' knowledge about the EU Ecolabel. Hence, another question was included addressing followings:

- Was the stakeholder actively involved in the EU Ecolabel development process for any paper-based product in the past?
- Is any licence already awarded to the stakeholder?
- Considers the stakeholder to apply for an EU Ecolabel license for printed paper products?
- None of the above

Only stakeholders involved in a previous revision or those having obtained a license, have difficulties to understand the scope. On the other hand, only stakeholders that have tried to obtain the EU Ecolabel for a specific product could be affected by the second question.

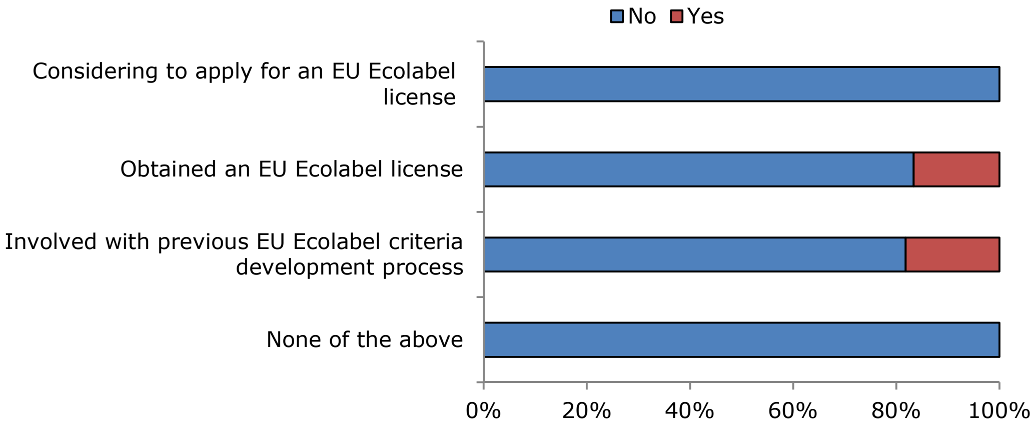


Figure 4. Difficulties encountered to understand the scope

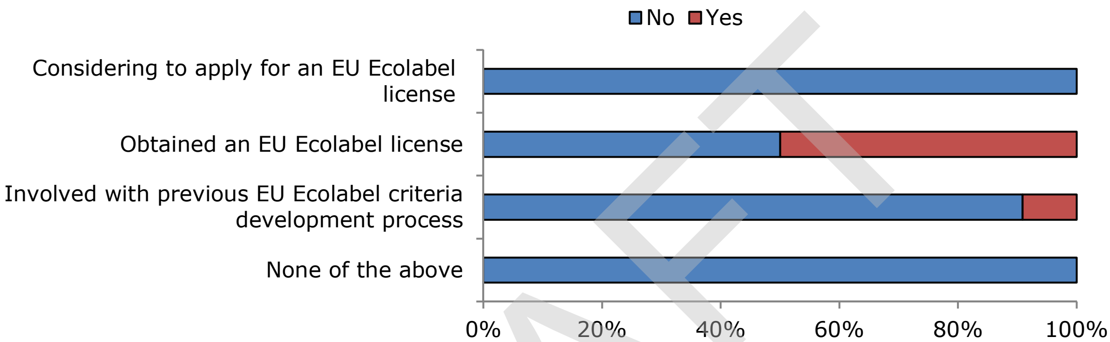


Figure 5. Difficulties encountered to award a product

Finally, the results of both questions have been analysed according to the different types of organizations included in the study. Industry (suppliers and intermediate) is the type of stakeholder more affected by the scope.

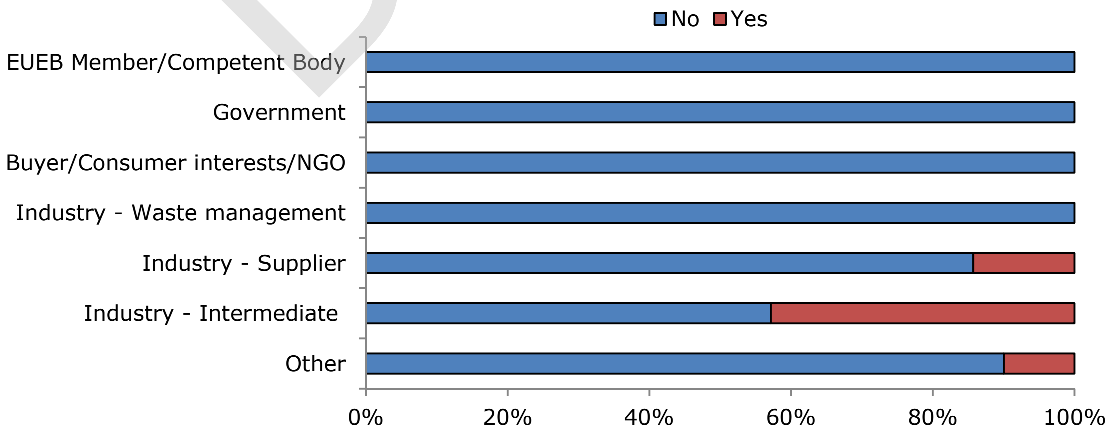


Figure 6. Difficulties encountered to understand the scope. Responses divided by type of organization

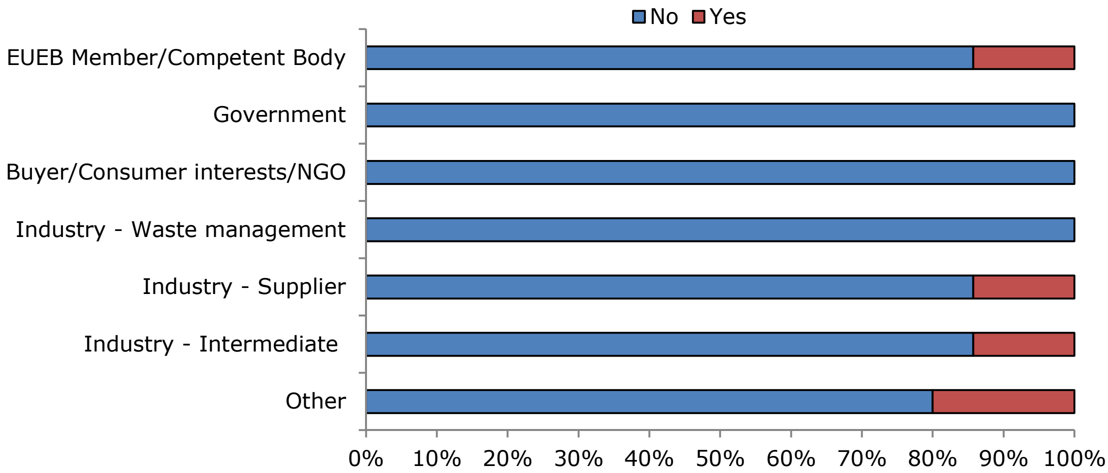


Figure 7. Difficulties encountered to award the EU Ecolabel to a product. Responses divided by type of organization

The results in Figure 8 suggest 31% of the stakeholders support an amendment in the scope. However, 34% do not see a necessity for scope alteration.

Stakeholders have also been asked about the possibility to change the product group scope from product to service. The outcomes show 17% of the stakeholders to agree with changing the scope; nevertheless, 26% are against this modification. It is important to note that 40% of the stakeholders are not sure whether the support or to be against this change as can to assess the benefits of such a decision.

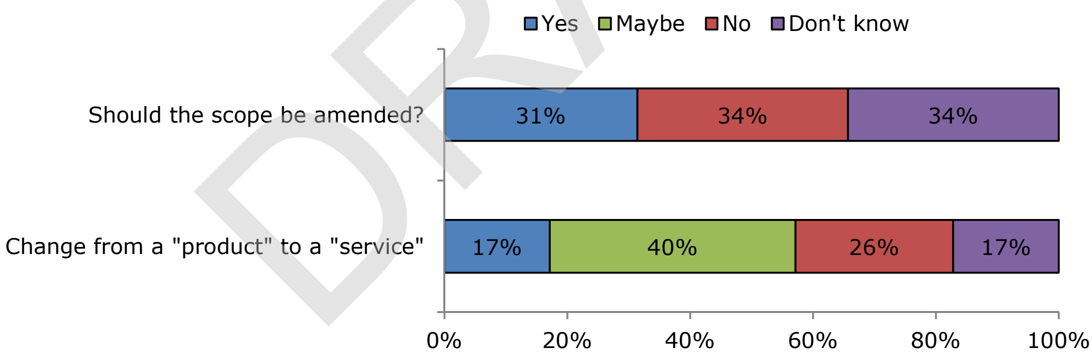


Figure 8. Stakeholders' opinion about current scope

1.4.2 Questionnaire results - Criteria requirements

A question was submitted to observe the interest of stakeholders in including new criteria. Their replies as presented in Figure 9 reflect 49% of the stakeholders are against any new criteria introduction, and only 23% considers necessary to include new requirements. Some of the proposals made during this consultation are:

- Carbon footprint
- Packaging for distribution
- Headset offset web printing and newspaper printing
- Mineral oil free inks

- Recyclability of the product and reuse of paper.

In addition, some comments have been received about the need to update the criteria requirements in the case of product scope alteration to service. The replies strongly advocate (49%) against such change.

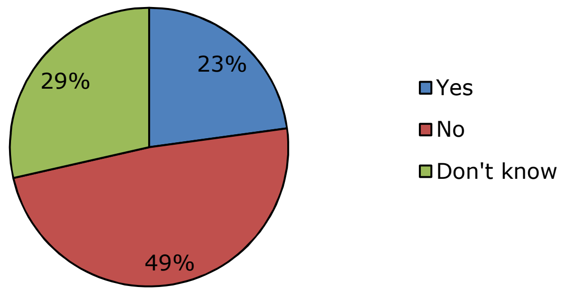


Figure 9. Stakeholders' opinion about current criteria

Criterion 1 – Substrate

Different questions have been asked about criterion 1 described as follows:

- Shall the printed paper product be printed only on paper bearing the EU Ecolabel?
- Should specifications including weight/m^2 of the paper be provided?
- Should paper supplier names be provided?
- Should a copy of the valid EU Ecolabel certificate for the paper be included in the application?

The results suggest, most of the stakeholders agree on keeping the criterion referring to the use of EU Eco-labelled paper substrate. However, 29% of the participants are against it. Some comments were received about the possibility of opening the criteria to other type 1 Ecolabels. Concluding, one stakeholder pointed out that in some cases it is not possible to obtain a printed paper EU Ecolabel licence as there is not the adequate quantity of EU Eco-labelled substrate.

Substrate specifications, including weight/m^2 met a strong opposition (37%) while the vast majority of responses highlight the neutral option. On the opposite, stakeholders' support on this requirement is moderate (17%) (Figure 10).

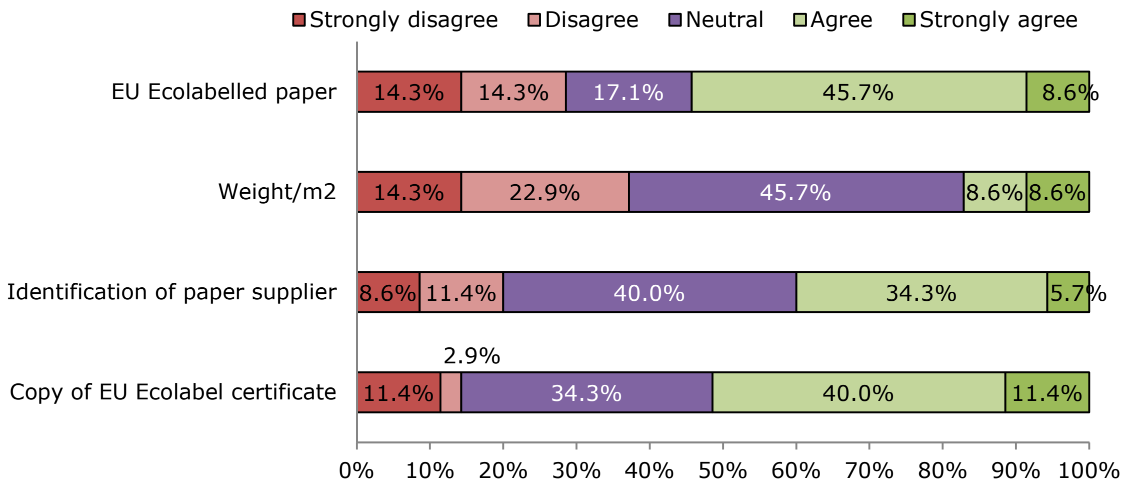


Figure 10. Stakeholders' opinions about criterion 1

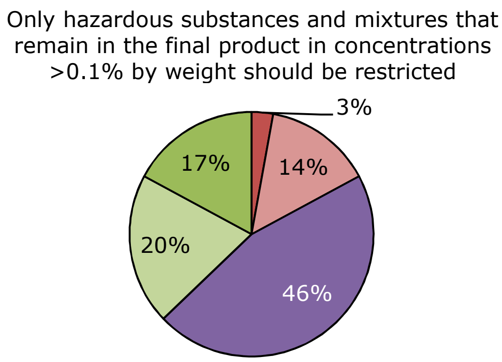
__Criterion 2 – Excluded or limited substances and mixtures__

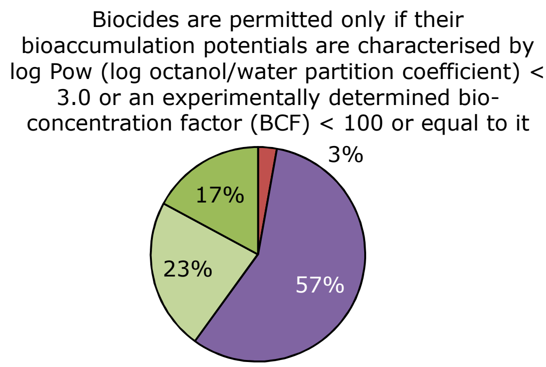
In general, the stakeholders agree with the current proposal of criterion 2 (Figure 11). However, most of the answers support the neutral choice. The latter varies between 26%–57%, depending on the specific substance.

The choice against the current sub-criteria reaches its max in hazardous substances limitation (17%), followed by the derogation of UV varnished and inks classified as H412 (12%). All stakeholders agree to restrict alkyl phenol ethoxylates, halogenated solvents and phthalates during the printing process.

Comments related to the specific substances include:

- H304 used in inks and tonners should be derogated. Also for washers and cleaners.
- H411, H412 and H413 should be derogated for gums.
- H371 and H373 should be derogated for developers.
- Exclusion of the following substances: fluorinated substances, nano-particles, substances considered to be hormone-disruptive or potentially hormone-disruptive, GMO starches, EDTA and its salts, sodium or calcium hypochlorite, poly and perflourinated alkylated substances or alkylphenalethoxylates and derivatives.





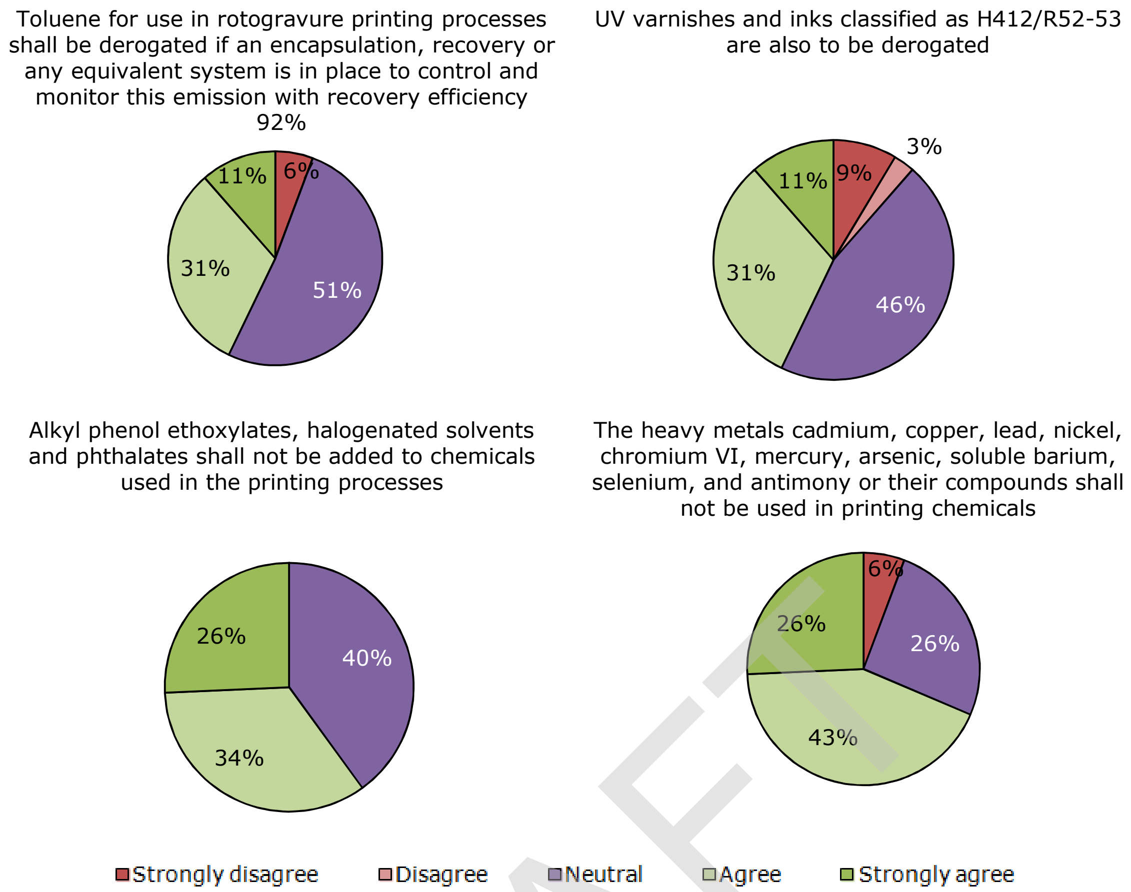


Figure 11. Stakeholders' opinion about criterion 2

<u>Criterion 3 – Recyclability</u>

Excluding the neutral choice (14%), all stakeholders agree with the recyclability requirement set in the criterion 3. Following recyclability, the de-inkability requirement is supported by 74% of stakeholders whereas 3% strongly disagree (Figure 12).

The use of wet strength agents and adhesives are restricted in the current criterion. In accordance with this, stakeholders agree on restricting these substances (46% and 60%, respectively). On the contrary, against these requirements, are less than 15%. In fact, the current EU Ecolabel is restricting only the non-soluble adhesives. Further on, the stakeholders agree to exclude water soluble adhesives as there are no relevant test methods to evaluate them.

The next question addresses the restrictions on coating varnishes and lamination. The results show equal percentages (29%) in favour and against to imposing these restrictions while less than half of the participants have a neutral opinion.

The last question referred to de-inkability. The majority of stakeholders (52%) agree the de-inkability of the product to be verified and demonstrated. However, some of them point out the proof of de-inkability shall not be mandatory.

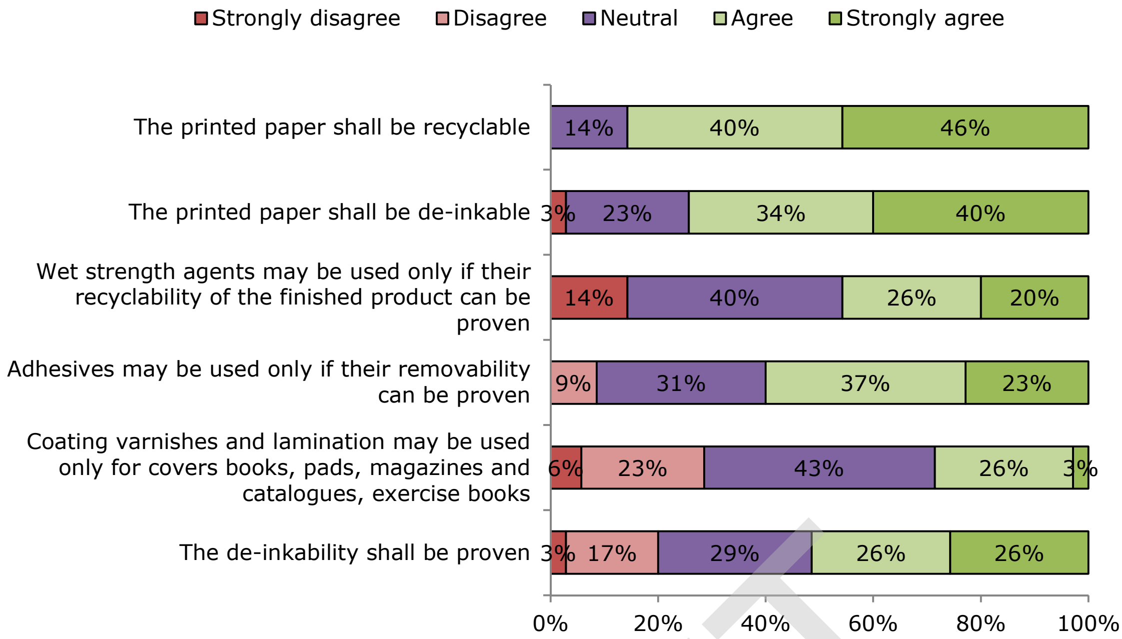
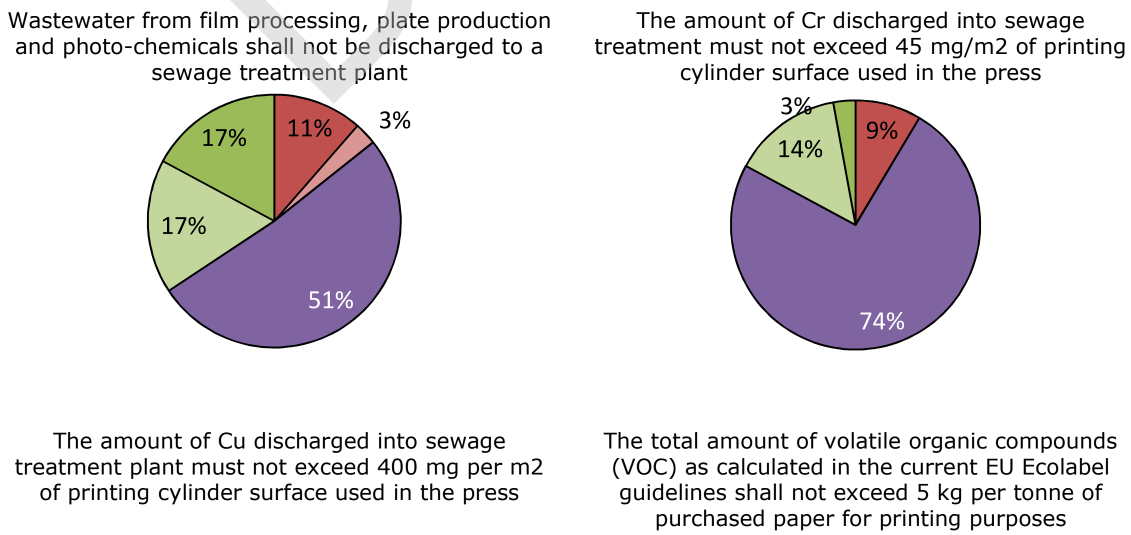


Figure 12. Stakeholder responses related to criterion 3

__**Criterion 4 – Emissions**__

The responses of the criterion 4 related questions (Figure 13) disclose a strong neutral preference (67%) of the stakeholders. It should be noted, only one quarter holds an opinion about that particular issue. In that specific case the agree choice outweighs the disagree option. Furthermore, the responses denote disagreements about the amount of VOC emissions per tonne of purchased paper and the discharge of wastewater from film processing, plate production and photo-chemicals. Consequently, they propose to ament the threshold of VOC emissions while a single stakeholder expressed the opinion the VOC restriction makes more sense in the case of scope modification to a service.



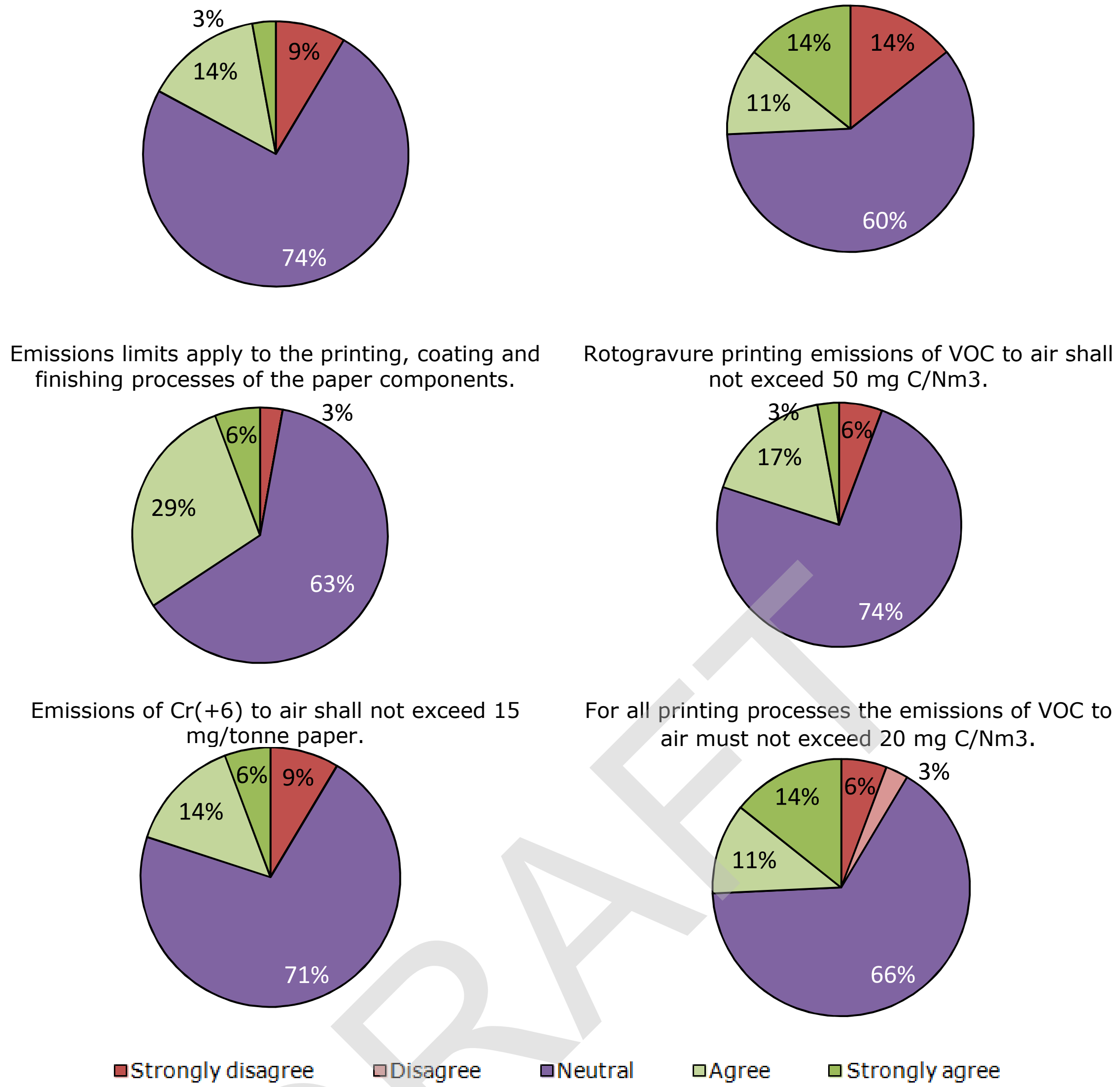
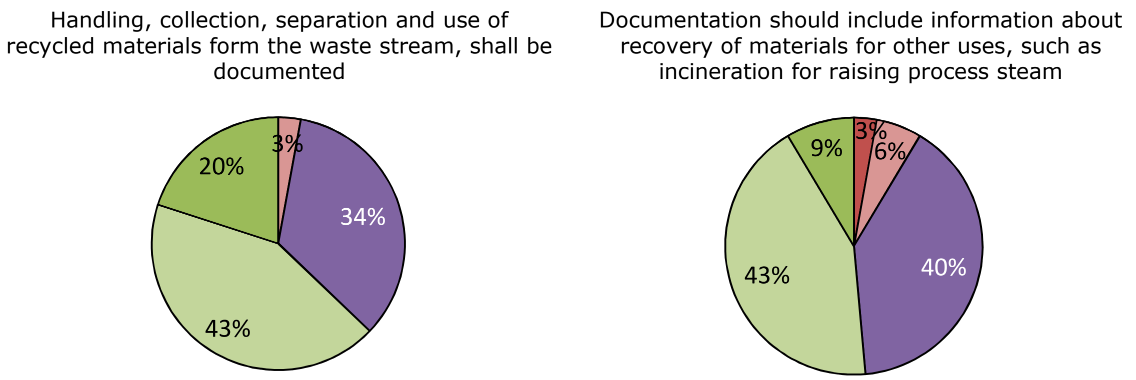


Figure 13. Stakeholder opinion about criterion 4

Criterion 5 – Waste

Concerning the waste management sub-criterion, most of the stakeholders agree with its requirements. However, when they were asked about the declaration of compliance, against and pro responses showed almost equal shares. The outcomes recommend a strong neutral tendency on this particular question Figure 14.



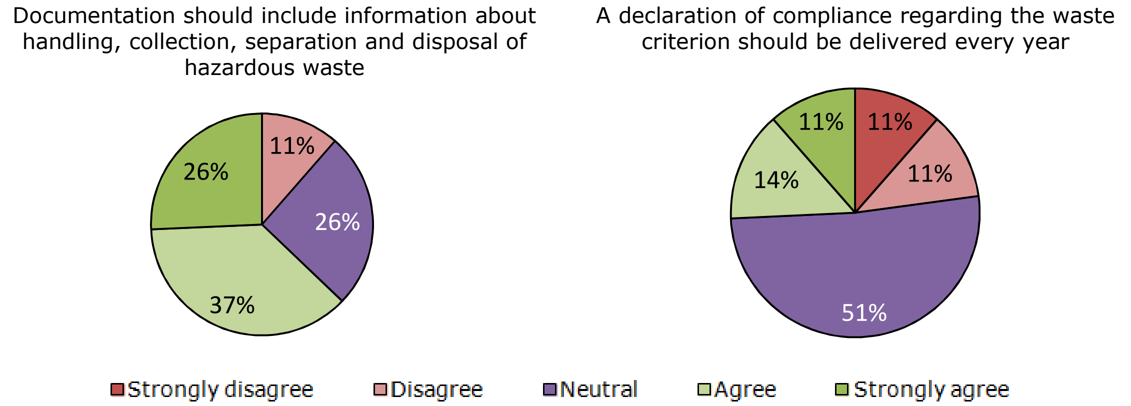


Figure 14. Stakeholder opinions about criterion 5

In regards to the sub-criterion waste paper, the 'not agree' choices, across all questions, are less than 22%. On the contrary, the majority of the stakeholders agree with the existing assessment and verification method (Figure 15).

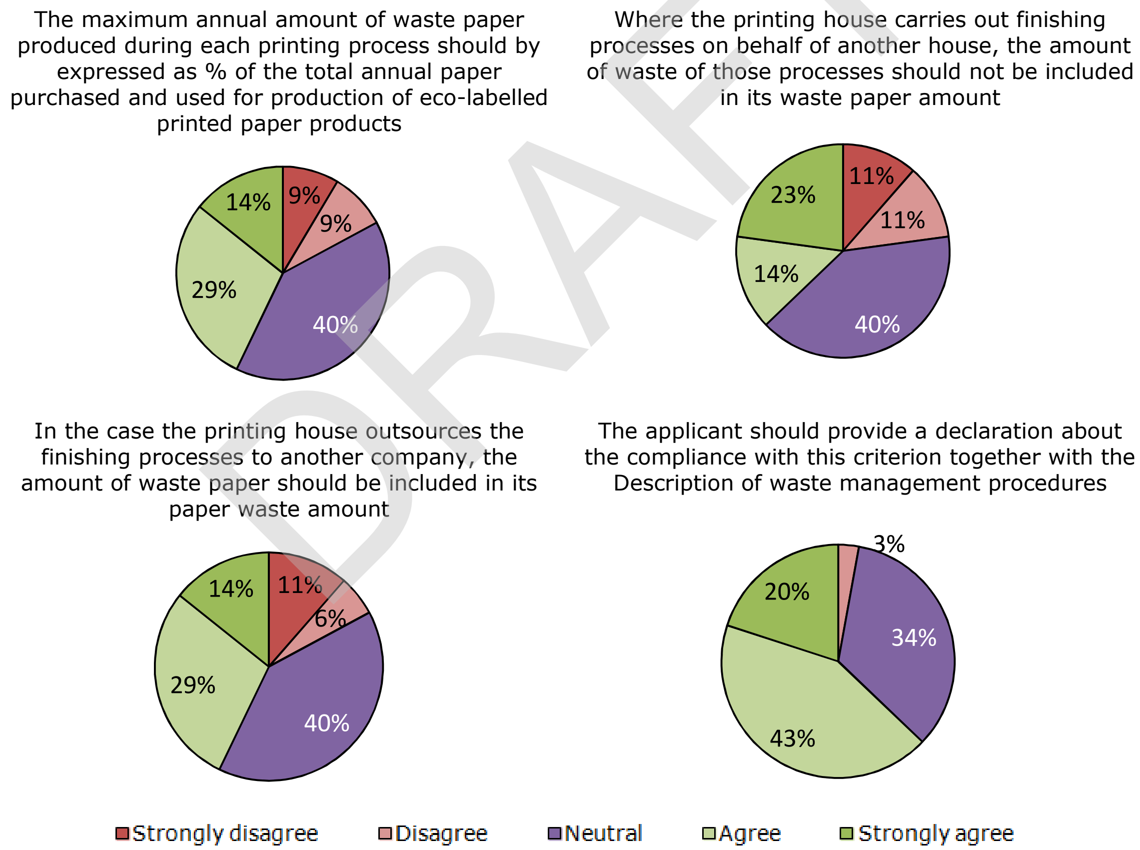


Figure 15. Stakeholder opinions about criterion 5

Criterion 6 – Energy

The neutral option is most selected by the stakeholders (40%-54%). However, the agree options is also selected in a moderate to high level (37%-51%). On the contrary, there is a smaller percentage (11%) that opposes the implementation of an energy consumption record as Figure 16 displays.

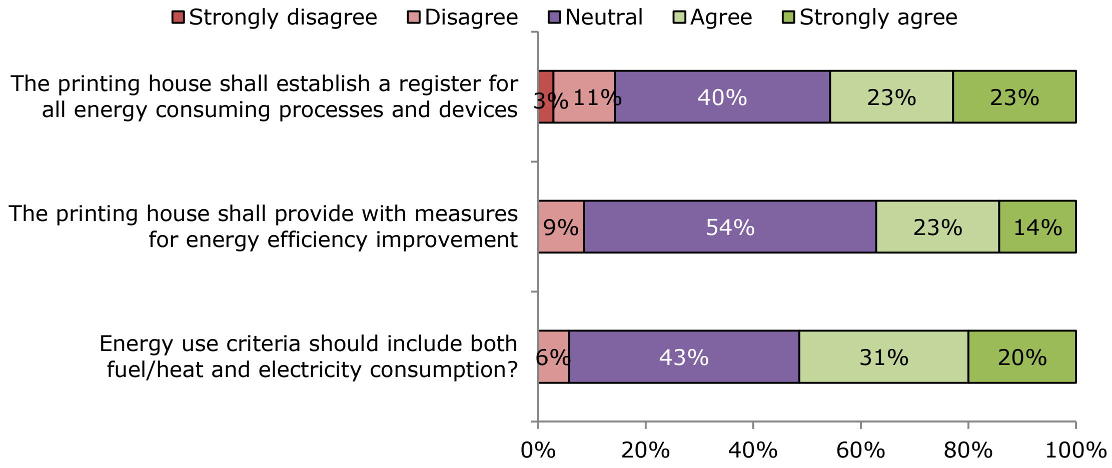


Figure 16. Stakeholder opinions about criterion 6

Criterion 7 – Training

Figure 17 shows 60%-77% of the responders in favour of the training requirement for the staff. Moreover, there is no disagreement to this particular criterion. The results indicate only a small amount of responses (6%) not agree with the methodology used for the assessment and verification of the training activities.

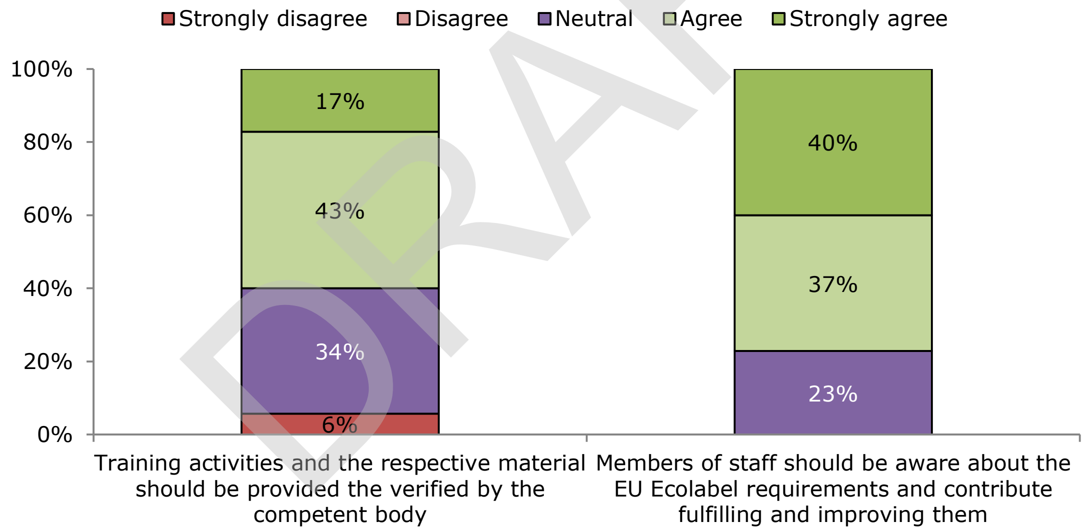


Figure 17. Stakeholder opinion about criterion 7

Criterion 8 – Fitness to use

Criterion 8 is well received by the stakeholders. Its acceptance ranges between 40%– 63%. The less supported option is the documentation of compliance requirements with the disagree option to contribute 22% (Figure 18).

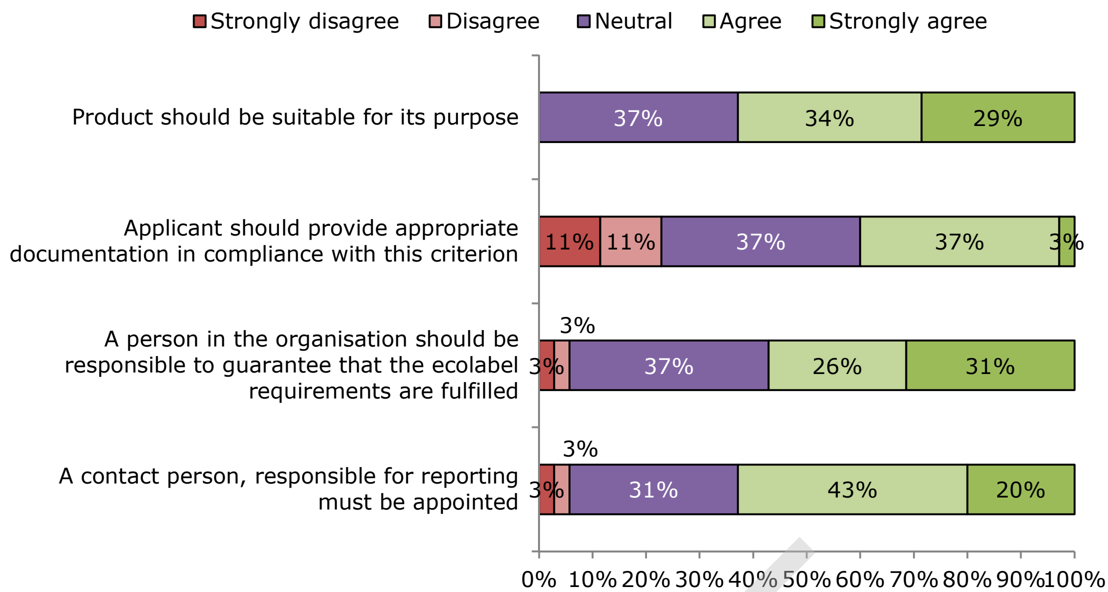


Figure 18. Stakeholder opinion about criterion 8

Criterion 9 – Information on the product

Almost 57% of the stakeholders agree with the Criterion 9 whereas a moderate percentage does not agree with the verification procedure. In general, one third of the stakeholders disagree with providing a sample of the product packaging whereas a similar percentage of responders agree on that (Figure 19). The question about the indication of endorsement to collect used paper showed 17% of stakeholders to disagree on complying with this obligation.

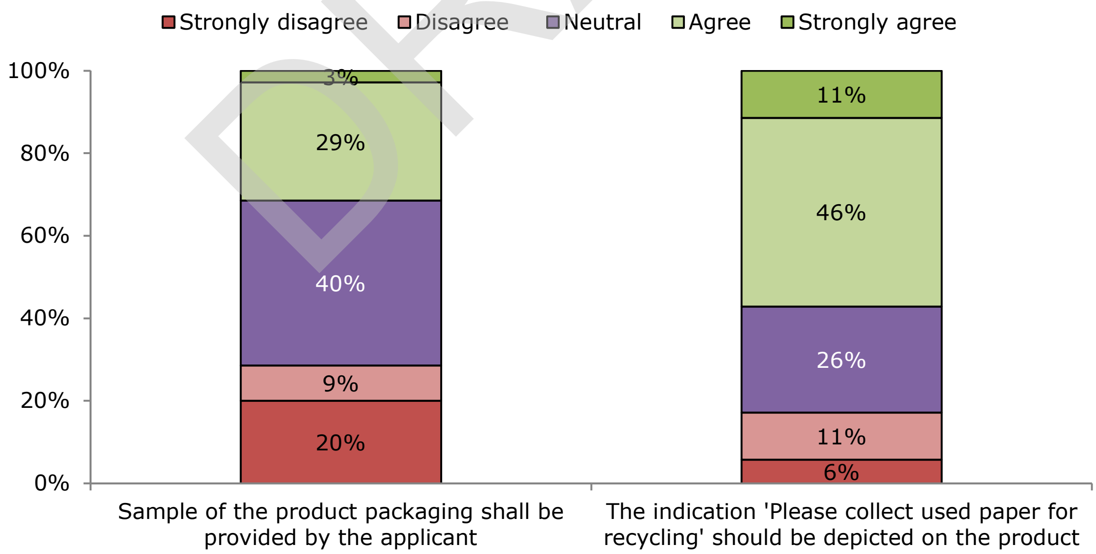


Figure 19. Stakeholder opinion about criterion 9

Criterion 10 – Information appearing on the EU Ecolabel

Figure 20 points out the majority of the stakeholders to support the implementation of this criterion. There is a moderate percentage (17%) of stakeholders that oppose to provide any sample of the product during the certification procedure.

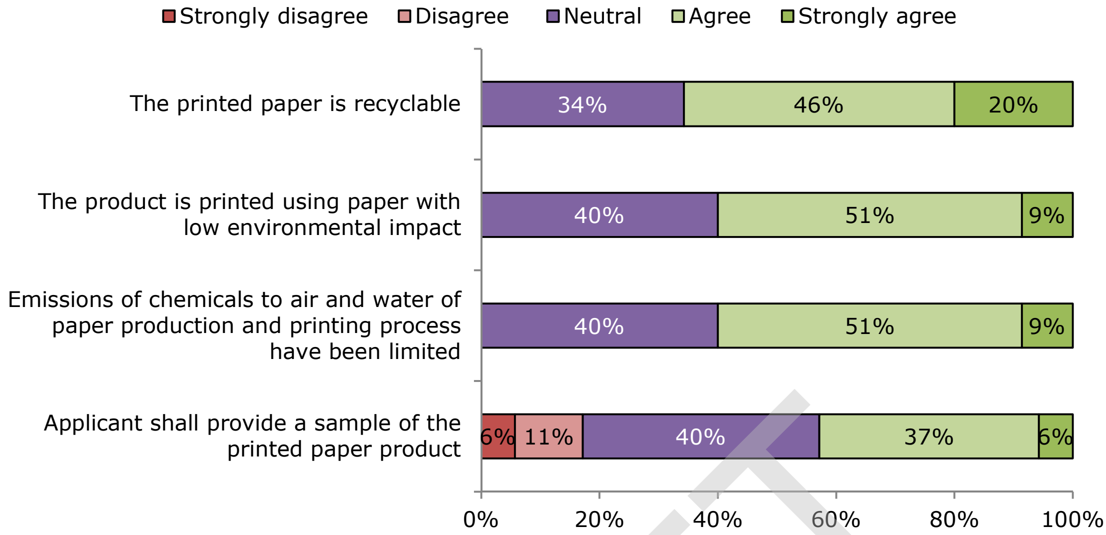


Figure 20. Stakeholder opinion about criterion 10

1.5 Existing legislation and standards

Relevant European environmental policy and legislation has been identified through the environmental regulations database. Specific EU legislation for printed paper products as well as several legislation and standards related to the environment, chemicals, health and safety that directly affect these products, have been analysed. The following environmental legislations are relevant for the production of printed paper products:

- DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control):
- The IPPC directive aims at reducing, preventing and controlling pollution in an integrated way using "best available technique" requirement (BAT). Printing installations are included in the BREF (Best Available Techniques Reference Document) on surface treatment using solvents.
- IPPC directive applies only for big plants. Installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating, with a consumption capacity of more than 150 kg per hour or more than 200 tonnes per year.
- COUNCIL DIRECTIVE 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installation.
- Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC

and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (Text with EEA relevance).

- REGULATION (EC) NO 1907/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)).
- DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy) for emissions to water.
- DIRECTIVE 2002/61/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 July 2002 amending for the nineteenth time Council Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations (azo-colourants)) amending Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations.
- COUNCIL DIRECTIVE 75/442/EEC of 15 July 1975 on waste and its amendments.
- Regulation (EU) N° 528/2012 concerning the making available on the market and use of biocidal products that will repeal and replace Directive 98/8/EC.

The European REACH Regulation (EC) 1907/2006 requires that all substances on the EU market are assessed for their impact on human health and on the environment. Appropriate measures to ensure all uses are safe to human health and to the environment must be introduced.

Raw material selection can be influenced by the requirements of specific environmental protection legislation, which applies to printed materials and articles, such as the Packaging and Packaging Waste Directive, and the Restrictions on Hazardous Substances Directive (RoHS).

Regarding voluntary approaches, a growing number of printed paper products manufacturers are implementing environmental management schemes (e.g. EMAS) in order to improve their environmental performance. Standards, which also have a voluntary nature, are also an important aspect to take into account such as BS EN 643:2014 on standard grades of paper and board for recycling which prohibits any material that represents a hazard for health, safety and environment. Moreover, there are two Technical Committees: ISO/TC 6 on Paper, board and pulps that develops standards on terminology issues, sampling procedures, test methods, product and quality specifications, and the establishment and maintenance of appropriate calibration systems and the ISO/TC 130 that addresses standardization in the field of printing and graphic technologies.

In addition, the main ecological labels in paper products such as Nordic Swan, Blue Angel, NF Environment, Paper by Nature, labels on forest management (FSC and PEFC), etc., have been identified in order to establish a comparison with criteria set in EU Ecolabel and introduce measures to encourage harmonisation with other ecolabel schemes. The following table is a brief comparison of the main labels used on printed paper products. It summarises the scope of each label and production processes with environmental criteria.

Table 1. Comparison of the main labels used in Printed papers products. Draft background report version 03, May 2013, Bureau Veritas

Label		Where	Scope						Forest Manage-ment	Paper Production	Board Production	Printing & Converting process
			Paper substrates	Exercise books	Magazines &Books	Envelopes	Filing products	Paper carrier bags				
Official European Ecolabels												
	EU Ecolabel Printed Paper	EU		√	√				√	√	Only for Copying and Graphic Paperboard with W < 400 Gsm	√
	EU Ecolabel Converted Paper Products	EU				√	√	√	√	√	√	√
	EU Ecolabel Copying and Graphic paper	EU	Copying & Graphic Paper						√	√	Only for Copying and Graphic Paperboard with W < 400 Gsm	
Official National Ecolabels												
	Nordic Swan - Paper Products; Envelopes - Printing companies	Scandinavia (Europe)	√	√	√	√	√	√	√	√		√
	NF Environment - Copying and graphic paper; Envelopes;- Exercise books	France	√	√		√			√	√		√
	Blue Angel - Printed matter			√	√							√
	Blue Angel - Recycled Paper; Recycled Cardboard - Printing and publication Papers	Germany	√	√	√	√	√		Only for virgin fibers < 20%	√ Recycled Paper	√ Recycled Cardboard	
			Only recycled material									
Other Labels												
	Paper by Nature	EU		√	√	√	√	√	√	√	√	√
Labels on Forest Management												
	FSC®	World	√	√	√	√	√	√	√			
	PEFC™	World	√	√	√	√	√	√	√			

2 MARKET ANALYSIS

The aim of this section is to provide all market-related information necessary for the revision of the EU Ecolabel for printed paper products (Commission Decision 2012/481/EU[3]).

The next sections offer an overview of the printing industry, and the printed paper products market at global and European level. Their current size in volume and value is portrayed. Further on the European market is examined considering member states, types of manufactured printed products and key printing technologies. Intra and extra EU28 trade activities are also investigated. The structure of the market, its key characteristics and sales forecasts are presented. The main drivers in the market are shown while the consumer perspective is adopted. Finally, an analysis of strengths, weaknesses, opportunities and threats for the printing sector is carried out following the SWOT approach.

2.1 Methodology and sources of information

Market data presented in this report has been mainly taken from published reports and official statistics. Complementary data about the printing sector have been gathered from other reports when needed.

The reference period covers the years 2009 to 2017 while the report incorporates the most recent data (2016-2017). Only in the cases updated data is not available, the respective from previous years are presented (2014-2015).

For the EU market data, the main indicators, related to the production and trade of printed paper products in the EU 28 and across each single member state, are evaluated. Production data have been extracted from the Eurostat database and market access database. The indicator used is PRODVAL, which is examined to assess the economic significance of production in the EU28 countries. PRODVAL data are expressed in terms of monetary value (million Euros). According to NACE, the statistical classification of economic activities in the European Community, printed products are included in the activity code 181. This division encompasses different activities related to printing sector. An overall investigation of all activities related to the printing industry (including pre-press, printing and binding) is performed. Printing categories (18.12) are analysed in more detail. Regarding this group those product types printed on other substrates different from papers have been excluded. The classifications[4] and the selection for the study are detailed in Table 2.

Table 2. PRODCOM classification for printed paper products to be studied

PRODCOM Classification	PRODCOM Code	Description	Included in the study scope
18.11 Printing of newspapers	18111000	Printed newspapers, journals and periodicals, appearing at least four times a week	x
	18121100	Printed new stamps, stamp-impressed paper, cheque forms, banknotes, etc.	x
	18121230	Printed commercial catalogues	x
	1812125	Printed trade advertising material (excluding	x

[3] 2011/481/EU: Commission Decision of 16 August 2012 on establishing the ecological criteria for the award of the EU Ecolabel to Printed paper products

[4]Product classifications according to Eurostat PRODCOM(http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/introduction)

18.12 Other printing	0	commercial catalogues)	
	18121300	Printed newspapers, journals and periodicals, appearing less than four times a week	x
	18121407	Printed books, brochures, leaflets and similar printed matter, in single sheets	x
	18121414	Printed books, brochures, leaflets and similar printed matter (excluding in single sheets)	x
	18121421	Printed children's picture, drawing or colouring books	x
	18121428	Printed dictionaries and encyclopaedias, and serial instalments thereof	x
	18121435	Printed maps, hydrographic or similar charts, in book-form	x
	18121442	Printed maps, hydrographic or similar charts (excluding in book-form)	x
	18121449	Printed postcards, whether or not illustrated	x
	18121456	Printed cards bearing personal greetings, messages or announcements, whether or not illustrated, with or without envelopes or trimmings	x
	18121463	Printed pictures, designs and photographs	x
	18121610	Printing onto textiles	
	18121620	Printing onto materials other than fabric or paper	
	18121910	Printed calendars of any kind, including calendar blocks	x
	18121920	Printed music (including braille music)	x
	18121930	Printed transfers (decalcomanias)	x
	18121990	Other printed matter, n.e.c.	x
18.13 Pre-press and pre-media services	18131000	Composition, plate-making services, typesetting and phototypesetting	
	18132000	Printing components	
	18133000	Other graphic services	
18.14 Binding and related services	18141010	Bookbinding and finishing of books and similar articles (folding, assembling, stitching, glue, cutting, cover laying)	
	18141030	Binding and finishing of brochures, magazines, catalogues, samples and advertising literature including folding, assembling, stitching, gluing, cutting, cover laying	
	18141050	Binding and finishing including finishing of printed paper/cardboard excluding finishing of books, brochures, magazines, catalogues, samples, advertising literature	
58.1 Publishing of books, periodicals and other publishing activities	58.11	Book publishing	
	58.12	Publishing of directories and mailing lists	
	58.13	Publishing of newspapers	
	58.14	Publishing of journals and periodicals	
	58.19	Other publishing activities	

Source: Eurostat. PRODCOM

The NACE rev2 18.12 code (Other printing) includes printing of magazines and other periodicals appearing less than four times a week, printing of books and brochures, music manuscripts, maps, atlases, posters, advertising catalogues, prospectuses and other printed advertising, postage stamps, taxation stamps, documents of title, cheques and other security papers, smart cards, albums, diaries, calendars and other commercial printed matter, personal stationery and other printed matter by letterpress, offset, photogravure, flexographic, screen printing and other printing presses, duplication machines, computer printers, embossers etc., including quick printing, printing directly onto textiles, plastic, glass, metal, wood and ceramics.

The printed material is typically copyrighted. This specific class also includes printing on labels or tags (lithographic, gravure printing, flexographic printing and other). On the opposite, it excludes silk-screen printing on textiles and wearing apparel (13.30), manufacture of stationery products (notebooks, binders, registers, accounting books, business forms etc.) (17.23) and publishing of printed matter (*58.1 Publishing of books, periodicals and other publishing activities*).

For imports and exports, Eurostat data have been used. For the codes no data available, information is gathered using the TRADE MAP[5] of the International Trade Centre (ITC). That is related to the product group 49 printed books, newspapers, pictures and other products of the printing industry as well as manuscripts. Data for intra-EU (transactions among EU member states) and extra-EU transactions (flows between EU and the rest of countries) are reported.

Forecasts are elaborated based on literature data which is extracted mainly from commercial market studies.

2.2 Structure of the EU printing sector

This section analyses the main characteristics that determine the performance of the sector (key actors, companies, competition, etc.) and the potential penetration of the EU Ecolabel in the market. The printing industry has a long tradition in Europe. Therefore, the sector is well linked with other forest-based industries, such as wood-working, pulp, and paper manufacturers. It is an important employer which attracts and recruits highly skilled personnel. However, it faces challenges related to customer habits changes, shifts to digital communication, and competition from non-EU countries[6].

The EU printing sector encompasses approximately 98,000 companies which employ around 505,800 workers. The industry is dominated by family-owned, small and micro companies that mainly operate in domestic markets; 90% of companies employ fewer than 20 people. EU printing enterprises generate an annual turnover of around €88 bn. Printed paper products account for €44 bn according to Eurostat data[7].

The sector reacts to niche markets and local needs. Modern technologies have increased the sector’s productivity and its ability to provide a complete range of services. At the same time, process automation has triggered a change of the main workforce from craftsmen to technicians.

The printing sector employs people with specific skills in science, technology, engineering, IT and design, yet the graphic industry offers jobs to skilled workers in the fields of finishing, logistics and delivery. In Europe, the sector makes significant annual investments aiming to enhance its competitiveness and mitigate

[5] TRADE MAP. Trade statistics for international business development.
https://www.trademap.org/Country_SelProduct_TS.aspx?nvpm=1||14719|||49|||2|1|1|2|2|1|3|1|1
[6] https://ec.europa.eu/growth/sectors/raw-materials/industries/forest-based/printing_en_en
[7] Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) - Eurostat

environmental impacts[8]. According to the latest data, the sector's investments in research are climbed at €229 m in 2016, corresponding to approximately 9.5 €/habitant[9]. This amount stands for 0.52% of the total sector's turnover. The investment rate (investment/value added at factors cost) related to printing was 12% (printing and service activities) in 2016[10].

The number of enterprises in the printing sector was 97,73810 in 2016. As it can be seen in Figure 21, it has been decreasing since 2014. A similar trend denotes Figure 23 on the number of employees.

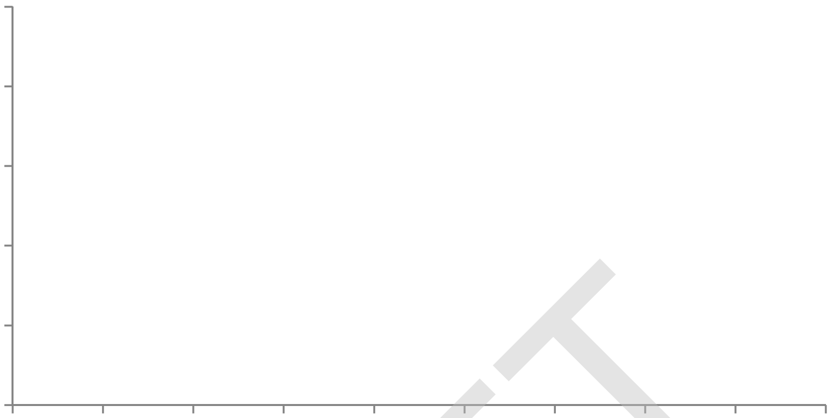


Figure 21. Number of enterprises in the printing sector (EU28)
Source: http://data.trendeconomy.com/dataviewer/eurostat/

The EU countries with the highest number of printing companies are France, Spain, UK, Germany and Poland (Figure 22).

Figure 22. Number of enterprises by Member State, 2016. (EU28)
Source: http://data.trendeconomy.com/dataviewer/eurostat/

[8] INTERGRAF. HOW THE EUROPEAN GRAPHIC INDUSTRY CONTRIBUTES. (https://www.intergraf.eu/images/Intergraf10prioritiesEUA4.pdf)
[9] EUROSTAT. Business expenditure on R&D (BERD) by NACE Rev. 2 activity. 2016 data.
[10] http://data.trendeconomy.com/dataviewer/eurostat/

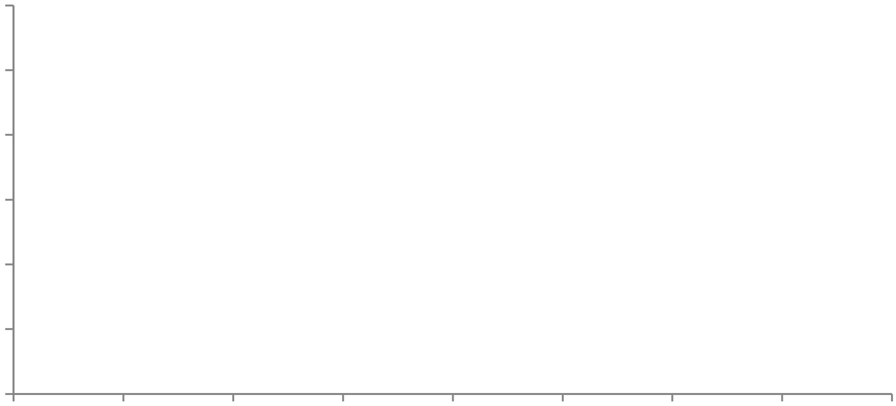


Figure 23. Number of employees (EU28)
Source: http://data.trendeconomy.com/dataviewer/eurostat/

2.2.1 Key actors

Main stakeholders involved in the manufacturing value chain are suppliers of raw materials (mainly chemical, paper industry and machinery manufacturers), designers, ICT and technological suppliers, equipment manufacturers, printing houses, finishing services, logistics, retailers and consumers. These actors are allocated in the different sub-sectors of the graphic industry (pre-printing, printing and post printing). Although companies were traditionally specialised in one of the processes, nowadays they focus on producing the final products. Thus, they are able to operate all relevant production steps while all printing operations are concentrated in one production site (Figure 24).

The printing industry usually carries out the binding, composition, layout, graphic design, plate making and press production stages. Most of the printing houses offer additional services, such as design and pre-press printing. Finishing includes binding, cutting, and folding along with storage, packaging and shipping.

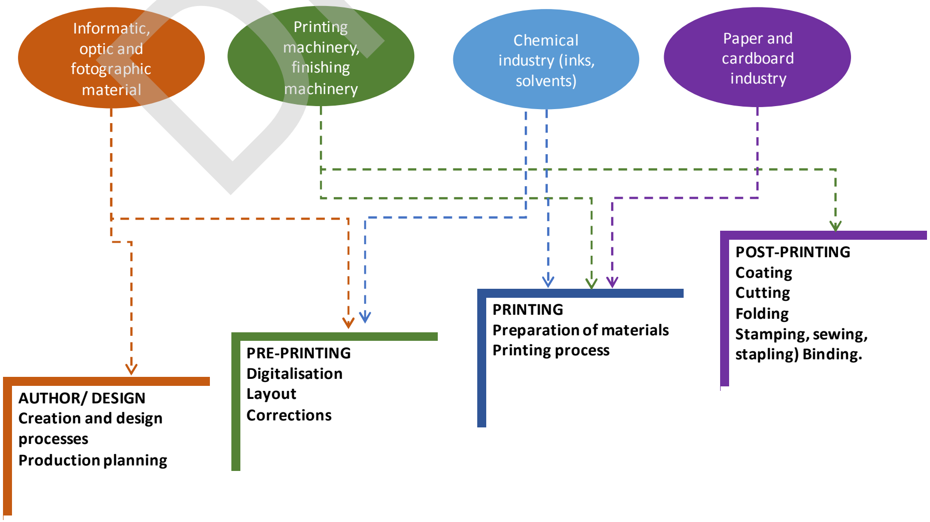


Figure 24. Providers and processes in the printed paper products production[11]

The distribution of the final product is usually carried out by publishers, marketing companies or niche actors of the value chain. The key customers of the printing

[11] ICEX (España Exportación e Inversiones). The printing market in Germany. Market study. 2016

industry are publisher groups, marketing agencies, public administration and companies. Hence, the printing sector is characterised by multi-channel distribution networks as shown in Figure 25 and explained below:

- Long distribution channel: This involves wholesalers and retailers.
- Short distribution channel: Retailers are in direct contact with the manufacturers
- Direct retail: The publisher is in direct contact with the final consumer.

Figure 25. Value chain in printing sector

2.2.2 Types of printing companies

Printing companies can be categorized based on the type of customers they serve, the types of material they print or the printing method they operate. Thus, the sector is usually split into 4 segments.

- Commercial printers: This category stands for the largest market segment. Commercial printers typically print a wide range of products related to marketing material, such as catalogues or leaflets. They usually operate a combination of machines including offset and digital presses. Most commercial printers work for a wide range of customers, such as private persons, small office or home office (SOHO) customers, small and medium enterprises (SME), governmental institutions and large enterprises. Commercial printers represent 34% of the market.
- Packaging printers: They are specialized in printing boxes, cartons, bags, cans, tags and labels. Packaging printers mostly use flexographic or digital presses. This type of activity accounts for 27% of the market.
- Publication printing: This particular segment focuses exclusively on newspapers, books or magazines printing. Most of them are specialized in one publication type e.g. newspapers whilst they target at high volume work. This segment reflects 32% of the market.
- In-plants: An in-plant company is a printing house which is part of a company or institution. It mainly produces printed material for its own employer,

although sometimes surplus capacity is used for commercial printing activities. Typical examples of in-plants are the printing centre of a university, the printing department of a ministry or the respective divisions of banks. There are not market data about these printing activities.

2.2.3 Large printing companies

Large printing companies are normally active in multiple business sectors. Thus, it is problematic to compile an importance list based merely on printing turnover. Nevertheless, the largest printing companies in the world[12] are as follows:

- Arvato – commercial printer. Germany
- Asahi Shimbun Company – newspapers & magazine publisher, Japan
- Bertelsmann – mass media company, Europe + Asia & Latin America
- Cenveo – commercial printer, USA + Europe & Asia
- Cimpress – web-to-print commercial printer, Europe (Netherlands) + USA, Latin Ameria, Asia & Australia
- Crown – packaging printer, USA + Canada, Latin America, Europe & Asia
- Dai Nippon Printing – commercial printer, Japan
- Dangnali Zhongguo – commercial printer, China
- De La Rue – security printer, UK
- Gannett Company – newspaper & publishing, USA
- Leo Paper Group – commercial printer, China
- News Corp – mass media company, USA + Europe & Australia
- Quad/Graphics – commercial printer, USA + Europe, Canada & Latin America
- R.R. Donnelley – communications company, USA + Europe, Asia & Latin America
- TC Transcontinental – newspaper & packaging printer, Canada + USA
- Toppan Printing – commercial printer, Japan

The printing and publishing companies with higher market value, according to the Forbes list, are listed in Table 3.

Table 3. Printing and publishing companies

Company	Country	Sales (2018) bn. USD	Market value bn. USD
S&P Global	United States	6.2	50.3
Thomson Reuters	Canada	11.3	26.8
Wolters Kluwer	Netherlands	5	15.6
Nielsen	United States	6.7	10.7
Pearson	United Kingdom	5.8	9.7
Dai Nippon Printing	Japan	12.7	6.5
Toppan Printing	Japan	12.9	5.3

[12] First Research. Commercial Printing Industry Profile. June 2018. Forbes 2018 Global list

2.3 Current and future potential for market penetration of EU Ecolabel and GPP

According to European Federation for Print and Digital Communication (INTERGRAF)[13], the printing industry shows high sustainability performance. For instance, in Europe more than 71% of the consumed paper is recycled. The industry also denotes significant adoption levels of environmental management systems, and has developed tools to manage its carbon footprint. Moreover, all products printed in Europe are compliant with the EU Timber Regulation and thus do not contain any wood from illegal logging.

Unlike products printed in Europe, imported printed products fall outside the scope of the European Timber Regulation and therefore might use raw materials from illegally harvested wood. This could generate a significant environmental loophole while creates competitive advantage for the imported products[13].

The commitment to a sustainable printing sector can also be translated in active involvement in the EU Ecolabel criteria development. Next to the introduction of the EU Ecolabel for printed paper products, 127 licenses have been awarded. Printed paper is one of the products categories with high licenses number, after touristic accommodation services (786 licenses), all-purpose cleaners (303 licenses), hand dishwashing detergents (140 licenses) and tissue paper (149 licenses). In the EU countries, most of the licenses are awarded to Austria and Germany (Figure 26).

Figure 26. Number of licenses per Member State (2017)
Source: Data from Joint Research Centre

The evolution of licenses between the years 2013-2017 is positive, as it can be seen in Figure 27.

[13] INTERGRAF. Vision for the European Graphic Industry. Policy paper. 2012

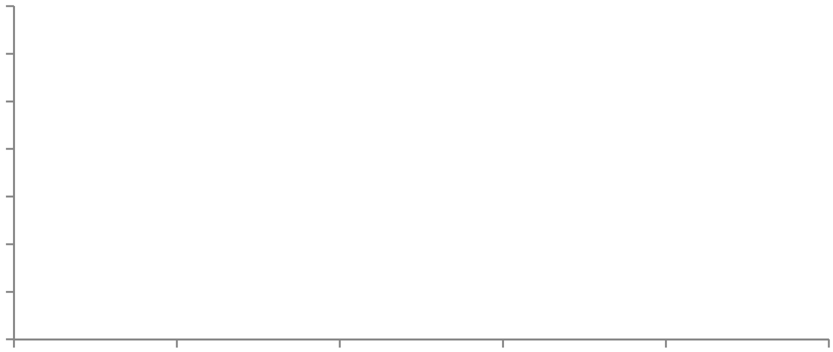


Figure 27. Evolution of number of licenses of EU Ecolabel for printed paper
Source: Data from Joint Research Centre

The categorisation of currently eco-labelled products shows brochures & leaflets (26%) are the most relevant product, followed by advertising material (14%) and catalogues (10%). The shares of the other product types are less than 10% (Figure 28).

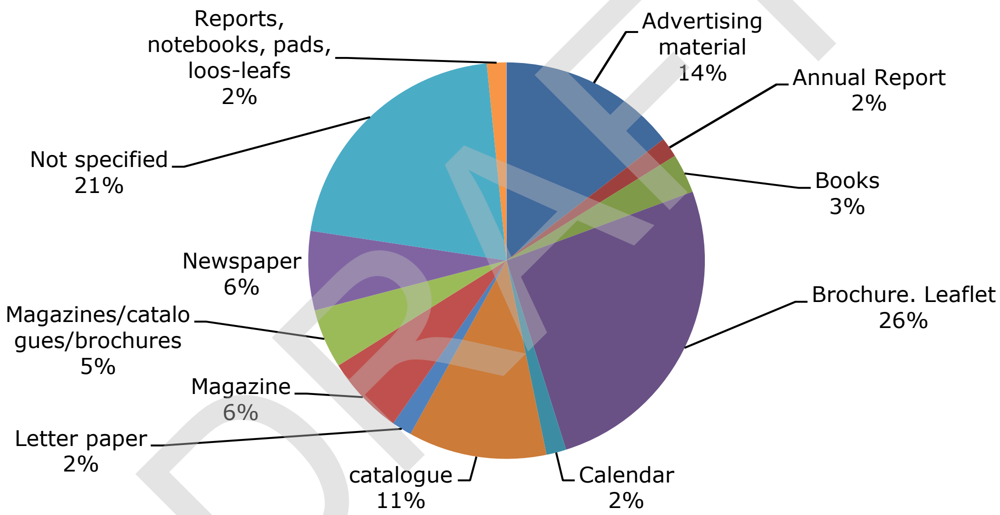


Figure 28. Typology of eco-labelled products
Source: EU Ecolabel web-page catalogue

However, it might occur possible overlaps with the EU product group "converted paper" which currently comprises 4 licenses and 122 products as can be seen in Figure 29. A classification of converted paper products can also be read in the same Figure 29.

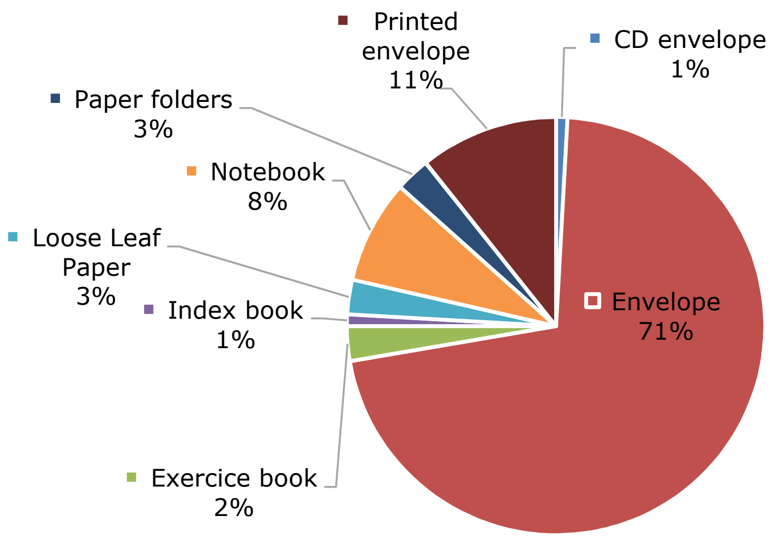


Figure 29. Typology of eco-labelled products
Source: EU Ecolabel webpage catalogue

Currently, there are no Green Public Procurement (GPP) criteria for printed paper[14]. However, The European Commission has collected examples of GPP practices to highlight how European public authorities have successfully launched 'green' tenders. The GPP brochure of good practice examples presents some of the most interesting case studies as collected over the years, and also includes GPP practices referring to printed products and printing services:

- Environmental requirements for printed materials, Cognac, France[15]
- Procurement of Reduced Environmental Impact Toners, Tuscany, Italy[16]
- Purchasing copy, printing and scanning services in Zurich, Switzerland[17]
- Resource efficient print and copy management solutions, Italy[18]

2.4 Global printed market overview

The global printing industry is expected to reach $980 bn in 2018[19]. The US is the world's biggest printing market. China follows in the second place since 2013, when the Chinese printing industry output exceeded $160 bn. In China, 105,000 printing companies are active with over 3.4 m employees. Moreover, China's continuous economic growth (9.3%) indicates that it will become the first printed paper producer in the next few years. Overall, the world economic trends show the printing sector to grow in emerging markets whereas to decline in mature ones. European countries account for 22% of the top 12 producing countries (Figure 30).

[14] http://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm
[15] http://ec.europa.eu/environment/gpp/pdf/news_alert/Issue35_Case_Study75_Cognac_printed_materials.pdf
[16] http://ec.europa.eu/environment/gpp/pdf/news_alert/Issue40_Case_Study84_Tuscany_toners.pdf
[17] http://ec.europa.eu/environment/gpp/pdf/news_alert/Issue53_Case_Study108_zurich_output_management.pdf
[18] http://ec.europa.eu/environment/gpp/pdf/news_alert/Issue54_Case_Study110_italy_print_management.pdf
[19] Pira International. The Future of Global Printing. 2018

Figure 30. Market share of top 12 countries in printing (2014)
Source: PRIMIR World Wide market for print 2014.

In the case the global market is segmented into regions, the markets development between 2011 and 2016 shows the increasing relevance of Asia. On the opposite, the global share of European countries and North America[20] indicated a fall. Globally, there are diverse market development trends (Figure 31).

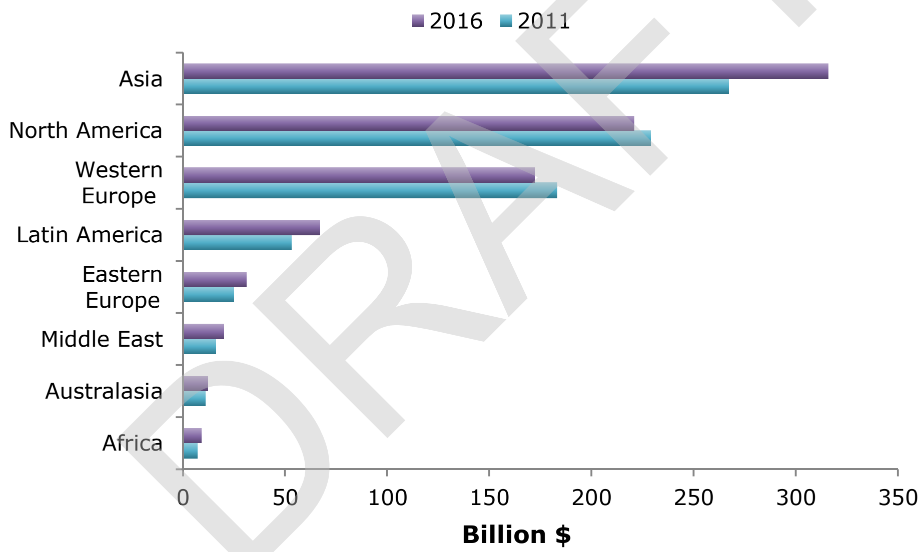


Figure 31. Worldwide printing market by regions. 2016
Source: Pira International.

Regarding printing technologies, digital printing is gaining importance compared to analogue printing. Printed packaging and labels are the most important constituents whereas graphic applications showed decline. Electronic versions become more important than printed material with E-books, and on-line newspapers and magazines to gain significant market share. The same trend is identified in electronic directories, catalogues and brochures. The market analysis shows declining sales of many print products, except for packaging and labels. The demand on the latter is growing as it can be seen in **Error! Reference source not found.**. They occupy 43% of the market, followed by other commercial printed materials and advertising. Magazines and newspapers are still relevant in the market.

[20] Pira International. Printing Market to 2016.

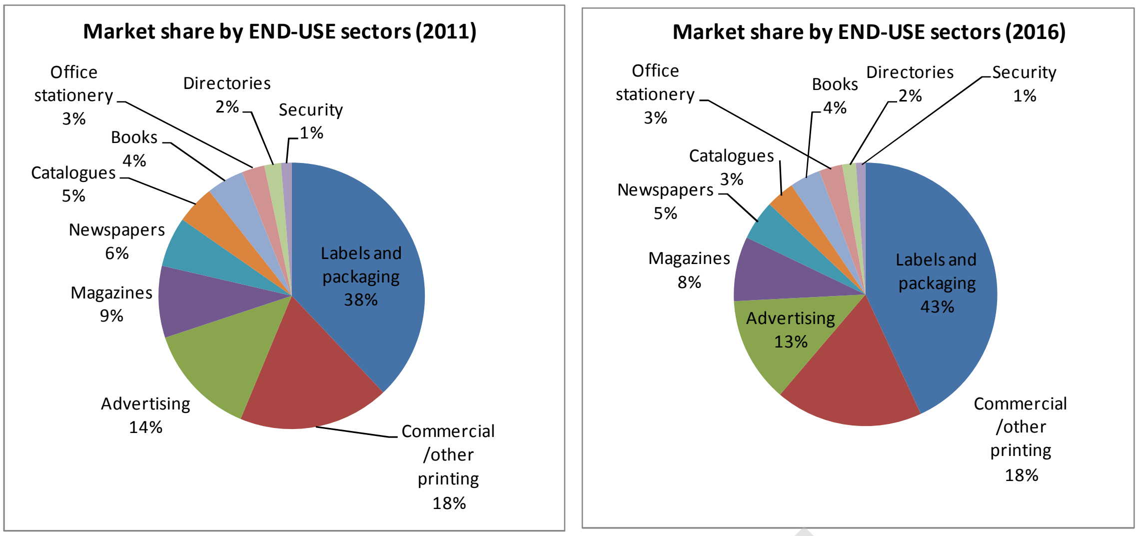


Figure 32. Worldwide monetary market share of printed products by END-USE sectors
Source: PIRA International

The importance of printed advertising materials fell contrasted to other advertising channels, such as internet. Nevertheless printed materials remain significant, accounting for approximately 29% of the total advertising investments (Figure 33).

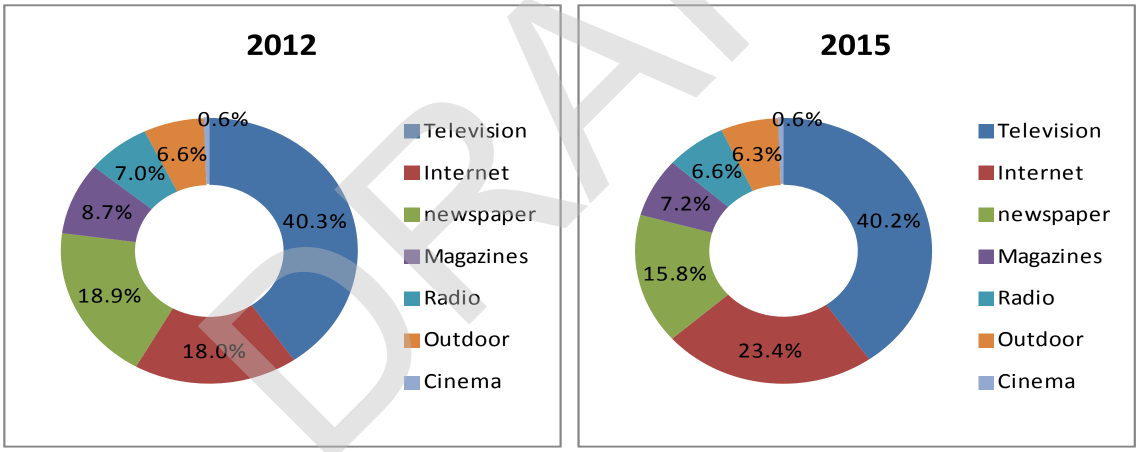


Figure 33. Worldwide share of advertising investments
Source: INTERGRAF

In the US, printed books experienced a decline from 2008 to 2012 reaching the low of the last decade in that particular year. After 2012, books sales started to gain momentum, and have slightly increased up to $113 bn in 2015. The British company Pearson is the largest publishing house in the world. Besides Pearson, Thomson Reuters, RELX Group, Wolters Kluwer and Penguin Random House also belong to the leading companies. The US has by far the largest publishing industry, followed by China and Germany. Printed books are still the preferred format for 65% of the readers in the US, although e-books have been gaining pace. In the US, in 2015, 73% of the publishers and authors published their books digitally. Despite the rising popularity of e-books, the number of readers is expected to slightly drop in the coming years.

2.5 European printing paper products market and trade (Supply & Demand)

European countries represent the third biggest segment of printed paper manufacturers, after Asia (37%) and North America (26%). Europe accounts for approximately 20% of the global printed paper production by value. Printing activities are divided into three groups (pre-press activities, printing activities and binding-related activities). Their production by value in 2016 can be seen in Table 4.

Table 4. Production value for different printing activities *(PRODVAL, Eurostat)*

Activity group	Production 2016 (Million €)	Production 2016 (%)
Printing activities (PRODCOM 18.11 and 18.12)	43,998	84%
Pre-press activities (PRODCOM 18.13)	5,855	11%
Binding activities (PRODCOM 18.14)	2,398	5%
Overall production	52,250	100%

The overall production by value reached €52 bn in 2016 while printing activities account for 84% of the total. The development of printed paper production between the years 2010-2016 is portrayed in Figure 34 which shows a continuous decrease during the latter period.

Figure 34. Evolution of the printed paper products production value in the EU 28 from 2010 to 2016
Source: Eurostat. PRODCOM

2.6 EU printed paper products production by geographical area

In terms of monetary value, Germany is the biggest producer (€10,000 m) in Europe. It is followed by UK, Italy and France, whose production by value exceeds €4,000 m each. Figure 35 shows a production fall from 2015 to 2016 in the majority of the European countries.

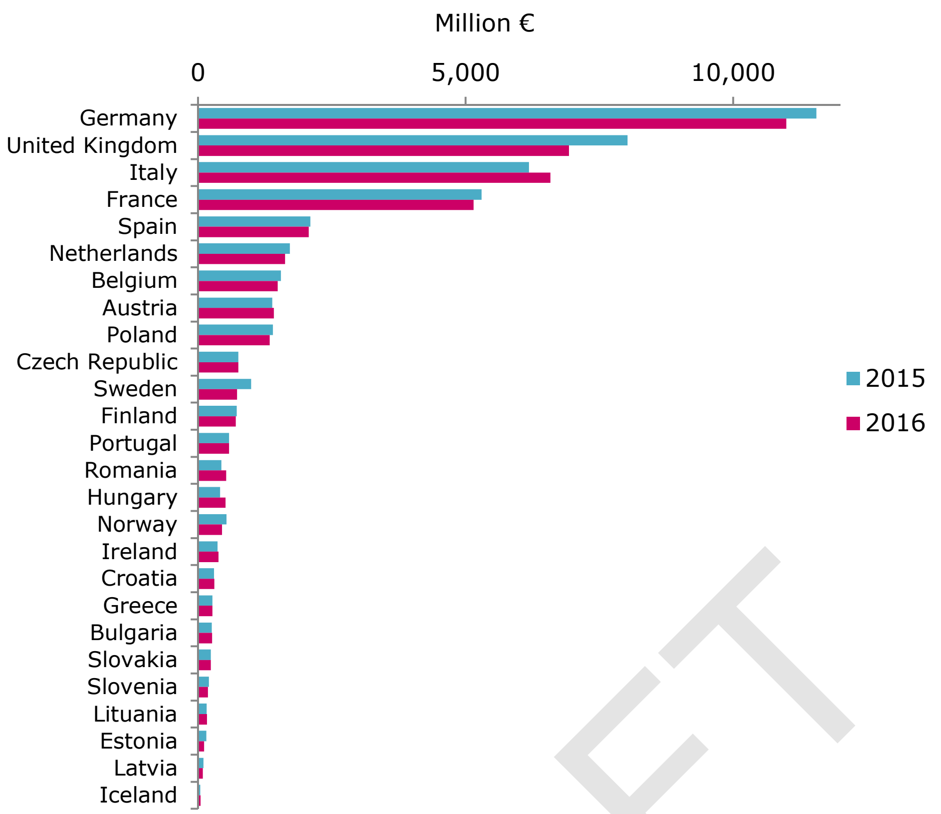


Figure 35. Production value of printed paper in the EU-28 countries (2016)
Source: Eurostat. PRODVAL. (No data for Denmark, Luxemburg and Malta)

2.7 Printed paper products production by type of product

According to PRODVAL, the EU printing industry produces diverse products (Figure 36). The ones with a high market share are advertising material (26% excluding catalogues, 8% of printed catalogues) books, brochures and leaflets (11%) while newspapers and journals are all together in the third place (16%).

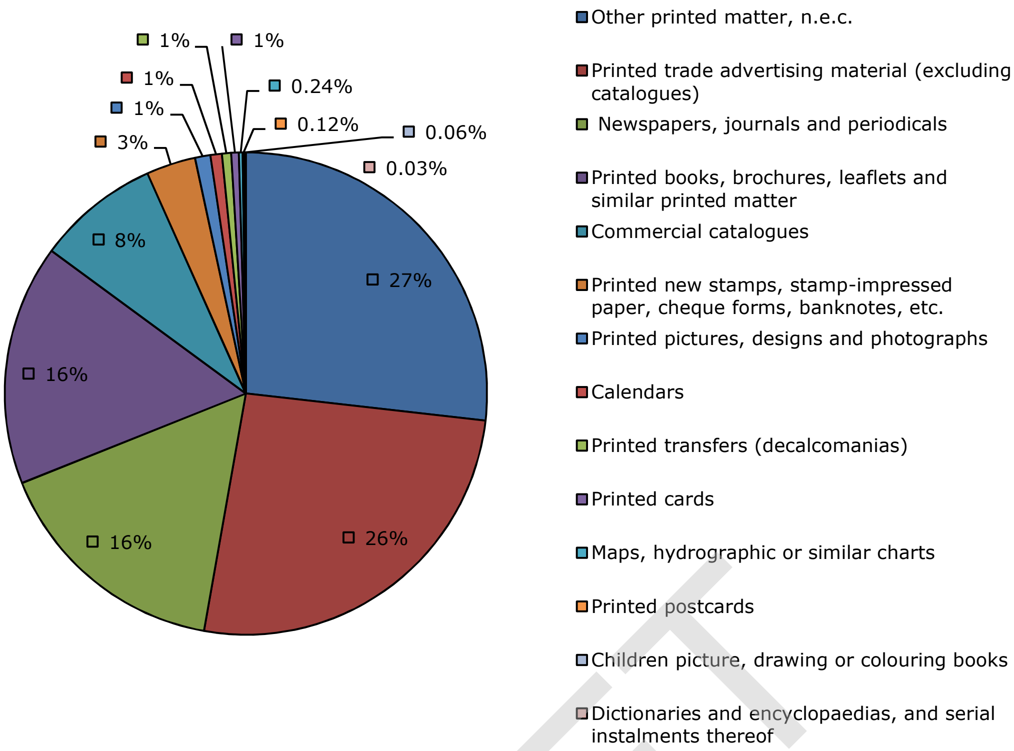


Figure 36. Market value of EU-28 printed paper by type of product (2016)
Source: Eurostat. PRODVAL

2.7.1 Book publishing

The total annual sales revenue of book publishers in the EU and European Economic Area (EEA) was approximately €22.3 bn[21] in 2016, recording some growth from 2015. In the same year, the largest market areas in terms of publishers' turnover were Germany, UK, France, Spain and Italy. Examining the long term tendency, 2009 showed a slight turnover fall in respect to the previous years (accounting for exchange rates) and a slowdown of the titles growth. The economic crisis had less impact on publishing compared to other business sectors. In 2010, growth restarted (especially exports), however, mainly due to variations in exchange rates. In 2011 and 2012, the market shrank again, and the title production growth was sluggish. In 2013 and 2014 the market slowed down further albeit the good export performance which became even stronger in 2015 and 2016. Discounting the exchange rate influence, 2016 could be considered the second consecutive year of growth (Figure 37).

[21] Federation of European Publishers. Statistics 2016 (https://www.mecd.gob.es/dam/jcr:ce7a8990-796c-4c0f-9f02-ff1efb050170/statisticsfep-2016.pdf)

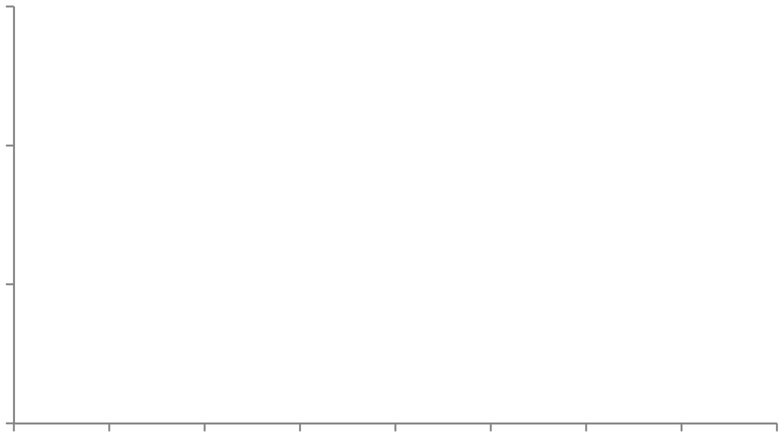


Figure 37. Net publishers' turnover from book sales in the EU + EEA, 2009-2016 (€ bn)
Source: Federation of European Publishers

Digital technologies were present in the book value chain since a long period, yet a true e-book market emerged only recently due to quality issues in digital reading. Overcoming that constrain, the digital book market has been growing steadily, initially at impressive rates, while slowing down in the two years 2015 and 2016. In 2011, this specific market segment represented no more than 1% of total while in 2016 denoted market shares of 6%-7%, with significant differences between the European countries.[22]

European publishers issued 575,000 new titles in 2015. The titles production kept on increasing during the surveyed period. European publishers held 22 m titles in stock of which more than 4 million in digital format.

The strong titles growth is accompanied by a steady decline in average print-runs (i.e. the number of copies of a title) across most countries. Factors that impose this trend are logical consequence of broadening the title basis and the increased efficiency in handling stocks aided by technological developments in the printing sector, such as Print-on-Demand.

Consumer books (including children's books) represent around 60% of the market. Educational and academic books generate another 40% of revenues. European book publishing has a significant export section with approximately one-fifth of its turnover to come from exports. That is interpreted in €4.2-5.2 bn per year (Figure 38). Exports are mostly driven by linguistic similarity, with the UK, France, Spain and Germany being the four largest exporters.

[22] Federation of European Publishers (FEP) The book sector in Europe: facts and figures. 2017

Figure 38. EU Proportion of EU publishers' turnover (domestic market/export), 2009-2015
Source: Federation of European Publishers

2.7.2 Newspaper and magazines

Other printed publication, such as magazines and newspaper have also experimented a decrease in the production during the last years. In 2015[23], there were four billion newspaper readers worldwide, 1.3 bn of whom read newspapers using digital platforms.

In line with this, the popularity of the written press in the EU decreased in recent years. The daily printed press consumption rate dropped from 37% to 29% between the years 2012-2016[23]. On the opposite, the online newspaper availability increased enormously during the last two decades. For example, there were five newspaper websites available in Germany in 1995 while there were about 700 online offers in 2016.

In the UK, a survey on the frequency of newspaper reading found that in the UK 19% of the adults read print newspapers on a daily basis whereas 23% of the respondents prefer digital newspapers[23]. In the rest of Europe, newspaper purchase showed a similar tendency. In Spain, the share of people reading daily newspapers dropped from 38% to 26% between the years 1997-2017. In Germany, the daily newspaper sales fall from 22.57 m copies in 2003 to an estimated 16.5 m in 2016. The reduction in newspaper usage also affected the industry. Consequently, earnings from advertising, newspaper advertising expenditure in the European Union, fell from €22–15.7 bn.

Regarding magazines[23], the European magazine sector experienced a steady shrinkage in revenues. They fall from €14-11.3 bn in the period 2011-2016. Digital magazine revenues showed an upward trend yet not sufficient to counterbalance the overall loss. Consequently, the magazine advertising expenditures in the European Union declined similarly, dropping from €10.1–7.1 bn in the period 2009–2015.

In the UK, a survey on the frequency of magazine reading found that nearly a third of the UK adults read print magazines at least once a week whereas for digital magazines the same result came out for only 19% of the respondents[23]. In the rest of Europe, magazine purchase showed a similar declining trend. For instance in Spain, it fell from 48% to 37% during the last decade while in France the average daily time spent for reading magazines per capita fell to less than 25 minutes. In

[23] Statista. Newspaper market in Europe - Statistics & Facts

Germany, the number of persons who stated to read magazines more than once a week during their free time shrank by more than four million between the years 2013-2016.

2.7.3 Other products currently out of the scope of printed paper EU Ecolabel

2.7.3.1 Packaging paper products:

Packaging printed matter, mainly labels and tags, is included within the NACE Rev2. code 18121990 (Other printed matter, n.e.c.). For that reason, specific market data for that product group are not available. Nevertheless, due to the importance of this product type, it is anticipated to account for a significant market share. Paper packaging has the highest market share of the total packaging market. The revenue of the corresponding European market was €49 bn in 2016 and is forecasted to reach €67 bn by 2022, growing by 4.6%. Production and consumption of printed packaging materials from 2007 to 2016, has increased by more than 3 Mt in cardboard/case materials and 891 kt in wrapping/other packaging. In Europe, packaging paper products production has increased by 4.6 Mt since 2007 (+15%)[24].

2.7.3.2 Wrapping paper

Two main types of wrapping exist in the market. First, kraft paper which consists of material made by pulp processed with a sulphur solution and second gift wrap suitable for wrapping gifts. Wrapping paper is usually included in the packaging paper categories, therefore, specific and updated market data are not available. The production of wrapping in the EU-28 rose at approximately 4.6 Mt in 2017[25].

2.7.3.3 Wallpapers

Wallpaper is a specific material type used to decorate interior walls. Wallpaper types include painted wallpaper, hand-printed blockwood wallpaper, hand-printed stencil wallpaper, machine-printed wallpaper, and flock wallpaper.

It is made of various materials, such as solid sheet vinyl, non-woven, easy walls with PCV or VOC, glasscloth, acrylic coated/vinyl coated paper: expanded vinyl: heavy-weight vinyl: fabric-backed vinyl: molded linoleum. Wallpapers printed on paper are not as common as in previous years, but they still exist in the market. The most common wall covering for residential use and also the most economical type is prepasted vinyl coated paper. Wallpaper printing techniques include surface printing, gravure printing, silk screen-printing, rotary printing, and digital printing. Unfortunately, recent market data are not available for this type of material.

2.8 Market of printing raw materials and main suppliers

As explained in section 3.1., main suppliers of the printing industry are chemicals (inks), paper and printing equipment manufacturers.

[24] Sten B. Nilsson CEO, Forest Sector Insights AB, Sweden. European market overvwie, 2017

[25] Wrapping Papers Production Quantity by country, FAO Data, (http://data.un.org/Data.aspx?d=FAO&f=itemCode%3a1621)

2.8.1 Chemicals

Several chemicals are used during printing depending on the operated production technology. The most relevant chemical products are inks, lacquers, adhesives, developers, fountain solutions and cleaning solvents.

The chemical industry contributes to 7% of total EU manufacturing added value (€597 bn in 2016). Nevertheless, only 2.3% of its production is used in the printing sector, with an estimated value of €13.73 bn.[26]

2.8.2 Inks

Publication inks encompass web offset inks (coldset and heatset), sheetfed offset inks, publication gravure inks and related overprint varnishes. Packaging inks comprise flexographic inks, specialty gravure inks, energy curing inks and the related varnishes.

The statistical data are obtained from the European Printing Inks Association (EuPIA). The results describe sales volumes in tonnes and sales value. It is estimated that the sample group accounts for 90% of total sales in Europe. The total printing inks colourants production in 2014 was 0.96 Mt, accounting for €3.1 bn. Publications and commercial products account for 54% of the consumed inks while the rest is consumed in packaging printing[27]. Main manufacturing countries are Germany, Italy and UK.

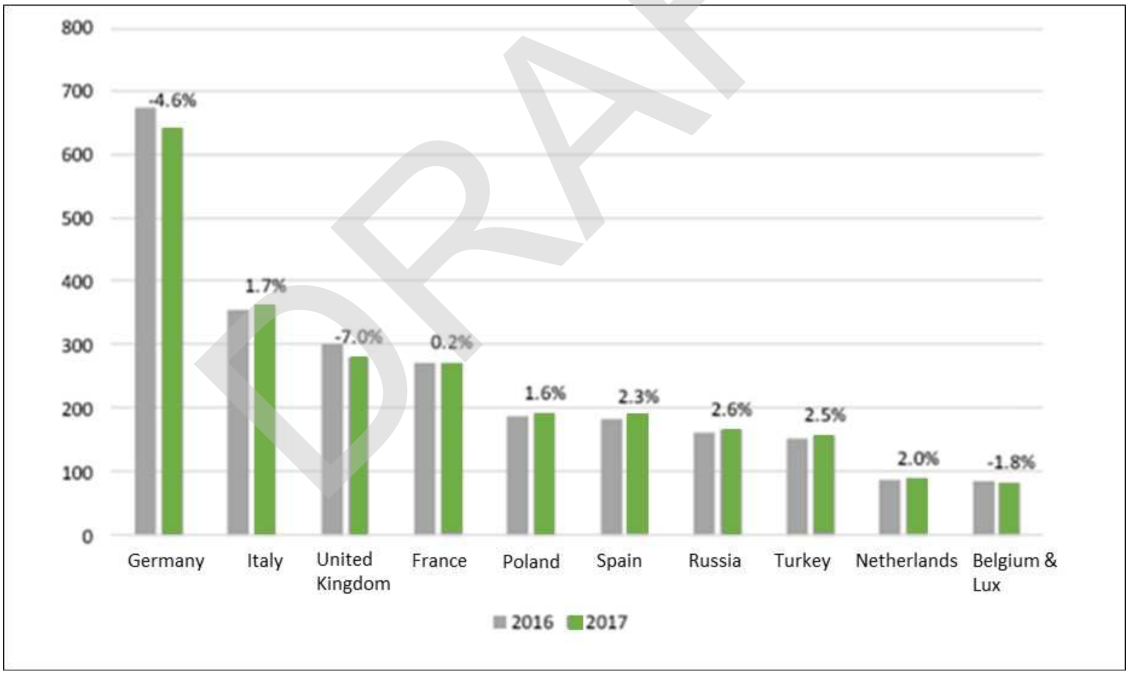


Figure 39. Printing inks value by country in million Euros (2006-2017)
Source: European Printing Inks Association (EuPiA)

2.8.3 Printing equipment

Another key sector is printing equipment and machinery manufacturers, including printing presses and binding machinery. Top countries for printing machinery production iare Germany, Japan, and the US while Goss International, HP, Presstek,

[26] CEFIC. Facts and Figures 2017 of the Chemical Industry (http://fr.zone-secure.net/13451/451623/#page=1)
[27] http://eupia.org/uploads/tx_edm/EuPIA_Annual_Conference_Leaflet_March_2018.pdf

and Xerox (all based in the US); Canon, Fuji Xerox, Komori, and Tokyo Kikai Seisakusho (Japan) and Heidelberger, Koenig & Bauer, and Manroland (Germany) belong to the biggest companies[28].

In the period between 2013 and 2017 the printing equipmen revenuest in Europe have grown by just 0.2% per annum in real terms. On the opposite, the printing volume, excluding packaging, falls globally by 9.5%, whereas digital equipment is taking on much more share. In 2016 the total sales of new printing equipment in Europe accounted for €4.42 bn.

2.9 Printing technologies in the European market

There is a wide variety of technologies and production procedures to manufacture print paper products (Figure 40). The most widely implemented are:

- Offset lithography
- Flexography
- Digital printing: inkjet & xerography
- Gravure
- Screen printing

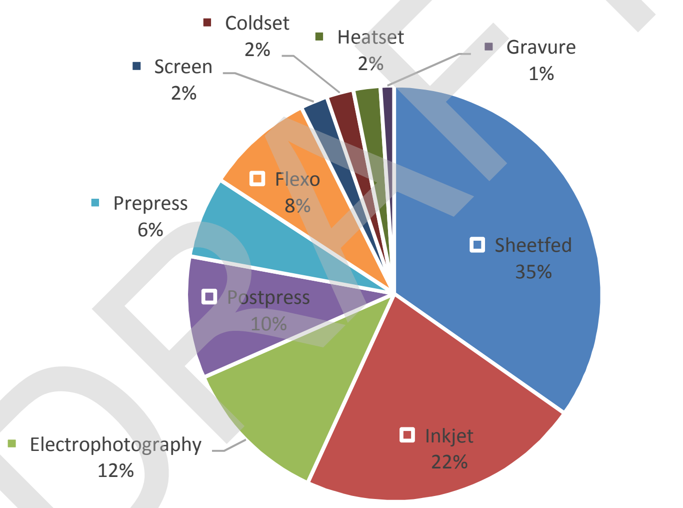


Figure 40. European sales of printing equipment, 2016 (% value share)
Source: Smithers Pira

Additional printing techniques were developed for tackling specific market needs. These include:

- Letterpress: Once a dominant printing technique, letterpress is nowadays operated for business cards, wedding invitations, etc.
- Flocking: used to add a (coloured) velvet-like texture to paper, textiles, etc.
- Pad printing: used to print on 3-dimensional surfaces.
- Intaglio: mainly used for stamps and paper currency.
- Thermography: This is more a finishing rather than an actual printing process. It produces raised lettering on the printed side of the paper and is used for wedding invitations, letterheads, business cards, etc.

[28] First Research. Printing Machinery & Equipment Manufacturing Industry Profile. 2018

A brief description of each technology follows while more details on the particular technologies are presented in section 3.

- Offset: In offset lithography, a printing plate, which is usually made from aluminium, contains the image to be printed. The plate is inked, however, only the image absorbs the ink. The inked image is transferred (offset) from the plate to a rubber blanket and then to the printing surface. Offset is nowadays the most widely operated printing technique. Hence, an extensive range of products, such as books, newspapers, stationery, corrugated board and posters are printed using offset printing. Although it is crucial in the printing sector, there is a trend for printing promotional material, main product of offset printing, to gradually shift to digital printing.
- Flexography: The content that needs to be printed is on a relief above the printing plate, which is made from rubber. The plate is firstly inked and subsequently transferred to the printing surface. Flexography is mainly operated for packaging and labels and to a lesser extent for newspapers. Some packaging printing is moving from flexography to digital.

Digital printing: Two digital technologies inkjet and xerography.

- Inkjet: The image that needs to be printed is created by small ink droplets. Inkjet printing is operated to print posters and signage. It is economically preferable for short run publications, such as photo, books (small run). Inkjet printers are occasionally combined with other types of presses to print variable data, such as the mailing addresses on direct mail pieces.
- Xerography: In xerographic printers, such as laser printers, the image to print is formed by selectively applying a charge to a metal cylinder called the drum. The electrical charge is used to attract the toner particles. These are transferred to the media that is being printed on. To secure that the toner is fixed properly, the substrate passes through a fuser which melts the toner into the medium. Laser printers are not only used in offices but also for printed books (small run), brochures and other types of documents.

Digital printing replaces offset, flexography or screen printing gradually. Nevertheless, in short run printing e.g. small format (A3 size), digital is taking over from offset for both colour and B&W printing. Conversely, labels are mainly being printed digitally while book publishers start to rely on print-on-demand. Apart from the above-mentioned techniques, there are other digital printing processes that are geared towards niche market segments:

- Dye-sublimation is a printing process in which heat is used to transfer a dye onto the substrate. Dye-sub printers are mainly used for printing on textiles, for proofing and for producing photographic prints. Some printers can print on a variety of materials such as paper, plastic and fabric.
- Direct thermal printing: The process heat is used to change the colour of a special coating that has been applied to the paper. This process is used in cash registers but also to add markings, such as serial numbers, to

products. To achieve this transparent ink is used which changes colour when heated by a laser.

- Thermal ink transfer printing: The process heat is used to melt a ribbon and print off onto the substrate. It is used sometimes, but tends to disappear off the market gradually.
- Gravure: Also known as rotogravure. It reflects a technique in which the image is engraved into a printing cylinder. The cylinder absorbs the ink and transfers it to the paper. Gravure is used for high volume work like newspapers, magazines, and packaging. This printing technique is losing market share to offset and flexography.
- Screen printing: This printing technique relies on a screen where certain areas of the mesh are coated with a non-permeable material. The ink can be pushed through the mesh via the remaining open spaces onto the substrate. In screen printing, the surface of the recipient does not need to be flat and the ink can adhere to a wide range of materials e.g. paper, textiles, glass, ceramics, wood, and metal. Albeit this advantage, screen printing is gradually being replaced by digital printing.

The market analysis outcomes suggest a shift to digital printing (Figure 41). The latter is gaining importance particularly in graphics (i.e. non-packaging applications). The digital market is rapidly expanding thanks to its competitive advantages in terms of enhanced productivity and lower costs. The respective market share doubled in value terms from 9.5% to 19.7% in the years 2008-2018. If packaging is excluded, the market coverage of this particular technique moves up from 23.5% to 38.1%. The print volume remains low though.

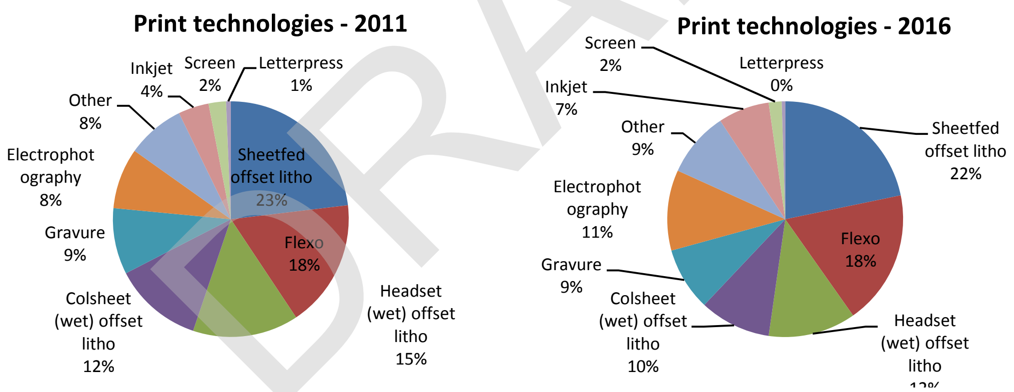


Figure 41. Market share of printing technologies (2011-2016)
Source: Pira International

2.10 EU paper printed products trade

Trade statistics are obtained from Eurostat and the Market Access Database (MADB), but imports/exports are not registered for the examined PRODCOM codes. Therefore, all relevant data are in accordance with the TRADE MAP[29] as obtained from the International Trade Centre (ITC). Data have been gathered for the code 49 which encompasses books, newspapers, pictures and other products of the printing industry and manuscripts.

[29] TRADE MAP. Trade statistics for international business development. https://www.trademap.org/Country_SelProduct_TS.aspx?nvpm=1||14719|||49|||2|1|1|2|2|1|3|1|1

Printed paper products are demanded all over the world, thus export represents a key activity for European companies. The EU exports, including intra-EU and extra-EU, were €17,984 m (40% of European production by value). The respective imports were worth €13,430 m (30%) in 2017.

The trade balance in the EU was positive indicating an export surplus of €4,554 m. Individual country data can be seen in Figure 42; Germany, United Kingdom, Poland, Italy, Netherlands, Czech Republic, Spain, Belgium, Latvia, Slovenia, Estonia, Lithuania, Malta, Hungary, Slovakia and Croatian are net exporters; whereas the rest are net importers (Austria, France, Ireland, Sweden, Portugal, Luxembourg, Greece, Denmark, Cyprus, Romania, Finland, Bulgaria). The results vary between intra-EU transactions and those between the EU and non-EU countries are detailed in the following sub-sections.

Figure 42. Trade balance of printed paper products in EU-28
Source: ITC TRADEMAP

At global level, the exports and imports are displayed Figure 43 and Figure 44 respectively.

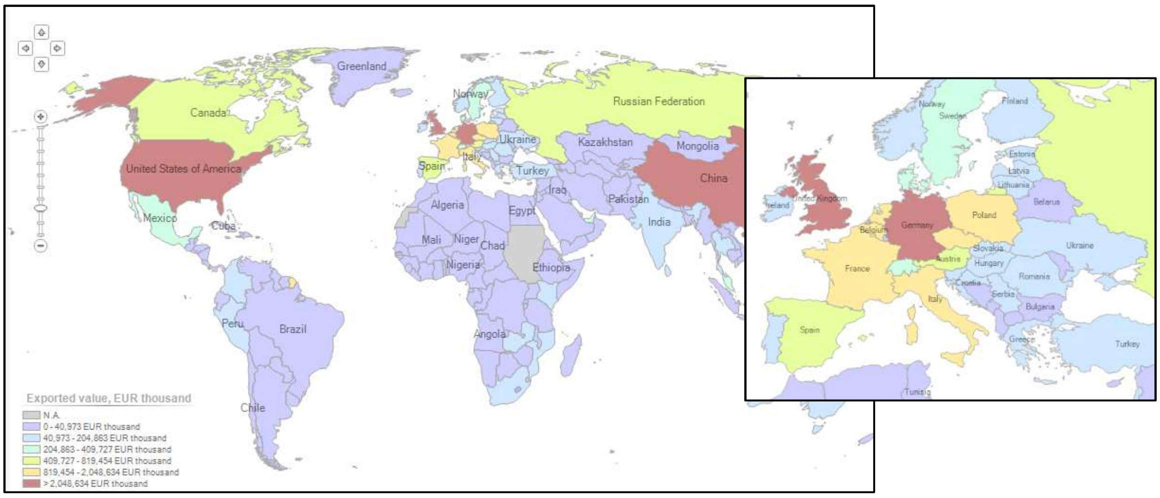


Figure 43. Exports at global and European scale (2017)
Source: ITC TRADEMAP

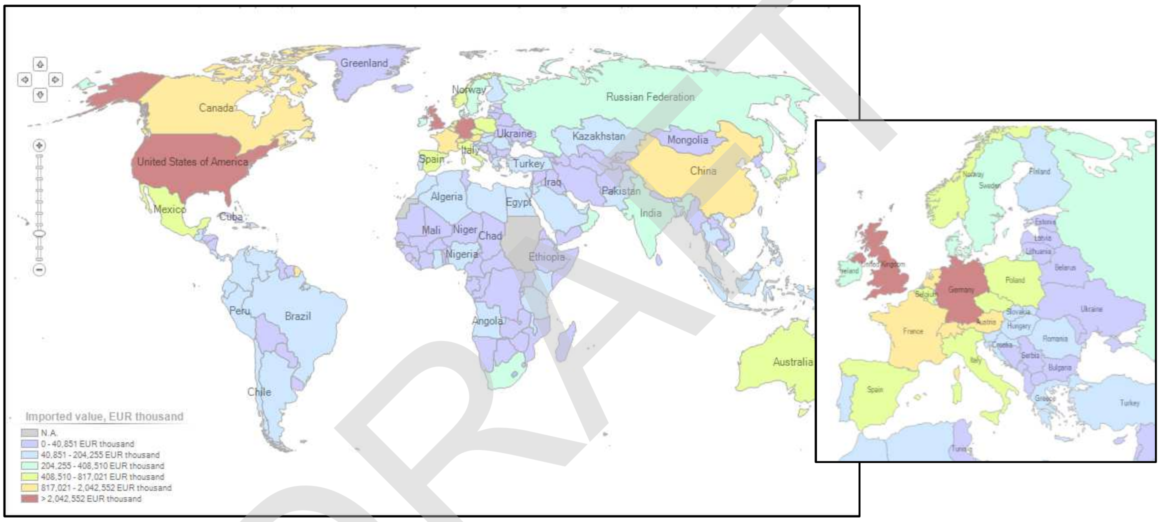


Figure 44. Imports at global and European scale (2017)
Source: ITC TRADEMAP

2.10.1 Intra EU-28 imports of printed paper products

The total intra EU imports by value were worth €8,934 m, representing 77% of the total imports in the EU. Imports recorded a drawback (6%) in the period between 2011 and 2014 (Figure 45) due to the global economic crisis. However, in 2015 signs of recovery were observed. Supporting the latter, this study identified the imports were 13% higher in 2017 over 2013.

Figure 45. Evolution of intra- imports in the EU-28
Source: ITC TRADE MAP

As illustrated in Figure 46, the four largest European importers are Germany (21% of the total EU), France (14%), Austria (9%) and UK (8%) reaching values over €800 m.

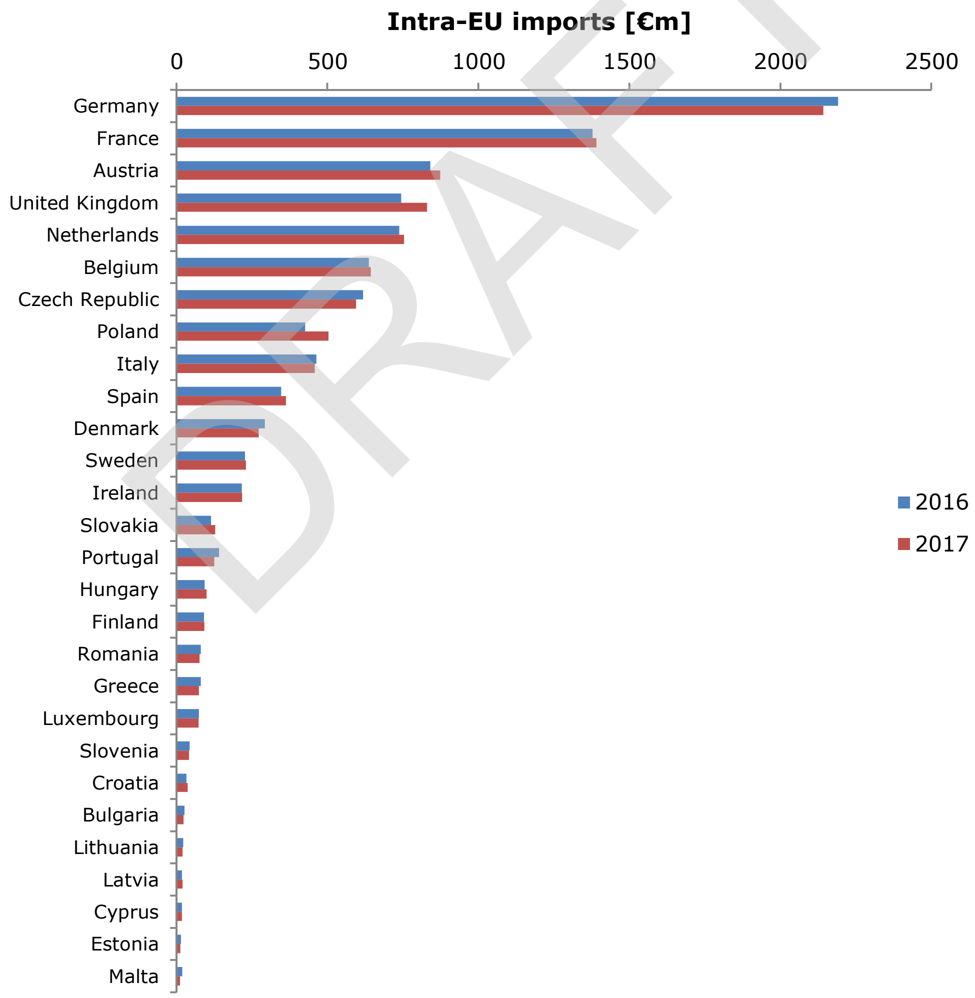


Figure 46. Intra- Imports by the EU-28 countries
Source: ITC TRADE MAP

2.10.2 Intra EU-28 exports of printed paper products

The total intra EU exports reached €12,362 m in 2017, representing 69% of the overall exports by value. Exports indicated a decline (3%) in the years between 2011 and 2014 again due to the global economic crisis. However, next to 2015 a recovery is observed. In 2017 exports were 6% higher than 2013 (Figure 47).

Figure 47. Evolution of exports in the EU-28
Source: ITC TRADEMAP

Germany is the largest printed paper exporter (23% of total). UK, Poland and Netherlands indicate significant amount of intra EU exports with values between €1-1.5 bn. The rest of member states show values below €1 bn.

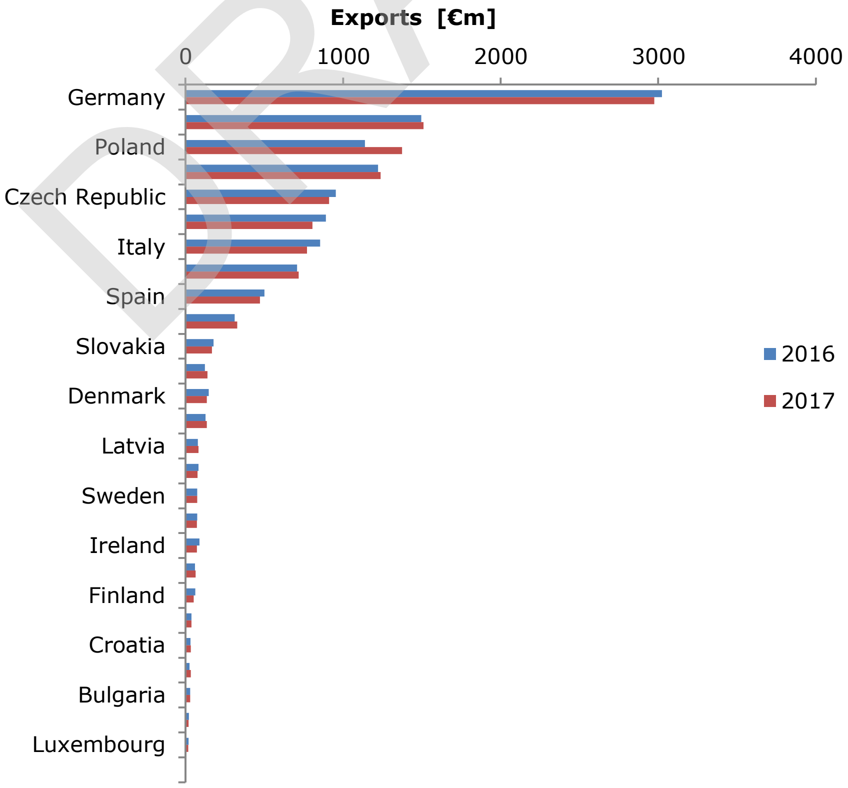


Figure 48. Exports of printed paper products by the EU-28 countries
Source: ITC TRADEMAP

2.10.3 Extra-EU printed paper imports of printed paper products

This section provides data on the import transactions between the EU and the rest of the world. Most of the imported products come from USA and China as show in Figure 49.

Figure 49. Top 15 EU suppliers of printed paper products
Source: ITC TRADEMAP

The extra EU export activities are represented in the map in Figure 50.

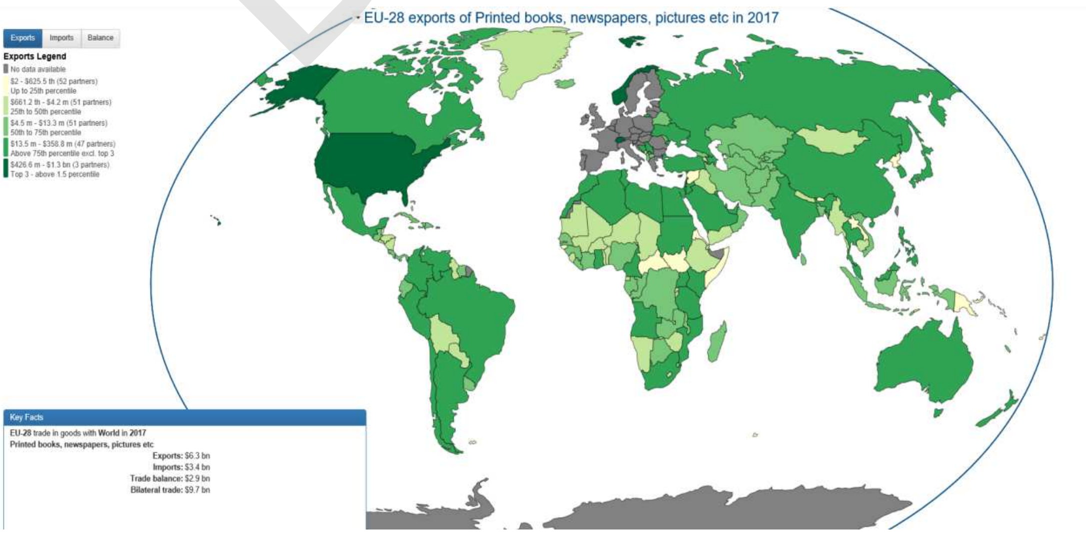


Figure 50. EU-28 imports of printed papers
Source: UN Comtrade data

2.10.4 Extra-EU exports of printed paper products

Extra-EU export activities represent 30% of the overall export transactions by value. Figure 51 shows the key export destinations outside the EU. The fifteen key extra-EU importers accounted for 24% of the total export transactions by value. Main importers of EU made printed paper products are Switzerland (6.2%), United States (5.1%), Norway (2.1%), Australia (1.8%) and Denmark (1.7%).

Figure 51. The top 15 export markets of European printed paper products
Source: ITC TRADEMAP

The extra EU imports are depicted in Figure 52.

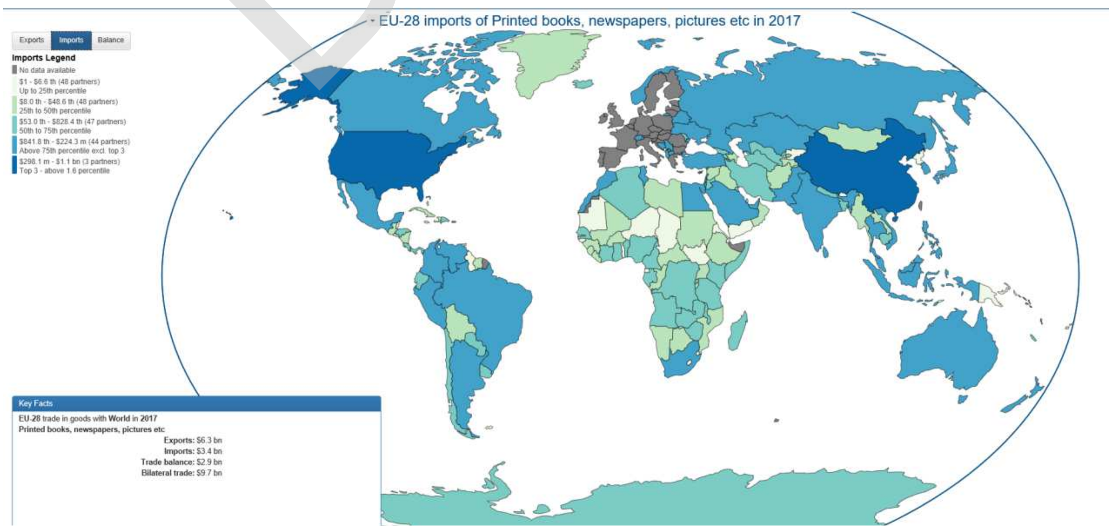


Figure 52. EU-28 imports of printed papers
Source: UN Comtrade data

2.11 Consumption

Eurostat does not provide any information on real consumption; therefore, the apparent consumption has been calculated by adding production value and imports and subtracting exports. The apparent consumption of printed paper products was valued at approximately €39,459 m in 2016, decreased by 4% compared to 2015. As shown in Figure 53, the apparent consumption has experienced a decrease since 2010, except for 2014 in relation t0 2013.

Figure 53. Apparent consumption of printed paper products in the EU
Source: Eurostat and ITC TRADEMAP

2.12 Forecasts

At global scale, after years of a continuous decrease, it is anticipated a market stabilisation. Hence, a flat trend in terms of production of printed products from 2017 to 2021 is forecasted corresponding to a global annual growth of 2%. This trend is driven by growth in package printing, economic growth in emerging economies and increase of digital printing[30,31]. Despite the forecasted stabilisation of the market, the global trend, expressed in production volumes, will remain negative (2010-2020) due to decreasing production rates of the past years.

Geographically there are drops in North America, parts of Europe and Australasia in both volume and value for digital and analogue print. On the opposite growth is expected for Latin America, Middle East, Eastern Europe and Africa. Asia is the biggest printing region, and will keep on growing in volume and value. China overtook the US in 2015 and became the biggest national printed paper market in the world (by volume). Nevertheless, the Chinese industrial output by value is significantly lower reflecting the different product mix and lower pricing, yet low production costs in China and India allow producers for increasing their exports considerably.[32]

In Europe, according to Smithers Pira[33], the evolution of printed paper production will experience growth of 0.8% from 2014 to 2020. The predictions for the different products are as summarised in **Error! Reference source not found.**.

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[30] Smithers Pira. The Future of Global Printing to 2020.
[31] Smithers Pira. European Printing Industry: Market Insights. Nick Waite. Smithers Pira
[32] Smithers Pira. What is the global future for printing? The Future of Global Printing to 2020. (file:///C:/Users/chidalgo/Downloads/The_Future_of_Global_Printing_to_2020.pdf)
[33] Smithers Pira. Print Market Overview: Employment – Markets – Technology

Table 5. Forecast of growth of different printed products in Europe

Printed product	Compound Annual Growth Rate (CAGR) 2014-2020
Books	↓ 4.0%
Magazines	↓ 1.6%
Newspapers	↓ 5.0%
Advertising	↓ 0.4%
Catalogues	↓ 3.6%
Directories	↓ 4.8%
Security	↓ 0.1%
Other commercial	↓-0.5%
Packaging	↑2.7%
Labels	↑3.6%
Total	↑0.8%

As already mentioned, packaging and labels are growing consistently[30]. Packaging printing usually refers to a label which is written electronically or contains a graphical representation and is placed on the package. There is huge demand on the global printed packaging market due to rise in manufacturing activities, growing population and smaller households. Moreover, product variety and no alternative form of packaging contribute towards increased label use (5%). However, the volume of paper based packaging will fall in importance compared to other materials, such as packaging films.

On the other hand, printed products for commercial purposes (phone books, magazines, labels, catalogues, advertising brochures, newspaper inserts etc.) and publications (newspapers, magazines, books) are declining significantly by volume and value. Regarding newspapers, the non-digital newspaper revenues are projected to decrease by 5% in the five-year period up to 2020 while those of digital format are expected to grow by 9.8% in the same period.

Figure 54. Trends in European printing 2000-2021 (€ bn)
Source: Smithers Pira

New technologies and electronic media are gaining place in publications and commercial products. Consequently, printed matter as communication medium is shrinking. The fusion of print and digital marketing campaigns highlights how printing matter might be evolving into a hybrid form of communication.

The so called 'new media' platforms, such as e-books, electronic and social media gradually replace printed products. Search engines substituted printed directories while satellite navigation and smartphone apps replaced road maps. Bank transactions are performed electronically, reducing demand on physical currency and cheques. In the same time online advertising gains momentum.

Regarding publications, newspapers are the products with the most rapid fall whereas magazines and other periodicals have also declined. Analysing the coexistence between e-books and printed books, it is hard to predict how these segments will develop in the coming years, since the printed books continue to have the readers' preference. Therefore, it is expected for digital and printed reading matter and business models to coexist in the foreseeable future[22].

Digital printing technology is expected to grow in faster pace, in the forecast periods[33], than the more established analogue alternatives. It is also the preferred technique for the packaging sector and labels. In 2015 digital printing accounted for only 2.5% of the printed matter by volume and 14.6% by value. The latter percentages are forecasted to increase up to 4% and 18.4% respectively by 2021.

The study examines essential analogue technologies and suggests lithography will lose importance by 2021. On the contrary, flexography will grow up in the same period due to cost improvements and automation. Offset printing is still the most widely used commercial printing and publications technology, yet a shift to digital high-speed inkjet technology is expected. The transformation is forecasted since inkjet is more effective and efficient for printing customised products. Reduced costs for colour printing and better return of investments are two key advantages which are foreseen from the broad adoption of the inkjet technology. The advertisement needs of businesses increase the demand on commercial printing, yet these are also depends on the growth of the economy and the consumer spending power.

In the publications and books area, the adoption of high-performance inkjet has lowered the unit costs of short-run printing. That permits publishers to order fewer copies of a new title at lower price compared to lithography. High-performance inkjet shows lower calibrations costs and less material wastage. Hence, production can be adjusted to demand depending on the success of the different products (especially books). As a result stock of final products and intermediates can be reduced improving the performance of the supply. The performance of printing technologies is portrayed in Figure 55.

Figure 55. Trends in European Printing Technologies 2015-2021
Source: Smithers Pira

2.13 SWOT analysis of European production sector

This section presents strengths, weaknesses, opportunities and threats of the printing sector following the SWOT approach. The most imports aspects are listed below and reflected in Figure 56.

Figure 56. SWOT analysis of EU printing sector

2.13.1 Strengths of the printing sector

- Standardised production: Customers prefer to know that their products conform to a recognised standard. That also benefits the printing industry as it provides the market with a more reliable product while increases printing efficiency. Standardised production improves the business to customer relationship.
- Modern facilities: The European graphic industry maintains modern and efficient production facilities enabling to remain competitive on the market. That is accompanied by and investment policy and the use of information technologies[34].
- Innovation and research on technologies: The European printing industry makes significant annual investments in research and new technologies to enhance competitiveness. Europe has a tradition in research and innovation concerning the printing sector. Technology improvements drive towards increasing productivity. According to the latest data, investment in research in

[34] Directorate-General for Enterprise and Industry (European Commission). *Competitiveness of the European graphic industry. Prospects for the EU printing sector to respond to its structural and technological challenges - Study*. 2007 (https://publications.europa.eu/en/publication-detail/-/publication/16f0d497-2eb3-4701-a6fe-da2e82a8f749)

EU rose at €229 m in 2016, corresponding to almost 9.5€/habitant.[35] That represents 0.52% of the sector's turnover.

- Well established and diversified industry: An analysis of printing industry profile in the EU suggests the European printing sector integrates all stages of the value chain. Hence, it can address diverse needs of the market while maintaining quality standards and time constrains.
- Flexibility: Small and dynamic enterprises provide a complete range of services whilst can adapt faster to changing demands. Small companies could take advantage of their agility and low cost structure to cover niche markets.
- Environment commitment and sustainability standards: The EU printing sector operates under strict environmental requirements and undertakes ambitious voluntary initiatives to demonstrate its commitment to sustainability. The sector has put in place an efficient environmental policy plan helping to reach world leadership in environment protection.
- Highly skilled employees: Process automation has triggered a shift unskilled workforce to specialised technicians.

2.13.2 Weaknesses of the printing sector

- Over-capacity: The fragmented nature of the printing sector in the developing countries and the improvement in the machinery efficiency in Europe cause a surplus capacity. That excess has increased over the last years, despite continued cutback of employment and companies' economic defaults. Overcapacity affects profit margin which in turn drives companies to look for niche markets or to act in the existing segments formulating mergers or creating synergies.[36,37]
- Short term decisions: The printing industry consists of few large companies and a high number of small family businesses. The latter are facing most of the challenges. Often, the lack of assets is not allowing long term strategic decisions. That result to slow down the effective collaboration between companies to address the global competition.
- Concentration of business clients: The past years have been marked by an intensive concentration of key business clients (editors, retailers) increasing their negotiation power in the supply chain. That drives prices low and puts pressure on printing houses. [34]
- Consumer perspective in relation to emerging technologies: Printed products are seen as traditional while new media are perceived as more interesting, modern and effective.
- Consumer perspective in relation to sustainability: Since printed paper products are paper-based, they are often not seen as a recyclable matter and a renewable resource, but rather as a forest destroying, environmentally questionable product.

2.13.3 Opportunities of the printing sector

- New services and products: The rapid adoption of new technologies in the printing industry is one of the most impacting issues at global scale. More

[35] EUROSTAT. Business expenditure on R&D (BERD) by NACE Rev. 2 activity. 2016 data.
[36] Thompson C. Graphicstart. *Challenges for the Printing Industry Globally in 2015*
[37] INTERGRAF. *The future of the European print industry – in our own hands. What the industry says*

efficient production enables printing houses to create new products faster while maintaining high quality standards. It also boasts closer cooperation with customers and creates more added-value through diversified services. The latter refers to 3D printing, intelligent labels, security print or flexographic printing.

- Customised services: On-demand printing and customised services may present an opportunity for printing houses. Especially small size companies could take advantage of their agility and low cost structure to target at niche markets. Companies can also propose diversified offers and so create better services, establish robust relationships with customers and create added value.
- Increasing customer requirements/demands: In terms of service, image quality and environmental performance of products may stand for a competitive advantage in the market.
- Improvements on sustainability: The sector can benefit from increased consumer awareness towards sustainability as it possesses a competitive record on environmental and social performance. That factor distinguishes EU printing houses from non-EU competitors. Sustainability improvements would allow the European printing industry to easily adapt to new legislation (waste, climate change, etc.).
- Research and innovation: New paper-based products with enhanced functionality, such as paper-printed electronics, smart labels etc., can offer marketing benefits. These new products could open new markets and bring higher added value for the printing industry.
- Cooperation with multi-media sector: Symbiosis between printing and multi-media companies can bring mutual benefits. That might be achieved via joint ventures which can more easily address new demands on products and services. An example of such cooperation represents the combined marketing campaigns. Printed products complement online advertisement using direct mail in the form of letters, flyers, brochures and postcards which are used to strengthen the impact of internet promotions[38].
- The European regulatory framework: EU regulations could be considered as an opportunity for all European companies which trade products in the EU and beyond. Strong environmental regulations support them to compete globally as the regulatory framework is less restrictive elsewhere while in the EU it might be a competitive advantage over imported products.

2.13.4 Threats of the printing sector

- Competition: Competitors placed in low-cost countries, notably in Asia, are capable of fulfilling European consumer standards and are putting strong pressure on prices due to lower labour costs. Imports from China have increased more than fourfold over a decade. The imports of printed products in Europe are increasing day by day driven by lower production costs. The strength of currency has considerable impacts on the printing demand globally; this explains why the Asia countries can be more competitive.[39]
- Changing habits: Changes in reading habits and the shift toward web-based media and e-solutions have significantly reduced the printing demand and the revenues from paper-based advertising. The growth in printing output is mainly

[38] Ink World magazine. The 2016 European Ink Review

[39] European Commission. *Strategy for the EU Forest-based Industries: A Blueprint for the EU Forest-based Industries*. 2007 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013SC0343&from=EN)

restricted to printed packaging and digital print, as seen in the previous sections.

- Economic crisis: The economic crisis has worsened the decline in demand on printed products. Economic conditions also have a significant impact on investment. It affects not only expenditure on advertising but on all printed material. Levels of disposable income have impact especially in `commercial traditional` printing. Adverse economic conditions result in cutting back advertising expenditures. For this reason, small changes in the global economy might a significantly affect the printing sector.
- Workforce and unemployment: The risk of unemployment is intensified by the workforce low mobility, partly due to its specialised and non-transferable skills.
- Difficulties on differentiation and innovation: The European printing industry is often suffering from uniformity of its products. Although some printing companies are disengaged from, it seems that innovation is stimulated mainly by suppliers (e.g. new substrates, improved inks or functionalities). These are covering the global market and offer the same solutions around the globe. Thus, European printers cannot maintain competitive advantages based on innovation.

2.14 Consumer perspective

This section aims to identify the factors affecting consumer behaviour in purchasing printed paper products. Consumer behaviour is useful to assess the degree of acceptance of EU Eco-labelled products. There are numbers of important factors affecting the overall demand on printed products.[40] They include:

- Trends in consumer spending
- The state of the global economy
- New technologies and their implementation
- Customer expectations change
- Globalisation
- Environmental concerns

One of the most important factors affecting the demand on printing matter is consumer spending (e.g. internet shopping, retail shopping etc.). Consumer expenses have a direct impact on companies budget for advertisement. The latter affects in turn a range of printing markets, such as advertising literature, catalogues and number of magazines and newspapers. There is a significant rise in website retailing/advertising with 'no' printing involved.

On demand digital printing is increasing due to customised purchase and internet dissemination. In particular, new technologies implementation has triggered a change in customer expectations. As printers are able to produce printed material faster, cheaper and more efficient, customers expect better products and services. This effect further promotes innovation in the sector.

In recent decades, the internet, together with information and communication technologies, such as personal computers and cellular phones, has provided an electronic alternative to newspapers and printed materials.[41]

To explore the relation of consumer attitudes on environmental sustainability of printed paper, a survey was carried out in 2016 in different countries (Australia,

[40] Global Content Publishing Market 2017-2021 (2017)

[41] Greg S. Latta, Andrew J. Plantinga, and Matthew R. Sloggy. The Effects of Internet Use on Global Demand for Paper Products. Journal of Forestry. 114(4):433–440 http://dx.doi.org/10.5849/jof.15-096

Austria, Brazil, France, Germany, Italy, New Zealand, South Africa, Spain)[42]. It considers the ongoing shift from paper-based communication to digital forms by corporations and governments, and reveals that many consumers want to retain the choice of using printed paper at no additional cost. Many respondents feel misled by 'go paperless – go green' or similar environmental claims and believe cost savings is the primary reason that organizations are going digital.

Although there are concerns about the environmental impacts of printed paper products, many respondents prefer paper-based communications than digital options for a variety of reasons including reading habits and a lack of internet access. The large majority recognize that paper-based communication can be environmentally sustainable when printed paper products are produced and disposed of sustainably. However, the acceptance of digital media is stronger amongst younger ages.

- 94% agreed that print and paper can be a sustainable way to communicate
- 79% agreed that reading from paper is nicer than reading off a screen
- 76% agreed that print on paper is more pleasant to handle and touch when compared to other media
- 76% agreed that paper is based on a renewable resource (65% in 2011).

A Eurobarometer study[43] suggests a third of Europeans state that ecolabels play an important role in their purchase decisions. More than a quarter (27%) mentions to have seen or heard about the EU ecolabel while around a fifth of them have bought products bearing an environmental label (19%).

2.15 Summary and conclusions

The market report outlines following key characteristics of the EU printed paper sector:

- The global printing industry is forecasted to be worth $980 bn by 2018. The sector is driven by growth in packaging and labels whereas graphic applications suffered a production decrease. Regarding printing technologies, digital is gaining importance over analogue printing.
- The US is the world's biggest printed paper market, followed by China. Emerging economies are displacing US and EU in production terms.
- European countries represent the third biggest manufacturing region for printed paper products, after Asia (37% of the world production) and North America (26%).
- The EU printing paper sector generates annual turnover of around €52 bn with printing activities to account for €44 bn. The EU printed paper market has experienced a continuous decrease in the production during the recent years. The leading producer country is Germany with production by value over €10,000 m. It is followed by United Kingdom, Italy and France. Their production values exceed €4,000 m each.

[42] The Attractiveness and Sustainability of Print and Paper – The U.S. Consumer's view. A Two Sides Survey of U.S. Consumers conducted by Toluna Inc., June 2016 (http://www.twosidesna.org/download/The-Attractiveness-and-Sustainability-of-Print-and-Paper-July-2016.pdf)

[43] Attitudes of European citizens towards the environment. October 2017

- The European printing sector is formed by 98,000 companies which employ around 505,000 workers. The industry is dominated by family-owned, small and micro companies.
- The EU printing industry produces different types of printed paper products. The products with the highest market shares are printed advertising material (26% excluding catalogues, 8% of printed catalogues). Books, brochures and leaflets contribute all together at 16% while newspapers and journals 16%. Other printed matter (27%) includes printed packaging.
- The main industrial printing processes are: Offset lithography, flexography, digital printing (inkjet and xerography), gravure and screen printing. Digital printing is now taking over analogue technologies in terms of market share.
- Main suppliers for printing industry apart from paper manufactures are: chemical industry (€713.7 bn), inks (€3.1 bn) and machinery (€4.42 bn).
- The total EU exports rose at almost €18 m in 2017 reflecting 40% of European printed paper production by value. The respective imports were worth €13.5 m (30%). The EU trade balance was positive by approximately €4.6 m. It is worth to note that 77% of imports and 69% of the exports are executed between EU member states.
- At global scale, it is forecasted the market remain stable in terms of production between 2017-2021 corresponding to a global annual growth of 2% and counterbalancing losses of the previous years. This trend is driven by growth in package printing, growth of emerging economies, and digital printing.
- At a European level, the printed paper sector will grow by 0.8% considering the period 2014-2020. Packaging and labels are the main drivers balancing market share losses of other printed paper products.
- New technologies and electronic media are gaining in publications and commercial products segments consequently printed matter lessens importance as a communication medium.

3 TECHNICAL ANALYSIS

3.1 Introduction

The technical analysis aims to present a comprehensive review of printing materials and technologies for printed paper products.

First, an overview of the printing process value chain including pre-press, press and post-press (or finishing) manufacturing stages has been presented. It includes the analysis of the non-paper components, printing, glueing, laminating and/or other finishing processes. Second, a list of conventional and digital printing technologies relevant for printed paper products have been compiled. The technologies regarded as the most important (considering relevance, market scale and overall environmental impact) are prioritised over other techniques.

Third, all relevant printing technologies are briefly described, including ink chemistry, and innovations recently offered to the market or still under development. The main advantages and drawbacks of each printing technology and printing ink in terms of sustainability, together with information of potential uptake of the main innovations in the sector and potential applications are described. The aim is to identify the sustainability drawbacks and advantages and to define which technologies should be included in the scope of the revised EU Ecolabel, or if there is a need to exclude or restrict any.

Products, such as printed tissue papers, printed paper products used for packaging and wrapping, folders, envelopes, and ring binders are excluded. Food contact paper products (e.g. printed carried bags or printed bread bags) are excluded as well.

On the other hand, paper surface finishing using processes such as size press, paper coating or paper dyeing are typically carried out by paper manufacturers. These processes involve a relatively high consumption of water and energy.

The coating is applied to the paper or board in form of a coating colour, consisting of pigments, binders and additives dispersed in water. There are different methods to apply the coating. After forming the coating layer, the water is evaporated in a dryer. The coating can be performed both in-line and off-line performing one or multiple steps. Usually, 10 g/m^2 is applied in each step, which corresponds to a thickness of approximately 7 µm.

In paper coating the machine speed is higher than board coating. This is due to the higher grammage of board, yet the machine is also controlled by the coating technique used. The fastest coaters, currently in operation, run at speeds of approximately 2000 m/min. Coated paper and board are printing substrates used for printed matters (e.g. magazines, catalogues, brochures and consumer packages of a different kind). Surface sizing is another type of surface treatment. Hence, a thin surface layer is applied on paper or board consisting of starch, to improve the surface strength. The size is applied in the form of a water solution using similar techniques as for pigment coating.

Surface technologies (i.e. paper coating and surface sizing) are outlined by the type of substrates in the current EU Ecolabel Regulation. Therefore, they are out of the scope of this revision. However, other surface technologies, such as post-printing coating, varnishing, laminating, etc. can also be relevant from an environmental point of view. These processes have been evaluated.

3.2 Printing processes

In Europe, printed paper is manufactured using conventional and digital printing technologies. The value chain for conventional printing consists of three steps: pre-press, press (printing) and post-press (or finishing) whereas for digital printing pre-press is not necessary.

3.2.1 Pre-press

Pre-press is the common expression for operations that need to be done before the actual printing (presswork). The main parts of this step are the following:

- Design
- Layout of documents
- Typesetting
- Graphic art photography
- Colour separation
- Proofing
- Image assembly
- Creation of printing support: Computer to film (Ctf) or computer to Plate (CtP)
- Testing

In conventional pre-press, the majority of these steps are done manually while in electronic pre-press, the so-called *desktop publishing,* these operations are done using a computer. The advantages of electronic pre-press are lower production costs and reduced production time. For example, manual film image assembly and plate making may be avoided.

Pre-press is similar to all printing technologies. In general, it does not involve the use of organic solvents or other chemicals, therefore, has no emissions to air. Emissions to water from the pre-press process can be silver compounds, used developer, or fixer and chromium compounds from cleaning chemicals. Manufacturing of image carriers, such as plates (for offset printing and flexography), engraved cylinders (for rotogravure printing) or stencils (for screen printing) also involves the use of chemicals that can be potentially hazardous for the environment. For example, chemicals are used for cleaning (surfactants), etching (acids), anodising and printing (UV curing inks) images onto aluminium plates.

Copper, chromium and/or ceramic compounds are used for engraving rotogravure printing cylinders. These compounds, particularly the metals, are restricted by wastewater legislation, hence, controlled in industrial facilities. Released emissions during the pre-press step will be discussed together with printing technologies in the next section.

3.2.2 Printing

Printing refers to the transfer image to paper using inks. There are different types of printing depending on the type of printing paper (e.g. newsprint, magazine paper, book paper, office paper, graphic paper, high-quality inkjet paper)[Error! Bookmark not defined.], the print-runs, quality and economics. The different printing technologies relevant for printed paper products are described in the next section.

3.2.3 Post-printing

Post-printing is the last step of production. It is a complex step influenced with several variables. Finishing encompasses coating, foil treatments (cutting, folding, stamping, sewing, stapling) and finally binding. Post-printing processes that could present a significant impact on the environment are lamination, glueing and varnishing

3.2.3.1 Lamination

Lamination consists of two or more polymers in web form which is transformed into multiple polymeric layers with enhanced properties. This is achieved by extrusion or hot melt lamination. Extrusion coating is achieved by heating together a mixture of two different polymer granules or pellets. The combined polymers are extruded as a single product. Cast and blown extrusion, are the two more widely applied extrusion techniques. Lamination is carried out using solvent-based systems where the adhesive-coated film passes through an oven to drive off the solvent before being pressed onto the printed surface. Nowadays, two-component epoxy type adhesives are used containing solvents, such as ethanol and ethyl acetate. Urethane type adhesives can be used alternatively. The emissions from this process are significant. In some cases, the vapours are incinerated or recovered for reuse. Water-based and solvent-free adhesives or UV curing laminating adhesives are also applied.

3.2.3.2 Glueing (or binding by using adhesives)

Glueing is a key step of finishing. For processing a book, e.g. the case for hard casebooks, adhesive binding is the most frequently used technique. Adhesive binding is often called 'perfect binding'. The adhesive can consist of natural products or can be synthetic, such as dispersion, hot-melt or polyurethane. Natural products are starch-based adhesives, dextrines and animal glues. Traditionally, most glues are water-based, hot-melt or solvent-based. For some applications of glueing such as pressure-sensitive adhesives, their effect should not affect the recycling process.

3.2.3.3 Varnishing

Varnishing (the terms coating and overprinting varnish can also be used) is a colourless, transparent printing ink formulation without pigments. It is spread over the printed surface for protection or decoration. Overprint varnishes dry by evaporation, oxidation or UV curing, and can be applied in line on the press or a separate machine·

Varnishes and adhesives can be water-based, high-solids, UV-curable or solvent-free (i.e. two-component formulations). All chemicals and materials applied in the pre-press (e.g. cleaning agents, UV curing inks), press (e.g. printing inks, toners, washing agents, dampening solution, algaecides and other additives), and post-press (e.g. laminates, varnishes, adhesives), relevant for printed paper products will be further described in the following section.

Regarding innovations in printing technologies, it is interesting to point out that a promising technology is printing by using radio frequency identification (RFID) antennas with conductive inks. The latest developments in digital technology bring along new possibilities, such as 3D image printing.

Pre-press focuses mostly on the accuracy of colour reproduction. A lot of attention is paid on how different devices reproduce colour information, as colour fidelity is one of the major aspects of print quality. The raster image processor (RIP) is the key technology for converting a broad range of data to a computer graphic. RIP technologies are common to all four printing processes.

Computer-to-plate technology for lithographic plate production uses a laser to expose the emulsion on the printing plate. Most plate-setters have a resolution of 2,000 to 3,000 laser spots per inch (lspi). The RIP calculates all the spots that must be turned 'on' to create the graphic that will be imaged on the printing plate. If the image fills a typical sheet-fed press, it is (30 inches x 3,000 lspi) x (40 inches x 3,000 lspi) = 1.08 trillion, which takes 10 gigabytes of computer memory to store and transfer. A printing plate for flexographic print production is created by turning a laser on and off at a slightly lower resolution. An inkjet printer uses the same RIP process to deliver the same one-bit data to each inkjet nozzle for each colour of ink in the printer.

Most inkjet engines have a resolution between 600 and 1,200 spots per inch — so the matrix grid is smaller, but in an eight-colour printer, the data for all eight nozzles must be synchronised and delivered simultaneously.

An electophotographic printer has a resolution similar to an inkjet printer and utilises a process alike RIP to change the grid of electrostatic charges to positive or negative. Each colour in the printer has a separate raster image that charges the drum in the right spot to attract that colour of toner to that exact location. The data for each colour must be synchronised for simultaneous delivery. The data must refresh the charge on the drum after each print to pick up new toner.

The future of paper and printing industry is expected to grow, yet slowly than the overall competition which will increase and customers become more demanding. Therefore, paper makers and printers need to focus more on the quality of the printing and reduce costs by using environmentally friendly materials and processes.

3.3 Printing technologies

There is a wide range of printing techniques performed using conventional and digital printing technologies. The selection of a printing technique depends on the ink properties (e.g. viscosity, surface tension), pattern geometry, the speed of the printing process, yield, quality and production costs. The most crucial printing parameters are listed as follows:

- Printing accuracy and resolution.
- Consistency by scaling up images. It will be affected by the ink composition and the drying process.
- Control of wetting and interface formation. The surface energy of the substrate and bonding between the printed layers and the substrate must allow creating a quality printed pattern.
- Ink compatibility with the printer components, such as rollers, doctor blades, and ink-jet heads.
- Process cost.

This section describes the main printing technologies while the different techniques included in conventional and digital printings are described separately.

3.4 Conventional printing

Table 6 portrays the key conventional printing technologies, relevant for printed paper products, their corresponding printing inks, applications for printed paper products and recent innovations associated with each printing technology.

Table 6. Conventional printing technologies, materials and innovations for printed paper products

Conventional Printing	Letterpress	Lithography (offset)	Rotogravure
Technology	Flat-bed press; Rotary press Flexography (from Rotary press)	Conventional offset: Sheet-fed offset; Web-fed offset (Heatset offset, Coldset offset) Waterless offset	Sheet-fed; Web-fed
Ink	Thick (paste) Water-based, solvent-based, alcohol-based, UV-inks	Low viscosity Oxidization drying inks; Solvent-based; Solvent-based, water-based, UV-inks	Solvent-based (toluene), water-based, UV-inks
Application	Newspapers, letterheads, business cards, envelope overprinting, books, labels, business forms	Books, newspapers, magazines, catalogues, puzzles and comics, prospects, posters, brochures and other advertising material, business cards, guides, flyers	Magazines, brochures, catalogues, advertising material
Innovation	• Pre-Press process: - Water-washable plate technology - Laser technology for plate making • Inks: UV-inks, EB-inks, ITX free, BPA-free, silicone-free, benzophenone and 4-methylbenzophenone free	• Emissions & residues: - CO_2 neutral machines (no emissions), CO_2 register, calculation, reduction and compensation - Harmless washing solution that can be released in the wastewater. • Pre-Press process: Direct Imaging (combines process-free CTP and the offset printing) • Equipment: High-speed cold set press with UV curing unit, heatset offset LED UV drying system, brilliant LED printer • Inks: Bio-based (vegetal oils, etc.), Cobalt-free inks, mineral oil free inks, hybrid inks. • Combination inline with finishing technologies	• Pre-Press process: - Laser engraving system for cylinders (faster, contactless) - "Xtrem" engraving: ultra-fine engraving - Thermal gravure technology • Inks: EB cured

3.4.1 Letterpress (Relief printing)

3.4.1.1 Letterpress (Flat-Bed Press)

Letterpress is the oldest form of printing, deriving from improvements of Gutenberg's original press. Letterpress was once used to print books, newspapers, magazines, and labels, but nowadays is rarely used for manufacturing printed paper products in Europe. Web offset and flexographic printing are also used for publications, especially those with illustrations. Older letterpress machines may still be found in some countries for printing newspapers, but their use has declined rapidly over the last 20 years**Error! Bookmark not defined.**. Long-run single colour books, such as paperbacks are printed on the web, usually by cold-set web offset but sometimes still by letterpress.

3.4.1.2 Flexography (Rotary press)

<u>Technology</u>

Flexography is used to print books paperbacks, comics and newspapers. It is the most significant technique for printing food flexible packaging. Flexography operates an elastic rubber plate, rather than a metal one (letterpress), to print onto plastic, corrugated cardboard and paper-based substrates. This printing process (Figure 57) is based on the transfer of ink from the ink tray through a fountain cylinder to an Anilox cylinder. The fountain consists of a texture with small wells to hold the ink which is then transferred to a plate cylinder (flexible rubber-like material). That leads in evenly distributed ink with uniform thickness. In the process of transferring ink from the Anilox to the plate cylinder, a blade or scraper operates to remove the excess of ink. To transfer the image, a substrate (i.e. paper) is fit in between the plate and the impression cylinder. Finally, the substrate is fed through either a dryer drum or UV ray device.

Figure 57. Flexography printing process

<u>Inks</u>

Flexography inks can be either synthetic or natural resins dissolved in low boiling point solvents, which results in liquid inks with low viscosity, rather than pastes. Commonly used solvents are low molecular weight alcohols, such as ethanol, n-propyl, or butanol, mixes of esters and glycol ethers and/or aliphatic hydrocarbons. Polymeric resins are typically based on nitrocellulose, polyamide and polyurethane while the dyes are organic molecules or metal-complexes.

Flexography inks contain plasticisers, to provide higher flexibility to printed films, and waxes, which add rub resistance. To formulate the ink, high solubility of all its components and high drying speed are desirable. The main advances in flexographic printing consist of improvements in the material of photopolymer printing plates and methods of plate creation. Furthermore, flexographic printing has improved its dot gain which translates into higher quality and accuracy.

A typical formula of a solvent-based flexographic, ink for printing on paper, is 20% of pigments, 54% of polymeric resins (e.g. maleic and nitrocellulose resins), 4% wax, 4% of plasticizer, 18% solvents (i.e. ethanol and isopropyl acetate). The equivalent of a hydrocarbon solvent-free ink is based on 12% of organic pigments, 26% of polymeric resins (e.g. alcohol-soluble polyamide and nitrocellulose resins), 4% wax, 1% fatty acid amine, 57% solvents (i.e. ethanol, n-propyl alcohol n-propyl acetate). Due to food packaging requirements and regulations, aromatic ink solvents have been replaced by ethanol and ethyl acetate. Similarly, MEK in adhesives and varnishes are used instead of plastic substrates and metallic foils.

Concluding, a typical formulation of water-based flexography ink, used for printing on paper and cardboard, is based on 50% acrylic emulsion, 2% monoethylamine, 25% pigment, 3% polyethylene wax, less than 1% antifoam and 20% water.

Applications

Newspaper printers are switching to water-based flexography. The category of security printing includes a large number of products like banknotes, passports, stamps, cheques, tickets and coupons. Also encompasses those that rely on the security of the information, such as company reports and accounts, financial documents and examination papers. However, this application requires a wide range of other printing processes, some of which are specific only to security printing. Cheap paper bags will often be printed by flexography, using water-based inks. Corrugated board is generally printed using water-based sheet-fed flexography. Envelopes can be printed by flexography while their printing, glueing and cutting can be carried out in the same machine.

Innovations

There are numerous potential benefits associated with CTP compared to traditional plate-making, such as increased productivity, improved print quality, reduced water and chemical use and materials, and reduced environmental burdens. For instance, chemistry-free plates are made by aluminium with a special coating. A laser alters the image area and the plate is rinsed with water. Nevertheless, chemistry-free laser imaging consumes more energy, so the respective cost and associated maintenance are higher. The durability of the image on chemistry-free plates can also be lower. Additionally, visible laser plate technology uses silver halide that generates effluents containing silver compounds while thermal laser plate technology uses ablation that generates particulate matter and off-gases, which could be potentially toxic. More effort on research and development of environmentally friendly pre-press technologies is still needed.

UV printing inks are increasingly applied in flexographic printing. These inks consist of binders, additives, photo-initiators and the dyestuff which are solid materials and contain no solvent. UV curing is the consequence of the cross-linking or polymerisation of the printing film resulting from the printed surface being exposed to short-wave UV light.

Innovative UV flexographic inks like Isopropylthioxanthone (ITX), Bisphenol-A (BPA), silicone and benzophenone free are already in the market. UV curing inks do not contain organic solvents. Therefore, a significant reduction in solvent emissions can be achieved by using this type of inks. However, in some cases, the energy consumption of the UV curing lamps may exceed those of the usual dryer. The UV lamps contain mercury and require special treatment as a waste. These inks contain reactive acrylates, monomers and oligomers, some of which are allergenic.

UV curing inks can be applied in flexographic processes for printing paper packaging, labels, and carton packaging for dairy products. Nevertheless, food packaging manufacturers often hesitate to use UV curing inks since the migration of small quantities of ink ingredients may lead to non-compliance with food legislation. On the other hand, most paper could be printed with UV inks. The limitation is, however, not the substrate but the existing stand of technology. UV curing flexo is used for: i) self-adhesive labels (not likely to be within the IED scope); ii) beverage cartons, labels on small narrow web presses (up to say 25 cm) and beverage cartons on presses with a width of between 100-150 cm. UV curing inks can also be applied to sizeable flexographic machines, however, no practical information has been identified.

Electron Beam (EB) curable inks consist of low molecular weight polymers that react with electrons provided by a vacuum tube. These inks contain no solvents, do not require the use of photoinitiators and do not cure until exposed to light and may, therefore, remain in ink fountains for long periods of time, reducing clean-up needs. The electrons drive the reaction, forming polymers and setting the ink. Electron beam dryers use polymerisation by electron bombardment to dry liquid and powdered coatings. Environmental benefits associated with EB technology are mainly based on zero VOC emissions. However, problems reported with EB curable inks include paper degradation and workers exposure to radiation. They are sometimes used for higher gloss coatings and metal decorating applications. It is a new technology applicable only to new presses, with high investment costs, but low to moderate operating costs.

3.4.2 Offset (Lithography)

Offset printing is a planography printing technique, i.e. the image and non-image areas are on the same plane acting as the image carrier. The non-printing areas are ink-repellent whereas the printing areas are ink-receptive. The latter is achieved using oil-based offset inks. The non-printing areas are kept clean using water or water-based solutions. The additives to the water are usually isopropyl alcohol (IPA) or isopropyl alcohol substitutes/extenders, etc. Waterless printing is also possible; in that case, the non-printing areas are kept free of ink by applying an ink-repellent coating. In the offset printing process, the surfaces with and without printed image lies on the same plane and differ in their wetting properties. The non-image area is hydrophilic and therefore can be moistened with water and a mixture of both water and alcohol. In contrast, the image area (ink-receptive areas) is hydrophobic and can be wetted with oil. A scheme of the offset printing process is shown in Figure 58.

Figure 58. Offset printing process

The offset is currently the most widely used printing technique due to its versatility, speed, quality, and cost-effectiveness. The latter is achieved by a series of developments in plates, such as life cycle extension and use of improved materials. Offset machines come in a variety of sizes, from small offset sheet-fed presses which print A3, to medium ones (1200 x 1600 mm) which can deal with many colours at a time, to large web presses printing paper two metres wide at very high speeds. The adjustability of the technique allows for the production of a vast variety of printed products.

Modern web presses are built with eight units which makes it not only possible to print eight colours on one side, but also to print four colours on each side in one run. Modern presses are also built to meet the increasing automation. New presses are equipped with automatic cleaning systems, blankets and impression cylinders, automatic systems for changing plates, etc..

Depending on the type of printing and the paper substrates, the offset (lithography) technique is further divided into sheet-fed offset, heat-set web offset and cold-set web offset. Offset inks used in sheet-fed and cold-set offset dry through adsorption into the paper and by oxidation. Regarding glossy paper, the adsorption happens too slowly for such modern fast printing presses. Modern high-speed web-fed offset presses, onto which non-adsorbent paper is printed, are equipped with forced hot air drying systems. These offset printing processes are called 'heat-set'.

One of the most important parts of a modern industrial offset printing is the computer to Plate (CtP) system. This method can quickly generate the needed numbers of dot gain compensation curves achieving accurate calibration.

3.4.2.1 Sheet-fed offset

Technology

The sheet-fed offset technique is normally used for printing volumes of up to 20,000 impressions whereas the mean value is approximately 7,000. A modern sheet-fed press can run more than 15,000 impressions per hour. Sheet-fed offset has higher costs for printing on paper. Single or multilayer cardboard for folding boxes is also printed in sheet-fed offset. Even plastic coated cardboard and thick plastic sheets can be printed that technique. Tin plates for metal boxes are printed in special offset presses. A sheet-fed offset press consists of the dampening, inking, plate, blanket and impression unit. The most common sheet-fed machine is those containing the three-cylinder printing unit.

Inks

The inks used for sheet-fed printing are thick, oily pastes which dry by adsorption into the paper and sometimes by oxidation. Therefore, they release no emissions. The basic constituents of offset inks are pigments, binders, solvents and additives. Moreover, certain substances are added to the inks to adjust their properties. The binder is the main constituent of the offset ink. It transfers the ink pigment over the roller system onto the substrate. The dampening solution used in the sheet-fed offset processes is similar to those in heat-set offset. Waterless sheet-fed offset excludes the application of dampening solutions. The rejection of the ink in the non-image areas is achieved by a silicone coating which is removed from the image areas. In such cases, the dampening unit is not used or disconnected from the press. New presses are also available without dampening units.

Applications

Most colour and short-run black and white books tend to be printed by sheet-fed offset. Overall printing houses are capable of printing books (short-run) by sheet-fed offset while providing in-house or off-site binding. However, long-run work requires special capacities. A very small number of specialised continuous belt presses are in operation which prints the entire book in one step rather than in several. They normally print by letterpress using flexible plates. The production of short-run books and booklets is mainly a local operation, but long-run work is exposed to national and international competition.

There is a huge variety of printed work known as general or commercial work, which includes advertising literature, company reports and accounts, postcards, calendars, brochures, leaflets, posters and the like, which are printed by sheet-fed offset.

There are two types of label, wet labels and self-adhesive roll labels. The former are usually printed by conventional sheet-fed offset, then cut for subsequent glueing and wrapping around cans and bottles. Self-adhesive labels are printed on the web and made up of several layers, including the backing paper, adhesive and front layer.

Self-adhesive roll label printing is a highly specialised operation, and the equipment is only used for that purpose. The presses may be rotary letterpress, flexography, or offset (water-based or waterless), and may also incorporate screen printing and foil blocking. This specific press may incorporate several processes.

Printing of business forms is also highly specific, although the market is rapidly declining due to increasing IT competences. It can be broken down into two areas: continuous forms and cut sets which are usually A4 size. Business form sets may be printed in sheet form, then collated to form the set, and glued by pasting one edge of a thick block of many sets, for later separation by the user.

Cartons made of a solid board are printed by sheet-fed offset on large, multicolour machines achieving high quality and accuracy. Alternatively to flexography, envelopes can also be ‘pre-printed’ by offset while printed sheets or printed reels are cut after printing.

<u>Innovations</u>

Sheet-fed printing is adequate for a wide variety of paper substrates. The latter differ in weight, type and size. This printing technique can use not only traditional but also spot colour and special inks, such as metallic, decorative or those with encapsulated aromas.

The trend in printing is to process orders at a faster pace. Hence, printers are forced to use multi-purpose inks with increased flexibility. Moreover, environmental regulations drive to chemically modified vegetable oils (fatty acids, alkyl esters, etc.) which are now used more often in sheet-fed processes. Faster drying inks with a higher abrasion resistance are also belonging to innovations while larger colour range of process inks is necessary. Thus, the popularity of such type of inks is growing rapidly. Innovative and environmentally friendly oxidative drying, cobalt-free, bio-based offset inks have been recently launched in the market.

3.4.2.2 Web-fed offset

This technology is divided into two different sub-processes heat-set web offset and cold-set web offset.

3.4.2.2.1 Heat-set web offset

<u>Technology</u>

Heat-set refers to an offset printing process where evaporation takes place in an oven using hot air to heat the printed material. Most offset inks do not dry by evaporation, but by oxidation or absorption in the paper, yet heat-set inks are the exception. Emissions to air arise primarily from the organic solvents contained in the inks. Solvents used in cleaning and dampening solutions (commonly isopropanol) are also important sources of VOC emissions. Solvents are driven off through evaporation may be released untreated or destroyed via thermal oxidation. Cleaning techniques range from wiping equipment with a solvent cloth to the use of enclosed cleaning units designed to recycle solvents.

The Heat-set technique prints on coated and uncoated, glossy and non-glossy papers to produce mass circulation magazines, holiday brochures and catalogues. The main issue on that technique is the solvent emissions from the driers.

<u>Inks</u>

The basic constituents of offset inks are pigments, binders (resins, varnishes and mineral oil) and additives (drying substances). Furthermore, certain substances (printing oils/thinner, rub resistance pastes, gloss agents, drying retarders, etc.) are added to the inks to adjust their properties. The binder content (high boiling petroleum fractions and vegetable oils) used in heat-set web offset is about 25%-50%.

In heat-set, there are only four standard colours. The inks are mainly organic, yet some few inorganic pigments are used. The most common are carbon black, titanium dioxide, aluminium hydroxide, iron blue, diarylide yellow, lithol rubine 4B, phthalocyanine blue. Phthalocyanine blue contains complex-bound copper. Normal pigments can contain heavy metals in the form of small impurities. A typical formulation of heat-set inks is based on 60%-85% resins, vegetable oils, mineral oils and binding agents; 10%-25% exclusive organic pigments and less than 10% siccatives (metal soaps), anti-oxidising agents (e.g. butyl hydroxyl toluene, hydroquinone), anti-skinning agents (e.g. cyclohexanone oxime) and complex formers (e.g. EDTA, tartrates).

Inks used in heat-set web offset printing are dried in ovens to drive off the solvent, yet the release VOC emissions to air. In these ovens, a hot air stream (180–300 ºC) removes 80%–90% of the solvent. Thereafter, water-cooled rollers are operated to cool down the hot web.

Applications

Magazines of over 10,000 units are usually printed by heat-set web offset. It is also used to print travel brochures, mail order catalogues, and advertising material. Some types of colour books can also be printed using this technique.

Innovations

The heat-set web offset technique is being improved in press speeds and volume of production. The respective inks are produced in large batches whilst their properties are changing. The majority of resins used in heat-set offset are still rosin esters of higher and more uniform molecular weights. Nowadays, inks dry faster, they indicate a very stable ink-water balance and their rheology is adjusted. Nevertheless, quite often, heat-set inks printed on newsprint need tiny modification.

Moreover, high-speed heat web offset based on LED UV technology has already been launched in the market.

Heat-set web offset ink formulations contain mineral oils from non-renewable sources. Their replacement by inks based on vegetable oils, such as soybean oil, is occasionally possible. The main advantage of the replacement is that vegetable inks are made from renewable sources and the sludge generated during de-inking is biodegradable. However, vegetable inks stick to the fibres making de-inking a challenging task.

Replacement of IPA in the dampening solution by ethanol or glycol ethers and optimisation of their concentration are some of the best practices that have been carried out in many heat-set offset printing plants in Europe. The fountain solution is also changing as alcohol-free fountain solutions are common.

3.4.2.2.2 Cold-set web offset

Technology

Cold-set web offset printing technology is analogous to heat-set web offset but without heating (i.e. thermal curing) units.

Inks

Cold-set web offset ink formulations are very similar to sheet-fed offset inks. These type of inks do not dry by evaporation but are oxidised or absorbed in the paper.

Applications

Cold-set web offset printing is used mainly for newspapers and business documents, printed on uncoated papers with no solvent emissions from the inks. Nowadays, all newspapers are printed by cold-set web offset. A typical local newspaper plant could have one or two presses with four units. Conversely, larger printing houses may operate up to ten presses. Cold-set printing machines with a narrower web are also used for the production of advertising flyers, paperback books and telephone directories.

Innovations

Innovative UV curing systems for cold-set web offset presses have been developed recently. The main printed paper products using this technology are newspapers, though, print covers, advertising inserts, catalogues and flyers are also printed by UV-curable cold-set inks.

3.4.2.3 Waterless offset

Technology

On the non-ink carrying parts, silicon layers are laser-hardened or burnt away to produce ink carrying areas. The hardened silicones have the same effect as the fountain solution. On traditional offset plates they can keep the plate clear of ink in specific places (Figure 59).

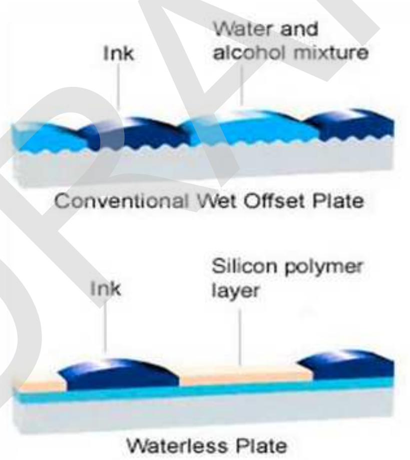


Figure 59. Conventional wet offset plate and waterless plate

Since no fountain solution is used, there is also no need for any additives, such as isopropanol or other wetting agents, therefore, no fugitive emissions occur, and paper losses are fewer during make-ready. Hence, the printing quality is better, and ‘make-ready’ is faster. Reduction in chemicals usage improves health and safety conditions. There is only one manufacturer worldwide who operates this technique. The application of waterless offset requires considerable changes to the printing process, additional cooling, and the use of special inks.

Traditional offset plates can be treated to last longer whereas plates in waterless printing need to be replaced during long print-runs. That means the production of additional plates, more frequent calibration, and enhanced paper losses. Hence, the resulting costs reduce the economic advantages of waterless offset significantly. This is also the reason why waterless offset is more often encountered in sheet-fed offset than in web-fed offset. Additional energy consumption for cooling the press is also necessary. Moreover, the plates are more difficult recycled than conventional offset plates.

The application of waterless offset requires considerable changes in the printing process, additional cooling of the press, the use of special inks and additives. These inks have a higher viscosity than conventional inks and, therefore, operate properly at specific temperatures. Application of waterless offset reduces the flexibility of the printing house. Pre-press activities may also need to be adapted. For example, it is reported, the process is not sufficient to print large areas with black ink. On the other hand, in waterless offset the dot sharpness results to better print quality. It is recently applied for printing newspaper, magazines, brochures, flyers etc.

3.4.3 Rotogravure printing

The European rotogravure printing industry uses 180,000 tonnes of ink annually (2006). This ink consists of 30 kt pigments, 50 kt resins and 100 kt toluene. More than 95 % of the toluene is reused since gravure uses a mono-solvent system. The formation of azeotropes (constant-boiling mixtures, which hinder purification) is not possible, so it is not necessary to distil the recovered solvent. Distillation avoidance saves time, costs and energy. The recovered toluene can be reused on site or delivered back to the ink maker.

The productivity of gravure printing is very high. There are currently 32 printing plants in Europe, operating 125 gravure presses. Advanced presses can print on a 4.32 m wide paper web at speeds of up to 16 m/s. Even with smaller units, the energy used per square meter of printed product is less than in alternative printing methods. This advantage increases the longer the print run.

The main environmental advantages of publication gravure printing are the use of easily recyclable and renewable raw materials and production of a very easily recyclable product. On the opposite, key environmental disadvantages arise from the technologies applied and materials used for manufacturing and engraving cylinders. These activities are time-consuming, costly and not environmentally friendly.

<u>Technology</u>

Rotogravure is a technique widely applied for printing paper products. It is based on an intaglio process, where a sunken surface is obtained after printing cylinders engrave the desired pattern. In this printing process, a group of micrometric cells (i.e. small cavities engraved onto cylinders) act as ink reservoirs that transfer ink to the paper surface by direct contact. The amount of ink contained in the cells translates into different colour intensities, and, therefore, the cell dimensions must be designed according to the desired colour intensity, thus, the deeper the cells, the brighter the colours. A rotogravure press is made up of a printing unit for each colour. Hence, the number of units will depend on the colour required in the final image.

Figure 60. Rotogravure printing process

The rotogravure printing technique is portrayed in Figure 60. The image carrier is a steel cylinder with a copper-plated surface in which small recesses, called 'cells', are engraved and carries the ink. The surface is normally plated with hard chromium to improve its wearing properties. In the press, there is a printing unit for each cylinder. The surface of the rotating cylinder dips into an ink pan filling the cells with ink (the inks for gravure printing are very fluid, whereas offset lithography ink is paste-like). Surplus ink is then wiped off by a blade, leaving only the amount of ink required in the engraved cells ready to be transferred to the substrate. An impression roller is used to apply force and press the paper web onto the engraved cylinder to transfer the ink and ensure a suitable ink covering. Finally, the printed substrate passes through a dryer before moving to the next colour unit for the next application of ink. Gravure applies the ink in controlled doses from different sizes of the cell. The larger the volume of the printing cells, the more ink is transferred and the stronger the tone.

Publication gravure is best known for being capable of producing very high-quality colour printing on lower quality, cheaper grades of paper. The press web width can be anything between 900 mm up to 4,320 mm at speeds of up to 16 m/s. Most publication gravure presses have eight printing units, one for each of the four process colours (YMCK) for each side of the paper. Occasionally a fifth printing unit per side is included (i.e. 10 units altogether) to allow a ‘spot colour’, such as a metallic or fluorescent ink for special effects. Today's rotogravure presses for publication gravure run at 15 m/s and more. It is almost totally a web-fed process, although sheet-fed presses are running at up to 10,000 sheets per hour. The use of hot air dryers aims at high-quality decorative effects when metallic inks are applied on metallised papers and foils. They are, however, seldom used at present, presumably because of the high costs of cylinder making, which make high (web) run lengths more economic.

Other similar processes are copperplate printing and die-stamping. Both employ the filling of recessed image areas with ink, but in these cases, the ink is thick and dries by oxidation and adsorption rather than solvent evaporation. Copperplate is used for the printing of banknotes and other security documents, while die-stamping is employed for letter headings.

<u>Inks</u>

Gravure inks are very similar to the flexographic inks. They are constituted by organic solvents such as esters and alcohols. These have a low boiling point and therefore become volatilised during the drying step. That reduces their migration from the printed paper to itself when rewind or in contact with paper sheets or folders. Apart from solvents, gravure printing ink formulations include polymeric resins (i.e. cellulose nitrate, maleic, acrylates, polyurethanes, and polyamides), plasticisers (i.e. phthalates, citrates, adipates), dyes and pigments. Besides organic-based inks, water-based gravure inks are widely used for printing paper products.

The pigments in the gravure printing inks are synthetic, mostly based on petrochemicals. Ink providers (European Printing Ink Makers Association) have established an 'Exclusion List for Printing Ink and Related Products' which excludes toxic and other very harmful materials as ingredients. The resins of the gravure inks are based approximately 80% on natural materials, for example, rosin, gum rosin, tall oil resin. The last is a by-product of chemical pulp production.

A typical formulation of solvent-based gravure printing ink is based on 4%-12% pigments, less than 8% extender pigments, 10%-30% polymeric resins, 2%-10% plasticisers/waxes/additives, and 40%-60% solvents (i.e. isopropanol typically for non-food paper products). The ink formulation varies significantly depending on the printing substrate, the press parameters and end use of the finished product.

In water-based inks, the water concentration usually is between 50%–60%. Aqueous dispersions, such as the styrene-acrylate copolymer, are used as binding agents. According to the purpose and the desired resistance, acid resins which are transformed into a water-soluble form by saponification with alkaline substances (ammonia or amines), are employed for modification. During the drying process, the amines or ammonia escapes and the binding agent resins become insoluble in water.

As for drying additives, ethanol and isopropanol are added in low concentrations. In most of the cases, the recipes contain additives, such as anti-foam agents, wetting agents and biocides. Dilution can be made with water. A typical formulation of water-based gravure printing inks for coated-paper is based on 32% binding agent (i.e. acrylic resins), 15% acrylic dispersed phase polymer, 2% alkali, 15% pigments, 1% antifoam, 2% wax dispersant, 3% isopropanol and 30% water. On the other hand, a typical formulation for water-based gravure varnishes for cartons is based on 15% hard acrylic resin, 35% acrylic emulsion, 2% amine or ammonium hydroxide, 5% wax emulsion, 5% wax dispersion, 2% release agent, 1% anti-foam, 20% isopropanol and 15% water.

The high speed of gravure presses requires the use of fast-drying inks, which are dried between the colours units in the driers. Therefore, gravure inks are low in viscosity, and nearly all of them are solvent-based. Publication printing inks contain 50% toluene by leaving the ink factory. A dilution is made in the printing plant to obtain the proper toluene concentration. Ink ready to use contains 70%–80% toluene. In packaging printing inks, ethanol and ethyl acetate are used almost exclusively. The solvents are evaporated by heat and air in the drying sections**Error! Bookmark not defined.**.

A typical formulation for solvent-based gravure inks for publications is based on 30%-40% binding agent (e.g. phenol resins, hydrocarbon resins, and ethyl cellulose), 8%-20% colourants (i.e. organic and inorganic pigments), 1%-4% colour auxiliary agents (e.g. waxes, dispersants, defoamers) and 50%-60% solvent (i.e. toluene). In the printing plant, inks of this type are extensively thinned before being used. The toluene concentration of the press-ready ink ranges between 70%–80% wt.

Reported data on annual gravure printing substrate consumption, in plants with two or three printing units, show a range from 40-90 kt. The reported values for paper substrates usage show a variation from 50 kg up to 70 kg of paper per kg of solvent or from 25 kg to 40 kg of paper per kg of ink. All rotogravure installations in Europe are equipped with activated carbon absorbers to recover the toluene that is evaporated. The presses are normally encapsulated. The recovered toluene is reused either on site to dilute the ink, or sold to the ink supplier. Solvent vapours from the inks in the packaging gravure are normally incinerated, although in Italy they are often recovered.

Water-based gravure inks contain some organic solvents. Conventional water-based inks rely on relatively high acid resins for water diffusion. More recently, the developed inks are based on water-dispersible polyester resins. The latter do not need neutralising agents, such as ammonia or amines to maintain their dispersibility properties. Currently applied inks are mainly based on toluene and therefore significant reductions in the use of toluene can, theoretically, be achieved. However, all publication plants are equipped with gas treatment systems and toluene emissions are already significantly reduced.

There is not any clear indication that water-based gravure inks can be considered as a cleaner technology, rather the opposite. The energy consumption for forced ink drying is higher and more waste is generated. It is difficult to de-ink paper products and treat wastes in normal de-inking plants. This limits the recycling capacity of products. The print quality is lower for water-based inks than conventional; therefore, they are not applied in publication gravure printing. One or two companies have recently started to introduce water-based gravure inks for printing paper, but these are still very much in the minority as the process needs improvements and modification depending on the product.

Water-based inks are subject of research and development. The major problem is that, with the existing recycling state-of-technology, de-inking of the paper is not possible. This, in combination with lower press speeds, printing problems with wide web widths and cross-media effects, has led to a temporary interruption of their use. They are used sporadically in packaging printing.

<u>Applications</u>

Publication gravure is applied to print magazines, catalogues and supplements with high print runs, such as news magazines, TV magazines, women's magazines, publications, catalogues, supplements, inserts and flyers published by large department stores and supermarket chain.

Very long run magazines and similar publications tend to be printed by gravure since the extra costs of making the gravure cylinder can be sustained. Due to high investment and the high output capacity, this technique is generally used in large companies.

Gravure is used for printing two types of graphic products, publications and flexible packaging. Minor graphic applications are labels, gift wrapping paper, cardboard packaging, banknotes and postage stamps.

<u>Innovations</u>

Not a great deal needs to be changed in many of the ink formulations. Gravure printing is well established and uses predominantly toluene-based inks. Gravure master image carrier presses are enclosed, ink systems are closely monitored, and the viscosity is kept at stable with the aid of automated controls. After printing, toluene is captured on activated carbon and recycled. This enables the capture and reuse of about 96%–98% of total toluene. It is cheap and reliable, and the industry is not ready to exchange it for water-based inks, which may be more environmentally friendly, but have some printability issues. Additionally, they are more expensive, especially for publication printing.

However, successful development of publication gravure inks has led to a new generation of toluene-based inks known as 'retention inks'. Retention inks have a modified formulation that slows the film formation and allows more extended evaporation of the toluene. The result is that a higher percentage of the toluene can be expelled directly into the ink drying unit and can be captured. Less toluene will remain in the product. Although they contain about 5% more toluene when press-ready, they can lead to less fugitive emissions.

These new inks are distributed by several manufacturers. The remaining toluene in the product, measured directly at the delivery area of the press, can be reduced by 30%–50%. Diffuse emissions can be reduced by approximately 1% of the total input. This corresponds to a reduction of 20% of the total emissions from a good practice gravure plant where total emissions are 5%–6% of the total input, including from waste gas treatment. These benefits can only be achieved if the waste gas from the dryers is extracted and treated. However, if adsorption is used, more energy is needed to desorb the higher load of toluene produced from the dryers.

On the other hand, the majority of gravure packaging inks have very similar composition to those used in flexographic packaging. A recent development in flexographic and gravure packaging is the use of friction inks to give higher friction to packages, such as sacks for food packaging and industrial purposes, ream wraps or reel wraps, and a variety of boxes. These inks are formulated with special adhesives that give them higher friction, so the products don’t slip or fall over during packaging or storage.

Finally, applications of energy curable gravure printing inks are also increasing, particularly for UV curable overprint varnishes, but also for low energy UV curable inks, EB curable inks, and hybrid inks. Hybrid inks are UV and EB curing ink formulations with water or solvents. These act as diluents, and there is a degree of evaporation at the print stage that enables improved wet-on-wet trapping. A significant advantage of these hybrid inks is that they are not classified as hazardous materials. This means manufacturers do not have to label the pack as hazardous. Hence, they can be transported in bulk whereas a UV ink categorised as hazardous cannot be transported in a container larger than 25 litres.

The largest weakness of the gravure technique is the engraving process which is time-consuming and costly. So, to regain the competitive edge, gravure had to come up with new image carrier solutions. In recent years, Daetwyler has developed a laser engraving system for gravure cylinders (HELL). This system has remarkably improved and automated the electromechanical engraving. Both systems have also developed solutions for the smooth engraving of edges, and so saw-tooth edges (a characteristic of gravure engraving) may finally disappear.

The Daetwyler Direct Laser System (DLS), now being used in the gravure market, features galvanic plating of the zinc/chrome layers, and this meets the surface structure and durability requirements for the gravure process. The laser beam, focused on to the cylinder surface, melts and vaporises the image carrier material and produces the cells. Laser engraving allows for a larger variability in cell shapes and sizes. By dynamically controlling the laser beam diameter, the width and depth of cells can be individually configured for publication and package printing. These new shapes can result in higher print densities and better ink release from the cells, and bring ink savings too.

Laser-engraved cells are spherical, providing improved ink release. For example, to achieve a comparable printing density, the depth of a laser cell is only approximately two-thirds of an electromechanically engraved cell. Consequently, finer screens are possible while still obtaining the required print density. With laser technology, it is also possible to create variable shape cells. The multi-shot laser can produce shaped cells, something that is not achievable with electromechanical engraving. These cells carry considerably more ink than single shot round cells

3.5 Screen printing

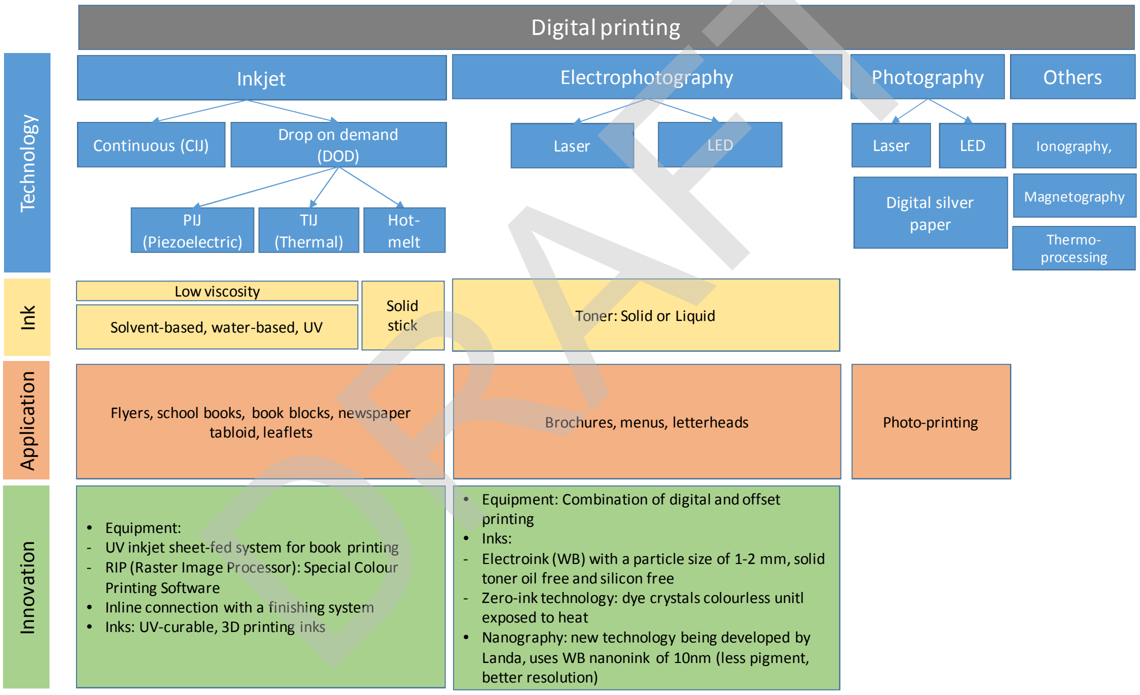
This technology is rarely used for manufacturing printed paper products in Euro. The screen is placed against the substrate and a wiper blade pushes an ink puddle across the screen. The ink is deposited through the porous image area. Since it transfers a heavy coating of ink, it is used for some labels where brilliant, fluorescent, or thick pastel colours are desired

Some examples of printed paper products based on characteristically thicker films, still manufactured by screen printing, are advertising material and posters, printing designs onto paper for transfer to T-shirts using heat, and thick coatings needed for 'scratch card' gaming tickets. The substrates printed in screen printing consist of about 40% of the printing on self-adhesive films, 20% of printing on plastics (including rigid plastics), and 20% of printing on cardboard. Much use of the process is also made for printing on textiles and metals. Run lengths are usually tiny, with two-thirds of all orders being under 1,000 copies.

3.6 Digital printing

Table 7 shows the leading digital printing technologies that are relevant for printing paper products, their corresponding printing inks, applications for printed paper products and recent innovations associated with each printing technology.

Table 7. Digital printing technologies, materials and innovations for printed paper products



Electronic or digital printing refers to printing where the complete workflow is managed using a computer. Digital printing also requires a printing system where the image produced can vary from sheet to sheet. It may be accomplished by a variable printing cylinder or by the software. Variable printing enables the production of personalised materials for direct mail, conferences, catalogues, etc.

Digital printers can be split into types:

- Laser printers (electrophotography). This includes monochrome copier/printers along with colour copier/printers from multiple sources, and some digital presses;
- Inkjet printers. This includes desktop printers, addressing printers in-line with finishing operations, wide format printers and high-quality proofing printers, as well as some digital presses;

- Thermal transfer and hot melt ink printers. This includes thermal wax and hot stick printers;
- Dye sublimation printers. This includes some colour proofing devices and 'photo quality' continuous tone printers;
- Magnetographic printers. This includes units sold by Nipson SAS printing systems;
- Ionographic printers. This includes Delphax printers from the Check Technology Corporation.
- Pictography printers. This includes the Pictography and Pictroproof devices sold by Fujifilm;
- Elcography printers. This includes devices sold by Elcorsy Technologies;
- Field effect imaging printers. This includes devices sold by the XMX Corporation;
- Image setters and plate setters. This includes devices that image film and plates (computer to plate systems).

Digital printing is the fastest growing segment of the printing industry. The key driver is a set of inks suitable for computer-driven printing devices. The process of creating high-quality digital prints on paper has merged into four major technologies namely digital photo print, dye sublimation, electrophotography, and inkjet. There are plenty of other digital processes for printing paper that can be used (e.g. solvent- and UV-curable-based inkjet printing, electrostatic or "e-stat" from reprographic shops, thermal wax/resin transfer, and blueprint reprographics), but these are either more obscure, more expensive, or have low quality scale, so not considered relevant for printing paper. Table 8 summarizes the main digital printing technologies for high quality results.

Table 8. Main digital printing technologies for high quality outputs**Error! Bookmark not defined.**

Type	Inks/dyes	Media
Digital photo print	Photo dyes	Photo paper
Dye Sublimation	Ribbon: dyes	Special paper
Electrophotography	Dry toner	Normal paper
Inkjet	Dye inks	Many options
	Dye or pigment	
	Solid resin ink	

The most relevant technologies will be explained in more detail in the next sections.

3.6.1 Inkjet printing

<u>Technology</u>

Inkjet printing is a non-contact dot matrix printing technology in which ink droplets are jetted from small nozzles directly to specified positions on various substrates (such as, textiles, paper, etc.) to create an image for different purposes. The principle where a liquid stream can be broken into small droplets of equal size and spacing was introduced by Lord Rayleigh in 1878. Based on the mechanism of droplet formation through the breakup of a continuous liquid jet, two main inkjet technologies were designed, continuous flow and drop-on-demand. The latter is further subdivided into thermal, piezoelectric, and solid ink.

Inkjet printers have higher-resolution in horizontal or print-head moving direction. Multi-pass droplet offsetting or "weaving" is one factor affecting an inkjet printer's addressable resolution. Regarding inkjet file resolution, manufacturing pixels per inch (ppi) is quite similar across the different brands (i.e. Canon 200–300 ppi, Epson 300–360 ppi, HP 150–200–300 ppi).

Continuous flow technology is the one that triggered the high-quality, digital-printing boom. However, continuous flow inkjet has become less popular over the years. Continuous inkjet (CIJ) involves the uninterrupted generation of drops from a drop generator. This breaks off the ink in small electrically charged droplets. They are deflected away from the drum and recycled, yet the uncharged ones pass through the deflector and end up hitting the paper to form the image.

Drop-on-Demand (DOD) technology is the most applied inkjet technique. It is called drop-on-demand since only the ink droplets needed to form the image are produced, one at a time, in contrast to continuous-flow where most of the ink is not used. The three main categories of that technology are thermal, piezo, and solid ink.

Thermal inkjet is based on heating of a resistance inside the print-head chamber. As the resistance heats up, a vapour bubble, surrounded by ink, is formed. The increase in pressure pushes the ink droplet out of the nozzle in the print-head. After the bubble collapses, more ink is drawn in from the ink reservoir, and the cycle repeats.

Wide-format, thermal inkjet printers used to come in either drum or plotter formats. Both narrow-format (desktop) and wide-format thermal plotter printers (also called "bar printers") have print-heads that pending on a rail or bar over the paper, which is pushed marginally by a stepper motor after each head pass. Some print-heads with their nozzles are integrated into the ink cartridges and are replaced when the ink changes. Others are separated from the inks, but still need replacing. Many come in the form of a monolithic print-head assembly that holds the ink cartridges (Figure 61).

Figure 61. The HP Designjet 130 six-color printer (with optional stand) can print on media 24 inches wide (Hewlett-Packard)

Piezoelectric inkjet: It is based on the mechanical stress (i.e. expansion or contraction) of liquid droplets occurring when certain kinds of crystals are subjected to an electric field. This is called the "piezoelectric effect," "piezo" for short and is crucial for operating this technology. When the crystalline material diverge inside the confined chamber of the print-head, the pressure increases, and a tiny ink droplet shoots out towards the paper. The returning deflection refills the chamber with more ink. Both the wide-format and desktop models of piezo printers come only in plotter versions with the print-head assembly moves over the paper to create the image. Piezo print-heads are typically single units with all colours included. They are a permanent part of the machine and usually need no replacing.

<u>Solid ink (hot melt) printing</u>: It is formerly called "phase change printing", is based on the use of an impulse heater, like thermal inkjet printers. Instead of creating a gas bubble they melt a solid ink which is kept fluid in the reservoir. The liquid ink is pumped through a piezoelectric inkjet head. Reaching the substrate, the ink solidifies on the surface. Since it is not substantially absorbed in the substrate, high colour saturations and large gamuts are obtained on a wide variety of substrates.

<u>Inks</u>

Normally, the thermal and piezo inkjet inks are solvent-based types containing volatile solvents, such as methyl ethyl ketone, ethyl and butyl lactates. More recently, UV curing digital inks have become available. Format difference of cellulose substrates also play an important role on the attitude of dyed cellulose substrates when dyed with different conventional (direct dyes, reactive dyes, vat dyes, sulphur dyes, azoic colorants) and functional colorants (such as photochromic dyes). Therefore, paper printed by inkjet is mainly applied onto coated paper specifically prepared to wetting and adhering inkjet ink drops while maintaining the required resolution.

On the other hand, the pigmented colours for phase change printing inks come in the form of solid blocks of resin-based inks, although the ink still ends up as a liquid after heating. These printers also have the affectionate nickname "crayon printers," due to similarity of the ink sticks to children's crayons.

<u>Applications</u>

Ink-jet printing and electrophotography are the main digital printing technologies for printing paper products. The inkjet technology has become the main print technology in display applications. Commercially, inkjet digital printing machines range from 1 to 10 m. They are equipped with four colour units and can carry out 1-300 runs. The length of print can vary from 1-30 m. They are capable of printing onto paper, board, plastics, textiles and metal.

Continuous flow inkjet printing involves high image quality and the ability to produce deep black colours. When printed on fine art paper, these prints have a beautiful velvety look, but indicate slow print speed (30–60 minutes per print). The time consuming maintenance and manual paper mounting have reduced demand on these machines.

The largest number of inkjet printers sold fall into the category of thermal inkjet technology. They're economically affordable and widely available and provide excellent image quality. With six to seven colour inks in dye and pigment versions, they are the printers having owned a significant share of the photographer, artist, self-printing inkjet market. Solid ink (hot melt) is able to create a definite relief effect onto the printed paper. Hence, the colours are brilliant and sharp since the ink drops do not spread out. Solid ink inkjet is fast, prints on a variety of media, and yields highly saturated images. Disadvantages include limited output size (letter/legal) and relatively poor image stability[Error! Bookmark not defined.].

<u>Innovations</u>

Innovations in inkjet printing technology are increasing in fast pace. Higher processing speed, primers as pre-coatings (i.e. Rapid Coagulation Primer, RCP) to guarantee printing quality and durability, new UV curable technology (i.e. sheed UV inkjet) and new technologies (e.g. Nanography) have been recently developed.

Rapid Coagulation Primer (RCP) solution reacts promptly with the ink on the paper surface. It leads to rapid coagulation of the pigment, preventing running of ink without to change the texture of the paper. The effect of RCP is depicted in Figure 62.

Figure 62. Effect of RCP using a Jet Press 720 printer compared to offset printing and conventional inkjet printing

The UV-continuous inkjet printing technique is growing very fast due to its good performance and the robust printing. It provides images of high quality and durability (i.e. suitable adhesion, scratch resistance and solvent resistance); high curing speed and curing degree (92%-98%). The latter reduces unreacted monomers from the curing process to the foodstuff and provides good optical properties, such as gloss, colour or brightness.

One of the options for printing 3D ink films is to use the drop-on-demand technique with a system of multiple droplet nozzles. Ink droplets are ejected and have to be cured immediately to avoid ink penetrations and spread into the substrate. After curing, the second and the three following layers of the ink are deposited on previously printed areas to create the 3D image.

Crucial materials for making 3D inks include thermoplastic resins and waxes. Resins control the viscosity of the ink at the melting point, and inhibit the crystallization of the wax, revealing the transparency of the ink. Polymers used for hot melt inks have melting points between 40-200°C. In a molten state, the polymer stabilises and therefore no formation of gaseous products or deposits occurs in the device. Examples of suitable polymers for ink compositions are alkyd resins, amides, acrylic polymers, benzoate esters, citrate plasticisers, coumarone-indene resins and dimer fatty acids. They also include epoxy resins, fatty acids, ketone resins, maleate plasticisers, long chain alcohols, olefin resins, petroleum resins and phenolic resins. Plus phthalate plasticisers, polyesters, polyvinyl alcohol resins, rosins, styrene resins, sulphones, sulphonamides, terpene resins, urethanes, vinyl resins, their derivatives and their combinations. No limitation is placed on the type or the amount of the polymer in the ink.

A crucial development of printing inkjet inks onto paper is anticipated for inks for printed electronics. Conductive inks allow electrons movement, so the inks can act as wires, resistors or antennas. For radio frequency identification (RFID), conductive inks can serve as antennas that receive the information from an RFID enabled computer wireless.

A resend trend shows a progressive move towards highly versatile, environmentally friendly, inkjet technology. Fast customization and progressive replacement of gravure, offset and flexography technologies has also been observed.

3.6.2 Electrophotography

Technology

Electrophotography is also called colour copy, colour laser or "xerography" ("xeros" for dry, "graphos" for picture). The respective devices are often called electrostatic printers. These devices include desktop and office monochrome laser printers, colour laser printers, colour copiers with digital interfaces, and digital colour presses. They use fixed LEDs instead of lasers. The Indigo uses liquid toners. They usually include postscript interpreters, either built-in or as add-ons. Electrophotography is based on the original xerographic process, where a charged photo conducting drum is selectively discharged by the laser or LEDs. The drum is toned by charged pigment particles, and the image is transferred and fused to the substrate with heat and pressure. Electrophotography printers can print on any kind of paper and other substrates. Colour printers and copiers use the same processes as monochrome printers and copiers. They may also be equipped with variable data software for customized printing.

This technique involves the use of dry toners and laser printers. The liquid toner version or "digital offset" is also used for printing paper. Many colour lasers operate hair-thin lasers to etch a latent image onto four rotating drums (Figure 63).

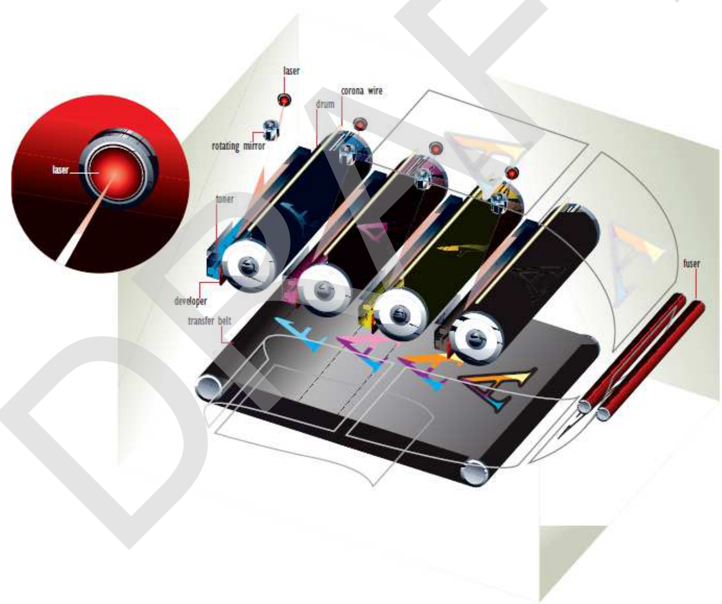


Figure 63. Single-pass, colour laser print technology (Xerox Corporation)

The drums attract electrically charged, dry, plastic-based pigment toner and transfer the image to an intermediate belt and to the paper where it is fused. Other laser printers transfer the toner directly to paper without the intermediate step.

Older technology devices apply one layer/colour at a time. The tendency is to apply the so called "single pass" printing which speeds up the process considerably. Maximum output size is typically 12×18 inches, although other formats are possible. In some printers, laser imaging is replaced by light-emitting diodes (LEDs).

Nowadays, colour lasers offer up to 1,200×1,200 dpi resolution and use their own combinations of stochastic and halftone screening for colour rendering.

Inks

The inks used in these machines are either liquid or dry toners. Liquid toner inks are two-part systems which include the toner itself and the carrier. The latter is a volatile solvent, such as ethyl acetate, methyl ethyl ketone or ethyl and butyl lactates. The toner is applied to the plate and the carrier liquid remains in the system. The remaining carrier with the toner is boiled off in the machine's fusing section.

Most modern presses have a solvent recovery system, and the liquid is retained for recycling. All solid (or dry) toners consist of a resin, pigment, charge modifier, dye and other essentials. A major difference between toners and conventional inks is the binder resin used. The most common resins are copolymers of styrene, acrylate esters such as 2-ethylhexyl acrylate or butyl acrylate, copolymers of styrene and butadiene, and polyesters. Toner inks differ from conventional inks in another issue. Namely, at a certain temperature they change from a brittle solid to a sticky rubber-like material. The resin is the fusible part of the toner while the binder provides bulk to the particle. Dry toner waste is basically plastic powder. Both liquid and dry toner waste can contain paper dust, clay fillers, or photoconductor dust and water. Broadly speaking, similar ink types are used in laser printing and in photocopying.

<u>Applications</u>

Colour laser printers are becoming more short-run printing presses in quick print shops as well as businesses. They are also used as primary colour output devices in graphic arts departments and design studios. Electrophotography printing is fast and reasonable, with 8x10 prints under €1.00 at many retailers, and images can be printed on a small range of substrates including matte paper and commercial printing stocks. The main disadvantages of electrophotography are the limited maximum output size (usually 12x18 inches) and the high initial cost of the machines.

<u>Innovations</u>

The ability to form a raised image using a desktop printer makes it possible to use this technology for a variety of specialized print products, such as business cards, postcards and certain children's books. A recent application includes printing of microelectromechanical systems (MEMS). These 3D structures may be digitally printed and serve different purposes, such as to produce maps. If the raised image attains the required height and firmness, it could be used for Braille printing.

Dry toner digital printing is the most widely-used digital printing technology. Combinations of printing techniques (or hybrid printing), such as offset and digital are possible, although some paper requirements and printing protocols should be accomplished.

Electrophotography creates several environmental benefits that are associated with innovations. For instance, avoiding emissions of halogenated hydrocarbons during production processes, achieved better design of new photoconductor manufacturing facilities, reducing toxic solvents, avoiding emission of heavy metals, improving reuse and recycling, using high-grade paper and improving de-inking of paper by removal of toner residue using new toner formulations.

3.7 Comparison of printing materials and technologies

To sum up, two different tables comparing technical and environmental aspects for printed paper products are presented (Table 9 & Table 10).

Table 9. Comparative qualitative environmental analysis for different relevant printing inks technologies applied for manufacturing printed paper products

Printing ink technology	Advantages	Disadvantages	Position on the market
Flexography	High productivity High resolution UV curing increasing	Pre-press required Waste and emissions	Well established
Offset	Very high productivity High resolution Bio-based components in offset ink formulations	Pre-press required Waste and emissions	Well established, but decreasing
Rotogravure	Very high productivity Very high resolution Retention inks established	Pre-press required Solvent-based Waste and emissions	Well established
Inkjet	Pre-press not required (non-contact process) Low cost per copy for small editions Water-based or 100% solid Very high resolution Low waste and emissions	Relatively small editions are required due to low productivity Lower print quality and higher production costs at high editions	Well established particularly for wide format printing of posters, but more common as home desktop printer
Electrography	Pre-press not required (non-contact process) Low cost per copy for small editions 100% solid High resolution Low waste and emissions	Relatively small/medium editions are required due to low/medium productivity Lower print quality and higher production costs at high editions High maintenance costs for electrography	Well established and increasing for office printers and industrial digital print presses

Table 10. Comparative qualitative environmental analysis for different ink technologies applied for manufacturing printed paper products

Ink technology	Advantages	Disadvantages	Position on the market
Solvent-based	Efficient solvent recovery systems Accomplishing the required performance	High VOCs Hazardous in workplace	Well established
Water-based	VOCs free Non hazardous Water washable installations	Specific paper substrates Limited colours Slow/poor quality in some applications Higher energy consumption	Established for some applications
Toner (100% solids)	High quality/price ratio on printed paper Recycling of cartridges is established	High quality paper required Reusing of cartridges should be promoted	Well established
UV/EB curable (100% solids)	VOC-free Faster processing speeds are possible Requirement of less space for industrial processing	Use of hazardous ingredients such as acrylates and photoinitiator (in UV curable inks) Still degradation of paper substrates (in EB curable inks)	Established for overprint varnishes and under development for the most of applications

3.8 Production flowcharts for the different printed paper products

To provide an overview of the main production operations, a summary of the different production flowcharts for the different printed paper products (i.e. books, newspapers, catalogues, advertising material, magazines, etc.) has been analysed (Table 11).

Table 11. Manufacturing value chain for printed paper products

Printed paper products	Pre-press	Press	Post-press
Magazines	-Design -Layout of documents -Typesetting -Graphic art photography -Colour separation	- Sheet-fed offset (short runs, below 10000 magazines) - Heat-set web offset (over 10000 magazines) - Cold-set offset - Rotogravure (very long run lengths)	- Surface finishing (laminating , glueing and varnishing) - Foil treatments (cutting, folding, stamping,
Newspapers		- Flexography - Cold-set web offset (the most of the	

Printed paper products	Pre-press	Press	Post-press
	- Proofing - Image assembly - Creation of printing support: film or plate (CtF, Computer to Film; or CtP, computer to Plate), including the manufacturing of image carriers such as plates (for offset printing and flexography); or engraved cylinders (for rotogravure printing). No image carrier is needed for digital printing technologies (i.e. inkjet and electrography) - - Testing	newspapers) Letterpress (rarely)	sewing, stapling) - - Binding
Business cards		- Flexography - Offset	
Books (long-run single colour books)		- Flexography - Coldset web offset (paperback books) - Letterpress (sometimes)	
Books (colour and short-run black and white books, and booklets)		- Flexography - Sheetfed offset (short runs) - Heatset web offset (some colour books of different run lengths.) - Cold-set web offset (paperback books)	
Telephone directories		- Cold-set web offset	
Labels (wet labels)		- Flexography - Sheetfed offset - Rotogravure (long run lengths)	
Labels (self-adhesive roll labels)		- Rotary letterpress - Flexography - Water-based or waterless web-fed offset	
Business forms		- Flexography - Sheet-fed offset - Cold-set web offset	
Catalogues		- Heat-set web offset - Rotogravure (very long run lengths)	
Puzzles and comics		- Flexography - Offset	
Prospects		- Offset	
Posters		- Sheet-fed offset	
Business cards, greetings cards,		- Sheet-fed offset	

Printed paper products	Pre-press	Press	Post-press
calendars			
Guides		- Offset	
Security papers (i.e. banknotes, passports, stamps, cheques, tickets, coupons, company reports and accounts, city financial documents and examination papers)		- Flexography - Sheet-fed offset (i.e. company reports and accounts) - Rotogravure (for banknotes and postage stamps)	
Brochures and advertising material		- Sheet-fed offset - Heat-set web offset - Cold-set web offset - Rotogravure - Electrophotography	
Flyers and leaflets		- Sheet-fed offset - Cold-set web offset - Rotogravure (very long run lengths) - Inkjet	
Letterheads		- Flexography - Electrophotography	
Menus		- Electrophotography	
Newspaper tabloids		- Inkjet	
School books and book blocks		- Inkjet	

3.9 Standards for print quality

Relevant technical standards applied to printed paper products have been identified and are presented in this section. The International Organization for Standardisation (ISO) has formulated technical standards for printing technology. These standards include printing processes, types of ink used, and graphic technology used in printing (Table 12). Particularly, ISO 12647 specifications include standard process control points and tolerances for various printing methods and processes while ISO 12647-2 covers the offset printing process. Standardizing production means that a number of production parameters need to be clearly defined, along with the specific tolerances. In the case of ISO 12647, these definitions include the colour and transparency of printing inks, definitions of paper types, solid tones which are described with CIELAB values, and tone value increases (TVI), per paper type and colour.

Table 12. ISO technical standards for printing technologies

ISO standard	Description
ISO 2836:2004 Graphic technology - Prints and printing inks - Assessment of resistance to various agents	This international standard specifies methods of assessing the resistance of printed materials to liquid and solid agents, solvents, varnishes, and acids.
ISO 12640-2:2004 Graphic technology – Pre-press digital data exchange – Part 2: XYZ/sRGB encoded standard colour image data(XYZ/SCID)	This part of ISO 12640 specifies a set of 15 standard colour images (encoded as both 16-bit XYZ and 8-bit RGB digital data provided in electronic data files) that can be used for the evaluation of changes in image quality during coding, image processing (including transformation compression and decompression), displaying on a colour monitor or printing. They can be used for many graphic technology applications, such as research, development, product evaluation, and process control.
ISO 12646:2004 Graphic technology - Displays for colour proofing - Characteristics and viewing conditions	This International Standard specifies requirements for uniformity, size, resolution, convergence, refresh rate, luminance levels and viewing conditions for a colour display used to simulate a hard copy proofing system.
ISO 12647-1:2004 Graphic technology - Process control for the manufacture of half-tone colour separations, proof and production prints - Part 1: Parameters and measurement methods	This and other parts of ISO 12647 specify parameters that define printing conditions for the various processes used in the graphic arts industry.
ISO 12647-2:2004 Graphic technology - Process offset printing, or when producing four-colour control for the manufacture of half-tone colour separations, proof and production prints - Part 2: Offset lithographic processes	This International Standard specifies a number of process parameters and their values to be applied when preparing colour separations for four-colour prints by one of the following methods: heat-set web, sheet-fed or continuous forms process printing, or proofing for these processes; offset proofing for half-tone gravure.
ISO 15790:2004 Graphic technology and photography - Certified reference materials for reflection and transmission metrology - Documentation and procedures for use, including determination of combined standard uncertainty	This International Standard specifies the documentation requirements for certified reference materials (CRMs), procedures for the use of CRMs, and procedures for the computation and reporting of the combined standard uncertainty of reflectance and transmittance measurement systems used in graphic arts, photographic and other imaging industries
ISO 2846-5:2005 Graphic technology - Colour and transparency of printing ink sets for four-colour printing - Part 5: Flexographic printing	This part of ISO 2846 specifies the colour and transparency to be produced by each ink in a process colour ink set (including extender) intended for four colour flexographic printing, when printed under specified flexographic printing conditions. It also describes the conformance test method.
ISO 15994:2005, Graphic technology — Testing of prints — Visual luster	This International Standard defines a measure of the apparent lustre of printed materials, termed "visual lustre", which is intended for communication amongst designer, client and the printer of products for which the visual perception of the surface lustre is important.

Source: National Printing Equipment Association (NPES) standards book

The ISO 12647 standard is split up in different parts. Since the standard covers various printing methods, a printer only needs to implement a part of the full specifications.

- ISO 12647-1:2005 describes the parameters and measurements methods. Essentially 12647-1 provides the basis for the subsequent print related settings.
- ISO 12647-2:2004 defines the process control settings for offset lithography.
- ISO 12647-3:2005 defines the process control settings for newspaper printing, more specifically cold-set offset lithography on newsprint
- ISO 12647-4:2005 defines the process control settings for publication gravure printing, which is used for high volume magazines, catalogues, etc.
- ISO 12647-5:2001 defines the process control settings for screen printing.
- ISO 12647-6:2006 defines the process control settings for flexographic printing.
- ISO 12647-7 is still being work on. It will cover off-press proofing processes.

Some studies are demanding more detailed tests for better defining the parameters affecting dot gain (i.e. printing substrate and screening description, for the printing conditions) and are not currently included in ISO 12647-2.

Regarding ISO 2846, it considers different printing technologies. Part 1 describes the sheet-fed/heat-set Web printing, part 2 refers to Cold-set/Newspaper, part 3 to gravure, part 4 to screen printing and part 5 to flexography.

Other technical standards relevant to print quality are:

- ISO 15397:2014 is applicable to papers intended for rotogravure, cold-set web offset, heat-set web offset, sheet-fed offset, and flexographic printing processes and proofing substrates.
- EN 12858:1999**:** Paper - Printing and business paper - Requirements for continuous stationery.
- EN 12281:2002: Printing and business paper - Requirements for copy paper for dry toner imaging processes.
- EN 12283:2002: Printing and business paper - Determination of toner adhesion.
- EN 17085: Paper and board - Sampling procedures for paper and board for recycling.

3.10 European environmental policy & legislation

For many years legislation has existed to control the use and emissions of toxic and harmful materials during production, and has sought to control the input of harmful materials into the environment. There is a significant amount of European legislations aim to control environmental pollution from manufacturing facilities.

Atmospheric pollution is an issue where printing has been criticised due to solvent vapours. However, the printing industry as a whole emits only 2% of the amount of gaseous emissions that come from motor vehicles. The main problem of VOCs (volatile organic compounds) is caused by ink solvents, press-room wash-up solutions and alcohols in fount solutions. Water-based inks are being used increasingly as do ultraviolet curing inks, both of which are free from volatile solvents. New types of solvent cleaners are being introduced for press cleaning. Vegetable cleaning agents are replacing petroleum distillates to clean rollers and blankets. Blends of water and slower evaporating distillates are widely used in US and are gaining in popularity in Europe.

Alcohols are being replaced in fount solutions by quinones and other non-volatile substances. In large flexography and gravure printing houses, solvent recovery and recycling is now common practice. The increased use of water-based products has highlighted the need for wastewater treatment. This includes the removal of heavy metals and colorants from ink wastes and saturated wipe cloths.

Chemical waste disposal from silver halide processing is very well controlled in the printing industry and causes no environmental concerns. Waste disposal and water pollution is subject to strict legislation in Europe.

On the other hand, it is interesting to point out that specific regulations for nanomaterial-based products are into debate worldwide due to their growing market and nanosafety concerns.

Traditional methods of toner manufacturing involve mixing and heating the ingredients and extruding them into strands, thereafter, are pulverised into small particles. The particles are mechanically sieved with a particle size of around 7μ. A new method proposes to develop the toner from the molecular level, making it possible to reduce the average particle size to about 5μ with a far more consistent size distribution.

Over the next ten years nanotechnology will be used to produce new toners. Ink makers will explore nanotechnology manufacturing methods to produce inks and varnishes more efficiently. The use of novel nanoparticles will widen the range of available colours, with better metallics and fluorescents. These will boost the development of special inks in security and emerging printing technologies for organic semiconductor and electronic devices. Conductive inks fall into highly pigmented systems, where a metallic component (commonly silver nanoparticles, but various other metals can be used) or to formulations where a metallic precursor is embedded in a carrier system (commonly silver salts that decomposes into nearly pure metal after printing).

Nanosafety aspects related to manufactured nanoparticles for different applications, including printing inks, is under evaluation. More effort should be put into clarifying and evaluating structure-function relationships by systematically modifying composition. With more data, theoretical modelling of nanomaterials diffusion will gain confidence in the future.

3.11 Technical background for criteria development

Key factors, influencing the environmental profile of printed papers, are use of renewable materials, emissions, energy consumption and waste. These factors are evaluated in the next sections.

3.12 Emissions to air and water

The directive 2004/42/EC amends the directive 1999/13/EC. The key objective of the directive 2004/42/EC is to limit the emission of volatile organic compounds in certain installations and processes like printing, surface cleaning, vehicle coating and dry cleaning. The product categories, which fall under the scope of this directive, only apply in European countries. Table 13 summarizes the emission limits form printing processes.

Table 13. Maximum emission limit values for printing processes**Error! Bookmark not defined.**

Activity (solvent consumption tonnes/year)	Threshold (solvent consumption in tonnes/year)	Emission limit value in waste gases	Fugitive emission value (% of solvent input)	
			New	Existing
Heatset web offset printing	15-25	100	30#	
(> 15)	>25	20	30#	
Publication rotogravure (> 25)		75	10	15
Other rotogravure, flexography, rotary screen printing, laminating	15-25	100	25	
or varnishing units (> 15) rotary screen printing on	>25	100	20	
textile/cardboard (> 30)	>30*	100	20	

Source: Official Journal of European Union.

 # Solvent residue in finished product is not to be considered as part of fugitive emissions.

** Threshold for rotary screen-printing on textile and on cardboard.*

In the heat-set web offset technique, the VOC-relevant raw materials and additives are as follows:

Inks are based on aliphatic hydrocarbons (33%–35%). These solvents are made by mineral oil. They are not volatile at ambient temperatures, but in the dryer. About 85% of the oil fraction is evaporated in the dryer as VOCs (equivalent to about 30 % of the total ink amount). Solvent residue in the finished product is not considered part of fugitive emissions because it is not volatile at ambient temperatures. One tonne of ink allows the printing of about 330,000 m^2 (both sides) or 100,000 catalogues (48 pages DIN A4 each).

Dampening solution consists mainly of water. Generally, it contains about 3% dissolved salts and up to 20 % isopropanol (isopropyl alcohol or IPA). Dampening solution can contain ethanol instead of isopropanol. At 20 °C, isopropanol has a vapour pressure of about 4 kPa and ethanol 5.9 kPa, therefore, both are classified as VOCs.

The implementation of good practices can to reduce the isopropanol addition into the dampening solution.

Other additives, based on less volatile or non-volatile organic compounds (often glycols), have been used to lower the isopropanol content of dampening solution. The VOC content of these additives can vary (1%-30%).

Cleaning agents are mainly based on hydrocarbons. Aromatic hydrocarbons have good cleaning properties yet their use has been restricted for health protection reasons. Common cleaners are mainly aliphatic hydrocarbons with vapour pressures of 0.1–11 kPa at 20 °C (100% VOCs, flashpoints of 30–80°C). Aromatic hydrocarbons are also contained yet to a lesser extent. Oily cleaning products, introduced in the 1990s, are based on natural oils, high-boiling mineral oils or mixtures thereof (0% VOCs, vapour pressure <0.01 kPa at 20°C, flashpoint >100 °C).

There are different reported good practices (e.g. direct piping of inks, printing additives, solvents, air extraction for the drying processes or the cooling zone, safe storage of hazardous substances) applied to minimize fugitive emissions. Techniques specifically used in heat-set web offset to reduce VOC emissions are low-VOC additives for dampening solutions, optimising the IPA concentration in the dampening solutions, use of waterless offset plates; automatic cleaning systems for blanket cylinders, web offset dryer integrated with thermal waste gas treatment (WGT).

Gravure printing involves the use and recovery of high quantities of toluene. The toluene concentration of the press-ready ink is about 80% wt, which is emitted yet most of it recovered, except for 2%-3% that remains in the final product. Retention inks might reduce fugitive emission by 1 % of the total toluene input**Error! Bookmark not defined.**. Toluene is easy to recover. It adsorbs well to activated carbon and is retrieved by heating the carbon with steam. The steam and solvent vapours are condensed and separated. The condensed steam will contain toluene to its maximum solubility of approximately 0.05%, in a range of 0.38-0.54 g/l. However, toluene is on the EU list II (Directive 76/464/EEC). As a consequence, technologies avoiding the use of hazardous solvents should be promoted. The toluene is partly reused and partly sold back to the ink manufacturers**Error! Bookmark not defined.**. A removal efficiency of 99% is technically achievable. However, there is a balance with increased energy consumption. Some toluene is lost as traces in the gravure printed products. This amount has been significantly lowered in recent years. That is achieved via modification of the ink composition.

The surface of the printed ink takes slightly more time to solidify. In this short time period, around 10 milliseconds, the additional toluene which evaporates in the printing unit is caught by the recovery system. When the printed matter leaves the production site, the toluene traces are lower than 0.04 %. Consequently, the airborne toluene concentration in nearby areas is far below 260 $\mu g/m^3$ of air. The figure of 260 $\mu g/m^3$ is the maximum concentration accepted by the WHO for private homes. At the workplace, higher safety standards are set. The maximum concentration allowed is 190 mg/m^3. This limit stand for the average over eight-hour working day. Organic solvents used as washing agents show volatilities between 0,1 kPa (or lower) and 5,0 kPa (or higher) (at 20ºC). Lower vapour pressure should be promoted in order to reduce VOCs associated to these washing agents.

3.13 Carbon Footprint

Figure 64 compares the global carbon footprint (CO_2 equivalents) associated with different technologies for printing paper, estimated for 2020.

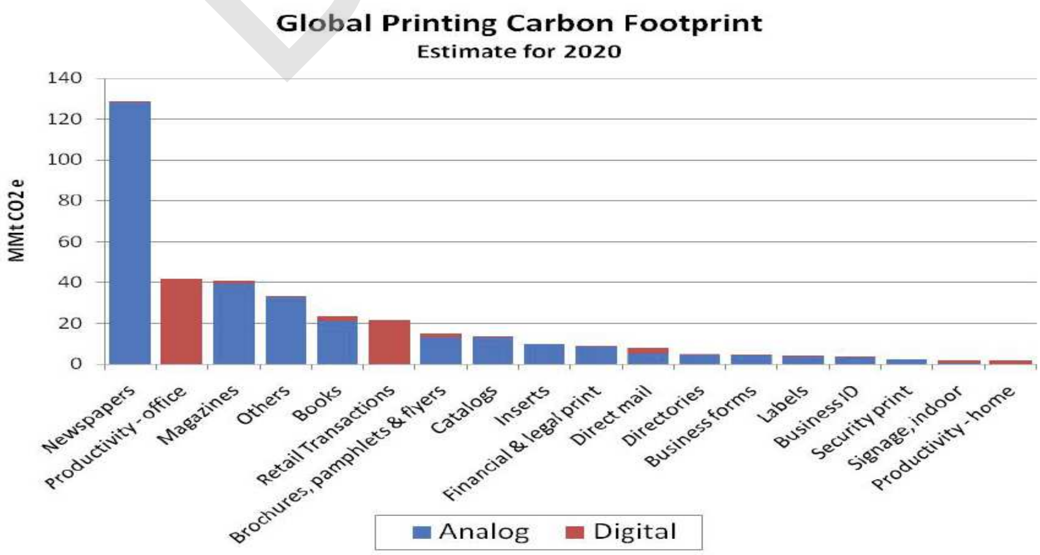


Figure 64. Global Carbon Footprint of print applications, modelled using the Ecoinvent database

Reduction suggestions for printing of newspapers, magazines, books, catalogues, etc. have been recently discussed.

3.14 Energy Consumption

Energy consumption encompasses electricity consumption, heating and fuel use etc., and is calculated as kWh per tonne of product. This refers to the entire production procedure including pre-press, printing and finishing, as well as other sub-processes/functions in the printing company. The latter includes chemical stores, paper and product stores, ventilation, lighting, internal treatment of water and emissions as well as support functions, such as offices, toilets, changing rooms and other common areas. This parameter does not include fuel, if any, used for the printer's own vehicles. Table 14 can be used to calculate the distribution between the various methods.

Table 14. Energy consumption according to the different printing methods

Printing method	Average energy consumption (kWh/tone of product)
Sheet fed offset (except packaging and offset printing of envelopes)	1253
Cold-set, newspapers	365
Cold-set, forms	997
Cold-set rotation (except newspaper and form printing)	825
Heat-set rotation	965
Gravure printing	864
Flexographic printing (except envelope production)	486
Digital printing	2592
Offset printing, envelopes	436
Envelope production with flexography	552
Offset, packaging	1564

Specific energy consumption associated with gravure printing varies between 0.4-0.75 MWh per tonne of substrate or from 10-30 MWh/million m^2 (all coated slides). The toluene recovery system (local extraction, steam generation, cooling water pumping) represents a significant share (approximately 50%) of the total energy consumption of the installation.

In addition to the general measurements (energy-saving lighting, optimisation of pressure level), the main energy-savings suggestions for the sector include heat exchange in the ventilation systems. That encompasses the toluene recovery plant, air conditioning, dust extraction lines, trimming line, reduced air ventilation at idle operation or maintenance, thermal insulation of tanks and vats with heated liquids (toluene recovery plant adsorbers, hot water tank), toluene recovery plant with variable frequency drives, heat recovery from the toluene recovery plant, air extraction and energy recovery from drying processes.

It is interesting to point out that UV and water-based inks need more energy to get dried than solvent-based inks UV inks. As the high energy supply to the lamps is turned into heat, large installations for cooling are also needed. For water-based inks, an increase in the energy consumption of the driers by 10% is reported.

3.15 Waste

The waste generated can be broadly classified as hazardous and non-hazardous waste. Various other types of waste, as produced throughout the printing procedure, are described in Table 15.

Table 15. Classification of printing wastes**Error! Bookmark not defined.**

Hazardous waste	**VOC**	**Pollutes wastewater**	**Non-hazardous solid waste**
Photographic waste including intensifiers, scrap film and photo developer.	Petroleum based inks containing xylene, ketone, and alcohols.	Any liquid hazardous waste dumped in the drains	Waste substrates such as paper, foil, film resulting from rejects and excess quantities.
Waste ink with solvents and different heavy metals.	Fountain and damping solutions such as isopropyl alcohol.	Rinse from photo processing	Water-based inks without heavy metal constituents.
Strong alkaline wastes such as sodium hydroxide	Cleaning solvents including acetone, methanol and toluene		
Strong acid waste such as sulphuric and nitric acid.	Various types of adhesives containing ammonia.		
Cleaning rags which contain solvents			

Source: *Rochester Institute of Technology*

Regarding heat-set web offset printing, the amount of paper wastage is usually higher than other printing methods. The reported proportion of paper waste in the overall quantity of substrate is about 15%. Waterless offset produces less waste, as there is no balance between ink and dampening to be achieved.

Waste paper recycling is mainly outsourced. In the case of medium- (offcuts) and high-quality (white) waste paper, a direct delivery to the paper mill was reported. Stated values show that the quantity of produced ink waste varies from 2 kg up to 6.5 kg per tonne of used ink.

During printing, the dampening solution can become contaminated with paper dust and small amounts of ink. These solutions contain AOX and small quantities of metals; therefore, special treatment is necessary. Large amounts of cleaning agents may arise, especially in large printing plants where most of the cleaning is done automatically. The estimated amount is about 100 kt cleaning agents per year in the EU-wide offset printing industry, which is disposed of. Wipes from cleaning the press contain organic solvents, ink and sometimes varnish. The amount usually varies depending on print-run.

Other wastes are photopolymer and rubber printing plates. The steel, polyester or aluminium sleeves are reused repeatedly. The polyester or rubber materials are glued to non-returnable metal containers, primarily aluminium, with traces of other metals, reel cores; glue, adhesive and film wastes. Blankets are discarded. Waste can also contain filters from filtering the dampening solution and discarded UV lamps from the platemaking process. UV curable inks cure rapidly under ultraviolet radiation. These inks contain photo-initiators which, under UV radiation, start a process of polymerisation of the binders. The binders are reactive acrylates. There are dampening solution additives that are not classified as allergenic (risk phrases R42 or R43) due to dilution. Wastewaters coming from dampening solutions and cleaning agents have also been identified. The total amount of wastewater depends on the working methods. On average 2–3 m^3/t ink is used and discharged, mainly from press cleaning activities. If treated, the effluent may be reused while the sludge should be managed accordingly.

The reduction of paper losses associated with waterless offset printing, due to the shorter make-ready periods, brings economic advantages in the case of short runs. It realises high quality work and reduction of chemicals use. Hence, it improves the workplace's health and safety conditions.

Regarding gravure printing inks, the main types of waste generated are paper waste, toluene, slurry toluene, waste ink, metallic copper, solid waste containing Cr(VI), de-chroming acid bath electrolyte, waste water treatment sludge filter pressed, cleaning rags from pressrooms, carton, paper reel wrappings, oil and lubricants, wood and scraps.

In most of the cases, printing is performed using four inks whereas mixing takes place in small rates. Based on data from two printing facilities, the percentage of wasted ink is estimated less than 0.1% of the ink input. Wasted ink is treated off site as hazardous waste. Leftovers are normally mixed with black ink and thus reused. Wasted ink can be distilled to recover the toluene while wastewater from the plating department is treated as hazardous waste elsewhere.

4 LIFE CYCLE ASSESSMENT OF PRINTED PAPER PRODUCTS

4.1 Introduction

This section aims to analyse the potential environmental impacts related to the printing industry, including the printing house impacts and those associated with the final products.

To identify the most important environmental aspects, a screening of published LCA studies has been performed. Next to that, a critical review of those studies has been carried out to draw key conclusions. This analysis aims to identify main environmental areas of concern and impact hotspots and to suggest environmental improvements.

Besides the screening, a streamlined LCA has been accomplished, analysing two standard products a magazine and a book, both produced using offset printing. These LCAs have been carried out by LEITAT, using primary data from the European Greening Books LIFE+ project. Inventory data and the impact assessment have been revised and updated in the frame of this work. The environmental analysis provides additional information about key parameters, such as energy consumption, waste, inks and emissions.

4.2 EU Ecolabel criteria analysis

The Commission Decision 2012/481/EU, for printed paper products awarding criteria, has been analysed. The EU Ecolabel includes ten criteria covering diverse areas of concern:

- Substrate: Raw materials
- Excluded or limited substances and mixtures: Raw materials and production
- Recyclability: End-of-life
- Emissions: Production
- Waste: Production
- Energy: Production
- Training: Production
- Fitness for use: Use
- Information on the product: End-of-life
- Information appearing on the EU Ecolabel: Others

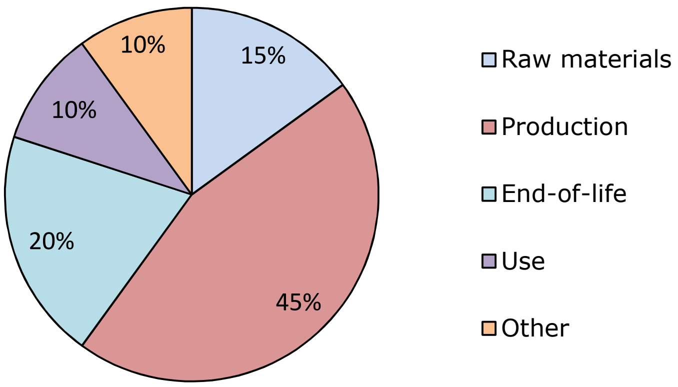


Figure 65. Distribution per life cycle stage of the criteria for printed paper products

Figure 65 portrays the assignment of the EU Ecolabel criteria across the product life cycle stages. The production stage includes printing, coating, and finishing and represents the life cycle stage with the higher number of related criteria (45%). This specific EU Ecolabel includes different criteria related to the emissions and waste generated during the manufacturing. However, other EU ecolabel products do not include the latter two aspects. Only some of them consider emissions and waste during manufacturing as in most of the cases only energy consumption is considered. Table 16 summarises the EU Ecolabel product groups and the criteria referring to manufacturing.

Table 16. Summary of the EU Ecolabel product groups that include criteria about the production process

Product Group	Emissions	Waste	Energy or water consumption
Rinse-off Cosmetic Products			
Absorbent Hygiene Products		✓	
Cleaning Products			
Textiles	✓	✓	✓
Footwear	✓		✓
Paints and Varnishes			
Imaging Equipment			
Personal, Notebook and Tablet Computers			
Television			
Wood-, cork- and bamboo-based floor coverings			✓
Hard Coverings	✓	✓	✓
Furniture			
Bed Mattresses			
Growing Media, Soil Improvers and Mulch			✓
Heat Pumps			
Water-Based Heaters			
Lubricants			
Sanitary Tapware			
Flushing Toilets and Urinals			
Paper Products	✓	✓	✓

Concluding, only 20% of EU Ecolabel products groups include criteria about air and/or water emissions and waste generation during manufacturing. On the other hand, 30% of the product groups refer to energy or water consumption.

4.3 Relevant LCA information from the previous revision

During the previous printed paper products revision in 2011, an LCA project related to printed products was developed by Denmark's Graphic Association with the aim to analyse the Nordic Swan label criteria while adopts a life cycle a perspective.

The LCA, as developed in this study, covers all stages of the life cycle, but transport activities. Regarding the disposal stage, it was assumed that 53% of the paper is recycled and the rest incinerated with heat recovery.

Considering these assumptions, the main results of the study are as follows:

- Paper is the crucial environmental impact contributor (Figure 66).
- When chemicals were included the environmental profiles of printed products differ. In that case printing processes could reach a contribution of 41%, while paper contributes at 31% (Table 17).

The impact categories included in the assessment are global warming potential, ozone depletion, photochemical ozone formation, acidification potential, nutrient enrichment, human toxicity, eco-toxicity, persistent toxicity, bulk waste, slags and ashes, hazardous waste, and radioactive waste. In most of the categories, the main contributor is the paper production, except eco-toxicity where printing is identified as the main contributor. However, environmental benefits due to recycling and incineration of paper waste can be obtained, achieving a reduction of the paper's overall impacts.

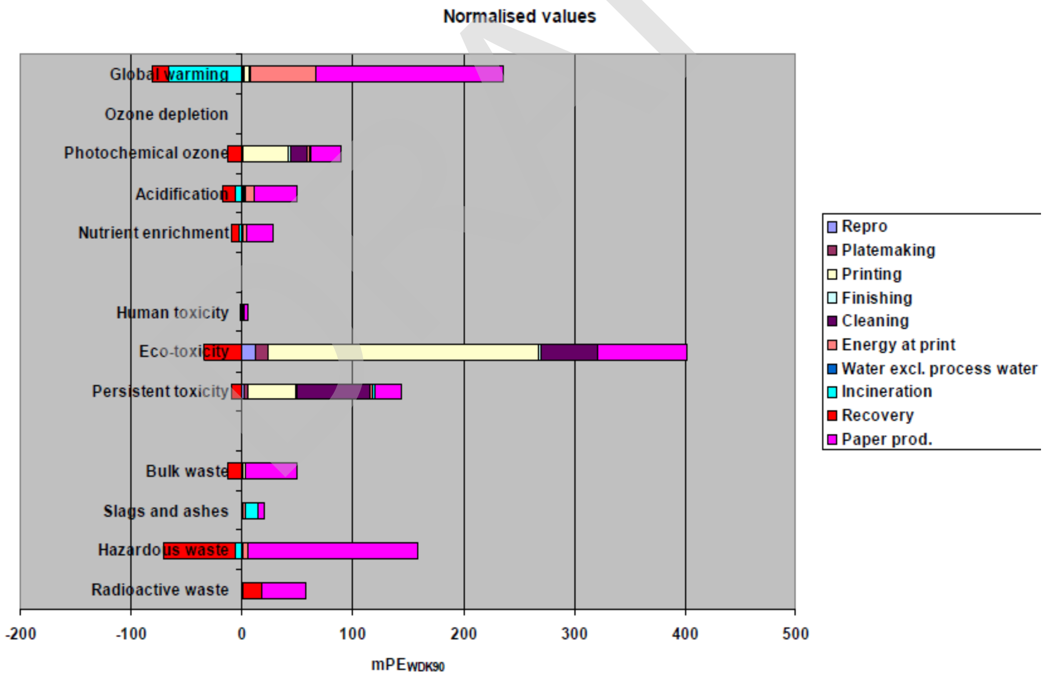


Figure 66. Normalized LCA profile for the reference scenario
Source: Ecolabelling of printed matter[44]

[44] Jonhsen, N., Bog, C., Poll, C., Larsen, H. F., (2006). Ecolabelling of printed matter. Technical University of Denmark.

Table 17. Summary of the results for the reference scenario; Normalized results are in mPE, also data in percentage are included. Results below 1mPE are excluded from the table

		Repro	Plate making	Printing process	Finishing	Cleaning	Energy consumption	Incineration	Recovery of paper	Paper production
Global warming potential	Normalized value	1,5	0,83	3,9	0,62	0,41	60	-66	-15	170
	Percentage	0,6%	0,3%	1,6%	0,3%	0,2%	25,3%	-27,8%	**-6,3%**	71,7%
Photochemical ozone formation	Normalized value	-	-	42	-	15	2,6	-	-12	28
	Percentage	-	-	47,9%	-	17,1%	3,0%	-	**-13,7%**	32,0%
Acidification	Normalized value	-	-	1	-	-	8,7	-6	-11	38
	Percentage	-	-	2,1%	-	-	18,2%	-12,6%	**-23,1%**	79,7%
Nutrient enrichment	Normalized value	-	-	-	-	-	3,5	-2,4	-7,9	24
	Percentage	-	-	-	-	-	12,7%	-8,7%	**-28,7%**	87,3%
Human toxicity	Normalized value	-	-	-	-	-	1,1	-	**-**	3,5
	Percentage	-	-	-	-	-	23,9%	-	**-**	76,1%
Eco-toxicity	Normalized value	12	12	240	1,4	51	0,033	-	-35	80
	Percentage	3,0%	3,0%	60,5%	0,4%	12,9%	0,0%	-	**-8,8%**	20,2%
Persistent toxicity	Normalized value	2	4	43	0,6	66	2	2,6	-10	24
	Percentage	1,4%	2,8%	29,8%	0,4%	45,8%	1,4%	1,8%	**-6,9%**	16,6%
Bulk waste	Normalized value	-	1,3	1,2	-	-	-	-0,12	-12	46
	Percentage	-	2,7%	2,5%	-	-	-	-0,2%	**-24,7%**	94,8%
Slag and ashes	Normalized value	-	-	-	-	-	2,5	11	**-**	5,8
	Percentage	-	-	-	-	-	13,0%	57,0%	**-**	30,1%
Hazardous waste	Normalized value	-	-	-	-	-	-	-6	-64	154
	Percentage	-	-	-	-	-	-	-3,9%	**-41,6%**	100,0%
Radioactive waste	Normalized value	-	-	-	-	-	-	-0,45	17	39
	Percentage	-	-	-	-	-	-	-0,8%	**30,4%**	69,6%

In Figure 67, the net impacts (savings due to incineration and recycling excluded) are compared to those excluding paper (paper production, recycling of paper and incineration are excluded). The results show paper does not reflect the higher environmental impact in photochemical ozone formation, eco-toxicity and persistent toxicity. Furthermore, regarding global warming potential, 43% of the total normalised result is not associated with paper.

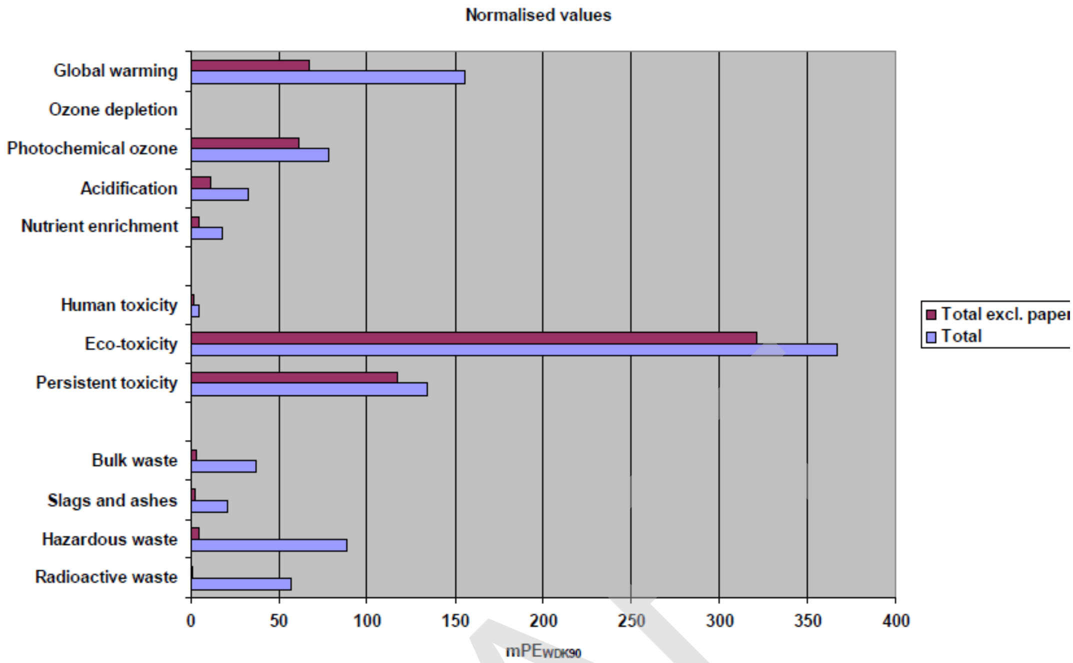


Figure 67. Normalized LCA profile of scenario comparing all life cycle stages, and excluding paper life cycle stages (production and end-of-life)
*Source: Ecolabelling of printed matter*Error! Bookmark not defined.

This study additionally includes a comparison between different scenarios. The following conclusions are drawn:

- When two printed paper products, one exclusively made of recycled paper and other made of virgin paper are compared, an environmental impact reduction of 16% in the aggregated impact is revealed.
- A reduction of more than 90% of ink consumption (assumed ink is made of 20% soya oil, 20% phenol resin and 29% paraffin) causes 56% reduction of the aggregated impact. The most affected impact category is eco-toxicity, and printing is the respective hotspot.

This study was the basis to develop the existing criteria for the EU Ecolabel in 2011. Regarding the current revision process, new LCA journal articles have been investigated to update the environmental information for printed paper and related technologies. Main findings are detailed in the following sections and classified by products type.

4.4 Environmental Product Declaration

The International EPD® System is a voluntary environmental declaration system applicable to any type of goods and/or services. Currently, there are Product Category Rules (PCRs) for books (*Books, in print)*.

The product group encompasses the following specific products:

- Educational textbooks, in print

- General reference books, in print
- Directories, in print
- Other books, in print

The PCR documents specify the assumptions for the underlying life cycle assessments (LCA) and set minimum requirements for each specific product group. The environmental information requested for *Books, in print* PCRs is described in Table 18.

Table 18. Summary of environmental requirements included in EPD program

Information	Requirements

Use of resources: inventory data	• Non-renewable resources
	  ◦ Material resources
	  ◦ Energy resources (used for energy conversion purposes)
	• Renewable resources
	  ◦ Material resources
	  ◦ Energy resources (used for energy conversion purposes)
	• Water use divided in:
	  ◦ Total amount of water
	  ◦ Direct amount of water used by the core module
	• Electricity (electricity consumption during manufacturing)

Potential environmental impact: impact categories	• Greenhouse gases (expressed as the sum of global warming potential, 100 years), in carbon dioxide (CO_2) equivalents. • Acidifying gases (expressed as the sum of acidification potential) in sulphur dioxide (SO_2) equivalents. • Emissions of gases that contribute to the creation of ground level ozone (expressed as C_2H_4 (ethylene) equivalents). • Emission of substances to water contributing to oxygen depletion (expressed as the sum of eutrophication potential), in phosphate (PO43-) equivalents. • Emission of the exhausting ozone gases expressed as the sum of the ozone-depleting potential in kg CFC–11 equivalents, 20 years.
Waste production	• Hazardous waste, in kg (as defined by regional directives) • Radioactive waste, in kg • Non-hazardous waste, in kg
Other environmental indicators	• Recycled material content (in % material content per declared unit) • Co-products used in other chains

4.5 Printed paper products LCA screening

Thirteen LCA papers are identified as potentially relevant to the revision process. In a next step, 10 out of 13 were analysed in detail. The rest is not qualified for inclusion according to the JRC's screening requirements. Additionally, a summary of the main findings of the screening is presented in this section. Most of the papers refer to printed paper products, such as books, magazines or newspapers while others compare printed to digital formats. In those cases, the information about the printed product is analysed further.

A summary of the main outcomes is also included in this section. The available literature is examined considering scope relevance, environmental indicators and outcomes of the impact assessment. Moreover, regarding aspects less covered by LCA studies, complementary information is obtained to compile the complete environmental profile of the product category. It should be noticed that environmental impacts can be associated with all life stages from raw materials to end-of-life stage, therefore, this study adopts a holistic perspective including all life cycle stages.

The products covered by the analysed LCA journal papers are:

- Magazines (3 studies)
- Newspapers (4 studies)
- Books (3 studies, including 1 scholarly book and 1 photobook)
- Leaflets (1 study)

The specific results of the screening case by case are included in Annex while the most relevant results are summarised in the following Table 19.

Depending on the journal article, the carbon footprint for one tonne of product (from cradle to grave) varies between 845–2,300 kg CO_2 eq. Due to several differences in the scope; the results are not directly comparable.

Nevertheless, it can be stated, despite those differences, the case studies show significant similarities. For example the GWP shows the raw materials (paper) stage has the highest contribution mainly associated with energy consumption. Manufacturing processes are second with impacts shares between 20%–37.5%. These are linked to energy, chemicals and generated waste. Packaging is not always included in the scope, however, it can have important impacts, especially regarding books and magazines. Transport impacts, if considered, range between 8%–12% mainly linked to distribution of the final product. Concluding, the end-of-life stage has notable impacts, especially for those scenarios where landfill is considered since incineration and recycling indicate savings. Figure 68 displays the impact contribution of the life cycle stages across different products.

Compared to the carbon footprint of newspapers and magazines, the carbon footprint of books is clearly higher. This can be partly explained by the fact that book is a more complex product and includes more materials and additional production steps.

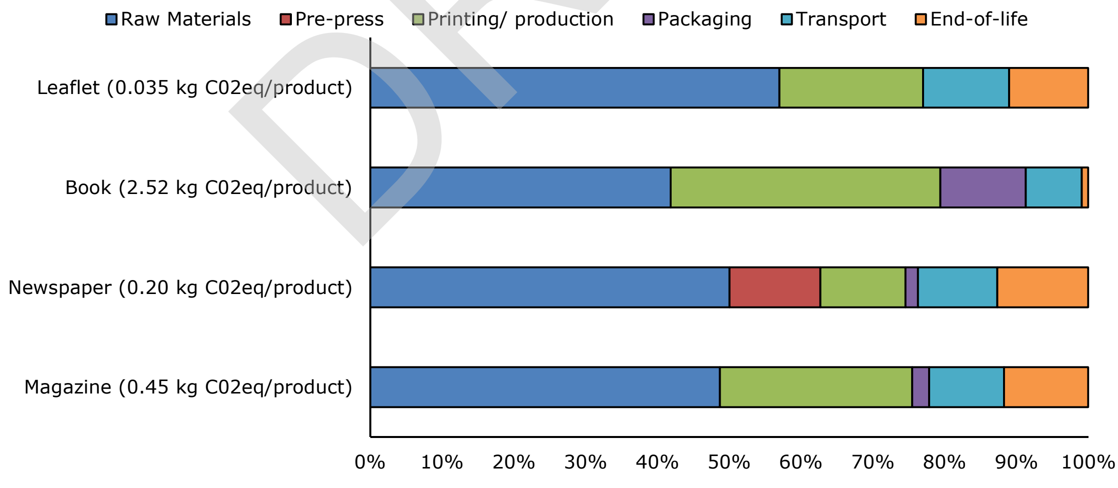


Figure 68. Average distribution of GWP of printed paper products

4.6 Summary of LCA studies results

The following table summarises main findings of the LCA studies analysis. The carbon footprint has been selected as representative impact since comprised in all LCA studies.

Table 19. Summary of main results of the analysed LCAs

Product	Technology	Reference	Carbon footprint		Life Cycle Stage							Sensitive analysis /improvement potential
			kg CO_2/ unit	kg CO_2/ tonne	Raw Materials	Pre-press	Printing	Production	Packaging	Transport	End-of-life	
Magazine (3 products)	Gravure printing	Boguski, 2010	0.82	2370	69.5%	-	25.6%		2.4%	3.7%	-1.2%	The % recycled fibers is not significant i for GHG. Increasing a 10% of recycled content only supposes the reduction of 1% of GWP impacts of magazines. High improvement potential in manufacturing and printing of the paper.
	Heatset web offset	Nors et al, 2009	0.21	1245	19.5%	-	56.5%		-	16.0%	8.0%	Improving energy efficiency and use of materials are the most efficient ways to reduce the carbon footprint
	Heatset offset	Pihkola et al, 2010	0.32	1128	34.0%	-	32.0%		-	13.0%	21.0%	The potential contribution of the magazine product system to environmental impacts is mostly connected to the energy and fuels used in different life cycle phases. The use of purchased energy plays the greatest role, both in pulp and paper production and in printing.
Newspaper (4 products)	Offset printing	Moberg et al, 2007	0.21	-	45.6%	19.3%	-		-	12.3%	7.0%	
	Coldset offset printed	Pihkola et al, 2010	0.21	1066	53.0%	-	13.0%		-	18.0%	16.0%	The introduction of green grid electricity decreases impacts in most impact categories
	Coldset web offset	Nors et al, 2009	0.17	845	18.0%	-	61.5%		-	9.0%	11.0%	Improving energy efficiency and use of materials are the most efficient ways to reduce the carbon footprint. Reduction of 20% of mil energy consumption leads to 8% of carbon footprint. Reduction of 20% of energy consumed during printing leads to 2% of reduction of carbon footprint. At the end-of-life, recycling and incineration represent savings of almost 50% of impacts in comparison to landfill scenario.
	not defined	Reichart et al, 2003	*Ecopoints*	*Ecopoints*	78.0%	10.0%	10.0%		2.0%	-	-	Impacts are reduced is there is the opportunity to buy parts of a newspaper. (e.g. printing on demand). Also the number of readers is a key aspect.
Book (3 products)	*not defined*	Kozak et al, 2003	5.45	-	59.1%	-	39.9%		-	0.5%	-	
	Sheetfed offset	Pihkola et al, 2010	1.16	2300	50.0%	-	46.0%		-	3.0%	1.0%	

Product	Technology	Reference	Carbon footprint		Life Cycle Stage							Sensitive analysis /improvement potential
			kg CO2/ unit	kg CO2/ tonne	Raw Materials	Pre-press	Printing	Production	Packaging	Transport	End-of-life	
	Digital Electrophotography	Pihkola et al, 2010	0.93	1879	28.0%	-	21.0%	16.0%	13.0%	22.0%	-	
Leaflet (1 product)	Gravure 4-colour printing	Pihkola et al, 2010	0.03	1630	57.0%	-	20.0%		-	12.0%	11.0%	
Catalogue (glued)	Digital (electrophotographic)	Nors et al, 2009	0.25	1255	48%	-	39.0%		-	13.0%	-	

Regarding the impacts of the printing technologies, direct comparisons are not reliable since printing techniques are used to produce different products and the modelling assumptions are not similar.

Advantages of digital printing include faster and flexible processing, lower consumption of chemicals and water and less waste. On the other hand, some issues remain, for instance, the recycling of digitally printed paper causes problems during De-inking since the existing flotation process has been developed for traditionally printed products. In inkjet, the small particle size of pigmented inks is problematic and dye-based inks can stain the pulp. De-inkability of digitally printed paper (large amounts) might require more energy and chemicals compared to traditional De-inking processes, thus the benefits from recycling decrease.

Some studies compare digital to sheet-fed offset technologies and suggest that digital indicates lower impacts up to 500 print runs. Nevertheless, when the print runs are increased above 500 the offset print performs better. That concludes the environmental impacts of both technologies vary significantly according to this parameter[73].

Figure 69 shows digital printing have slightly higher impacts than offset, but that depends on the print run while gravure printing is the technology with the highest GWP impacts.

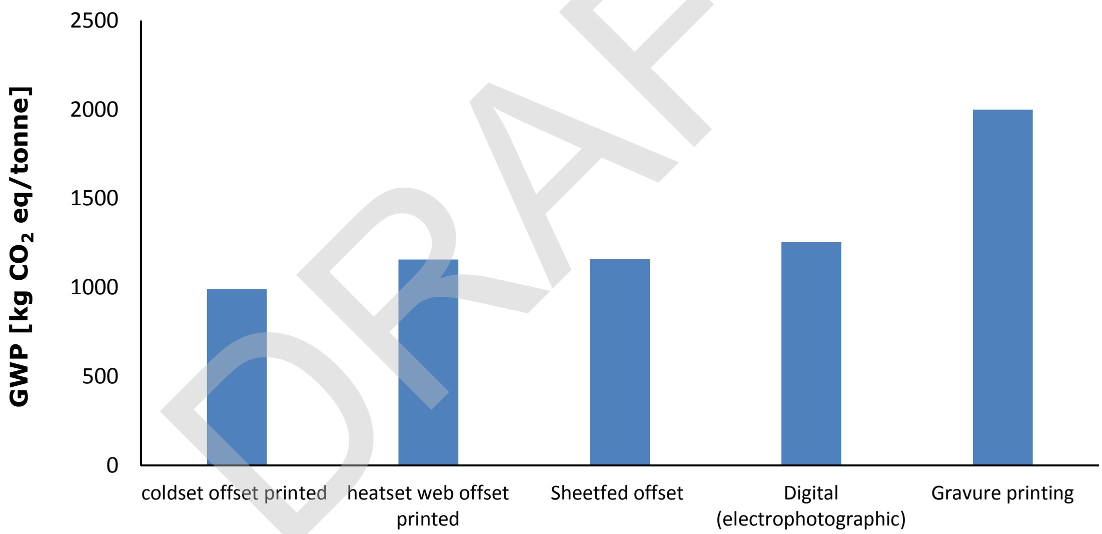


Figure 69. GWP per tonne of production across printing technologies

4.7 Conclusions from LCA Screening

Raw materials

Most of the screened articles conclude the paper production is the main hotspot. Raw materials (paper substrate) have on average an impact contribution between 28%–78%. This high share, in the majority of the impact categories, is sourced to the high paper content in the final product.

Impacts from paper are mostly caused by the energy consumption in the paper mills (representing up to 70% of raw materials impacts for some studies) while the remaining 30% are mainly caused by fibres supply and in minor extent by the consumption of other resources, such as water. Consequently, impacts of energy production depend on the energy mix. Sensitivity analysis is carried out suggesting 20% decrease in the electricity consumption in paper mills could lead to 8% GWP fall.

Since paper production is the main hotspot, the selection of the paper type and its manufacturing should be targeted for impact mitigations which can also be reflected in the environmental profile of the final product. To evaluate impact mitigations, some articles implement sensitive analyses considering diverse types of paper and production parameters. It is expected, the introduction of recycled fibre in paper production to lead to impact mitigations. Nevertheless, some LCA studies68 found the percentage of recycled fibres does not affect the GWP significantly. For example, in the case of magazines, 10% increase of recycled content leads to only 1% GWP mitigation.

<u>Printing process</u>

Next to raw materials production, printing has also important environmental contribution causing 25% of the total GWP. In most cases, electricity consumed during printing is a hotspot (6%–8%). Other relevant activities are the chemicals used in the process (10%). Introducing energy management measures in printing houses could reduce the environmental impact. However, a 20% reduction of electricity consumption leads to only 2% GWP mitigation.

Regarding inks, in some LCA studies they are included in the raw materials stage, yet others comprise them in the printing stage. A clear environmental advantage for vegetable inks in comparison with mineral-based inks cannot be stated in most of the cases.

Toxicity assessment indicates high relevance of printing at the categories human toxicity, terrestrial and freshwater eco-toxicity due to chemicals used in that stage while emissions of metals contribute additionally. The observed terrestrial eco-toxicity impacts are sourced to herbicide and insecticides originating in the production of printing colours. This, together with the high eutrophication impacts during ink manufacturing, stresses the need to investigate the overall impacts of mineral versus bio-based materials[73]. However, it should be noted that toxicity and eco-toxicity evaluation might include moderate to high calculation uncertainties.

<u>Waste</u>

The generated solid waste amount during manufacturing of one tonne of the product is approximately 340 kg. Most of it is either recyclable or combustible. Landfill waste usually includes ash from pulp and paper manufacturing and mixed wastes from the printing house. Additionally, a small amount of hazardous waste is produced. This equals 0.5% of the total waste production. Most relevant waste type is paper scrap (80% of the total) which ends up in paper recycling. The current study suggests 50% decrease in print house waste could lead to 4% reduction of GWP.

Printing is also related to VOCs generation and other emissions to air and water. Nevertheless, emissions to air and water are difficult to be included in the LCA impact assessment due to limitations in impact evaluation methods. Metal emissions cause human toxicity and freshwater eco-toxicity impacts. Emissions to water of the three metals cobalt, nickel and vanadium are responsible for over the half of the freshwater eco-toxicity load.

Additional impact mitigation measures can be decided during the product design phase. They can determine the amount of used paper and ink, as well as the use of other materials. One significant parameter is the paper grammage. The carbon footprint of one newspaper printed on 40gsm is 12% lower than those printed on 45gsm paper, due to the reduced amount of emissions from the paper production[72].

Packaging

Packaging is not always included in LCA studies. In some cases, like the LCA of a packed book, it was found that packaging materials, mainly corrugated board and LDPE film, contribute up to 13% of the total GWP. That is explained by the high amount of packaging materials used as every book is packed separately.

Transport processes

They show moderate impacts ranging between 8%–12% of the total GWP. In the case, printed products (newspaper, magazine, advertisement) are delivered to the consumer, and the total transport contribution rises significantly. The delivery is usually operated using small vehicles while only small amounts of products can be delivered at a time which explains the reduced transport efficiency.

Use stage

Differently to digital products, the use stage does not consume resources or energy, so it is not environmentally relevant. Nevertheless, the number of users per printed product is significant. If the functional unit is related to the number of readers, the more readers, the lower impact of the product will be. Also, lifespan is a key issue as the PAS 2050 standard allows for the impact of stored carbon to be credited to the product However, it is important to mitigate emissions rather than to rely on carbon storage benefits.

End-of-life waste management

The environmental impacts of that stage rise at 8% of the total. Most of it is sourced to landfill which is mostly linked to methane emissions. On the other hand, incineration produces electricity that can replace electricity from the grid. Recycled material can substitute primary pulp under certain qualifying conditions. Therefore, some LCA studies perform sensitivity analysis to examine the influence on different end-of-life management scenarios. For instance, newspaper recycling can provide savings (up to 60% of total saving) compared to landfill scenario while incineration goes beyond (75%).

Other impact categories

Many of the chosen LCA studies cover other impact categories besides climate change[73]. It was found the majority of the impacts, apart from climate change, in terrestrial acidification and particulate matter formation are caused by energy consumption and fuel use. Acidification is mainly caused by sulphur and nitrogen oxide emissions which also affect particulate formation. Freshwater eutrophication impacts are caused by phosphorus emissions from pulp and paper production and printing ink manufacturing. The photochemical oxidant formation is sourced to nitrogen oxide emissions produced during heat and power generation and road transport.

Methane and carbon monoxide contributes to photochemical oxidant formation. Ozone and other photo-oxidants cause breathing problems, damage leaves and reduced grain harvests. Considering fossil and mineral resource depletion, the pulp and paper production phase is the biggest contributor. Minerals resource depletion is exclusively caused by electricity consumption during pulp and paper production. Fossil resources depletion is mainly associated with energy consumption.

Apart from the gathered information as a result of the screening, additional scientific literature has been consulted to address aspects, such as chemicals or emissions which are not well covered in the LCA. Moreover, although LCA papers investigate the whole life cycle, specific data on finishing processes are not assessed in detail. Therefore, technical reports have been additionally considered to tackle these limitations.

4.8 Magazine life cycle assessment

This LCA study provides a life cycle assessment of a magazine. The study is carried out in the framework of the European Life project "Greening Books". Manufacturers and suppliers of the printed paper sector collaborated and provided inventory data. Moreover, data, modelling assumptions and life cycle impact assessment have been updated in light of the current EU Ecolabel revision process.

The goal of the LCA is to identify the potential environmental impacts of a standard magazine printed in Europe while identifying its hotspot stages and activities. It examines the whole life cycle, considering raw materials production, manufacturing, and use and end-of-life waste management. The manufacturing procedure also considers design, impression and editing of magazines. The offset printing technique is adopted in the scope, as it is the broadest applied magazine printing technique.

The functional unit has been defined aiming to present a standard magazine, with the most common properties covering adequately the diversity in the market. This study classifies magazines into two main categories: Consumer magazines (all magazines available on a newsstand) and business to business (B2B) magazines.

The useful life of a magazine varies depending on the topic of the publication. This LCA considers 3 months useful life. The functional unit is defined to reflect characteristics of the common traded magazines in the market as follows:

> “The functional unit is defined as a magazine including 28 pages and with a page size of 21 x 29.7 cm, printed in 4+4 inks and considering 2,000 copies print run.”

After defining the functional unit the next Table 20 outlines its main characteristics.

Table 20. Information related to the functional unit

Characteristics	Metrics	
Total paper surface	0.87	m^2
Printed surface*	0.87	m^2
Pages	28	pages
Page format	21 x 29.7	cm^2
Magazine weigh	100.42	g
Colour printing system	4+4 inks	
Life duration	3	months
Print run	2000	copies
Printing system	Offset	

*The printed surface is supposed to be equal the page surface, since non-printed margin usually does not exist.

In this study a single editorial process has been assumed. It also assigns the environmental loads to functional unit considering a single print run of 2000 copies. Consequently, inventory flows, such as design or plate gravure, have been allocated to functional unit accordingly. Moreover, infrastructure and equipment impacts are excluded. Regarding printing, the study considers the magazine is printed in 4+4 inks while using the sheet-fed offset technique. A straight forward distribution channel is assumed where the magazine is transported from printing house to the final sale point (newsstand). Additional distribution activities, such as return of magazines are not considered.

4.8.1 System definition and boundaries

The examined system can be divided into the following stages: Raw materials production, magazine production (pre-printing, printing and post-printing), distribution, and use and end-of-life waste management.

Raw materials production

In this stage, paper and inks are analysed as they stand for the main constituents of magazines. It includes the extraction of raw materials and the respective industrial processes while transport is excluded. Chemicals and additives consumed during printing are considered is the respective stage. Additional issues related to paper and inks have also been addressed in this study. Firstly, as paper makes up the core magazine part, the study compares impacts by adopting different scenarios using recycled and non-recycled paper. Secondly, two types of inks have been analysed: mineral oil and vegetable oil inks.

Production (Pre-printing, printing and post-printing)

Sheet fed offset printing has been chosen as the standard technique for magazine printing. The production stage can be divided into three main steps:

Pre-printing

- Creation and design: The production of a magazine starts with the creative procedure which includes activities, such as writing, correcting, design, and layout. At this stage multimedia devices are used; therefore, electricity consumption is highly relevant.
- Plate production: Plate production impacts are included in the study. The most widely used plates are made by electro-grained aluminium which is coated by a slim layer of term-sensitive varnish.
- Plate gravure: Plate graving is executed using computers. The image is graved into the plate via laser. Once graved the so called developer is applied onto the plate to remove the emulsion layer from the areas not affected by the laser.

Printing

- Printing: During the main impression process, the engraved plates are damped with a solution, which contains isopropyl alcohol and water, and later on with ink. Next to printing, the paper is dried using cold or hot air, to stabilise the ink.
- Cleaning: Cleaning is done when the impression process is finished or when colour change is necessary. During this activity, raps, solvents, cleaners and degreasing substances have been considered. Thereafter, cleaning is analysed together with the impression step in the impact assessment part.

Post-printing

- Finishing: This step follows the printing phase and includes the processes of folding and stapling.

Packaging

It is assumed that magazines are packed in cardboard boxes of 50 magazines each. Some magazines are individually packaged, usually with a plastic film to protect them and the extra-components that might contain. This kind of packaging is more common for magazines distributed by post. However, the current study contemplates only cardboard packaging.

Distribution

Two types of distribution channels are established: magazines which are sold in newsstands and magazines sold through subscription. In this study only distribution to newsstands has been assumed.

Use

The publication has a reading period of 3 months. Nevertheless, its life can be extended, depending on type of the particular magazine. Approximately 90% of all magazines are discarded of within a year of publication[45]. In this LCA, the average life of a magazine has been considered 3 months. During this phase, no environmental loads have been anticipated as reading does not required additional resources.

End of life

When the magazine is damaged, beyond use, or the content is outdated, the user chooses to throw it away. The LCA analyses end-of-life waste management scenarios to reflect impact of this stage. To elaborate these scenarios, Eurostat data have been used as a reference. According to the later, the recycling rate for paper in Europe was the 72% in 2015[46].

[45] Environmental Impacts of the Magazine Industry and Recommendations for Improvement. The PAPER Project, Independent Press Association. Conserve tree Co-op America May 2001.

[46] Confederation of European Paper Industries (http://www.cepi.org/topics/recycling)

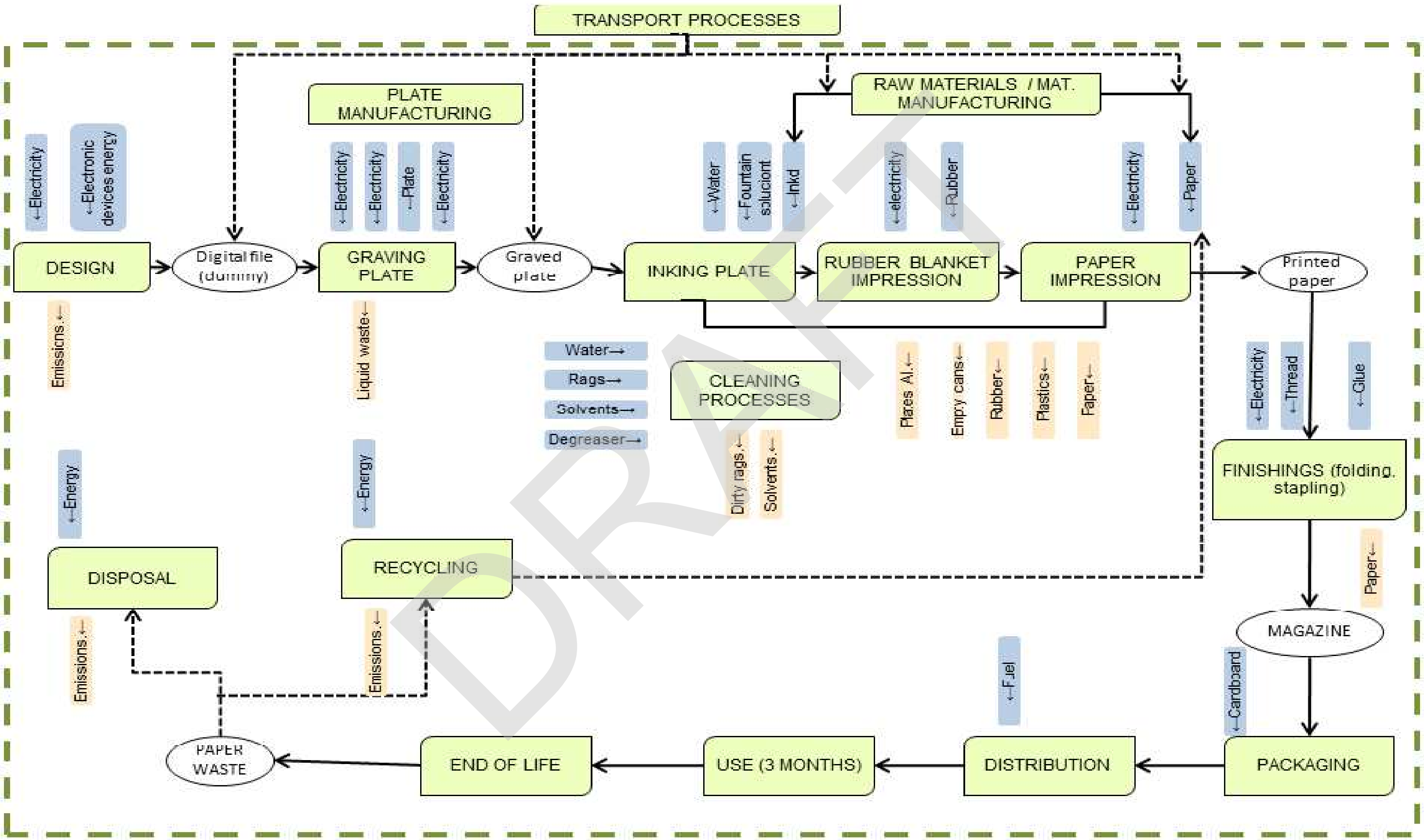


Figure 70. Flowchart of magazine system

4.8.2 Life Cycle Inventory

Life cycle inventory (LCI) involves the compilation and quantification of inputs and outputs for a product system throughout its life cycle (Table 21). To compile the inventory, different sources of information have been used. Regarding manufacturing processes, information from manufacturers and suppliers has been gathered. The so called primary data have been obtained from Spanish suppliers, such as paper suppliers, ink producing facilities. In the case primary data not available, the study considers inventory databases and literature. The Ecoinvent 3 database is the main source of secondary data. It should be noted that datasets which correspond to central European countries data are adopted to compile the inventory.

Table 21. Summary of inventory for a magazine

	INPUTS		OUTPUTS	
	Coated paper 115 gr.	135.1 g	-	
	Ink	2.62 g	-	
Creation and design	Electricity (European mix)	0.0445 kWh	-	
Plate graving				
Plate production	Aluminium	4.26 g	-	
	Iron	0.013 g	-	
	Mg	0.008 g	-	
	Mn	0.002 g	-	
	Electricity	0.005 kWh	-	
	Water	0.055 l	-	
Plate graving	Developer	4.3750E-05 l	Liquid waste	0.0004 l
	Replenisher	3.5000E-04 l	-	
	Plates Al	0.014 un.	-	
	Electricity	0.0062 kWh	-	
Printing	Engraved plate	0.014 un.	Aluminium plates	0.014 un.
	Fountain solution	0.0012 l	Paper (shrinkage)	2.65 g
	Rubber	0.017 g	Rubber	0.017 g
	Electricity	0.0021 kWh		
	Water	0.0013 l		
Cleaning	Solvent	0.001 g	Solvents	
	Degreasing	0.0005 g	Dirty rags	0.001 g
	Rags	0.001 g	-	
	Concentrated cleaner	0.001 g	-	
Finishes	Electricity	0,00017 kWh	-	
	Staples (Iron)	0.076 g	-	
Packaging	Board	11.7 g	-	
Distribution	Lorry transport	220 km	-	

4.8.2.1 Raw materials production

The first stage of the inventory is the production of raw materials of the magazine. Paper and inks has been considered as the main raw materials since they are the main components of a magazine. Throughout the magazine manufacturing several other raw materials are used, e.g. chemical substances or additives. However, chemicals and additives are considered to be part of the manufacturing process.

Paper

Normally, magazines are printed on paper made from virgin fibres. Less than 5% of magazine is made up from recycled paper which contains 10%–30% recycled fiber[45].

As described in the functional unit, the most commonly used paper is the coated version with a weight of 115 g/m^2. Woodfree coated paper is one or both sides coated with kaolin or calcium carbonate, and it is used for all kind of printing and graphic purposes. Its production encompasses production and preparation of chemical pulp, use of paper machine and on-site energy production. Fuel gas consumption, cleaning activities and wastewater treatment are also included.

The chosen page format (DIN-A4 21 x 29.7 cm), as described in the functional unit, is the standard format that allows for reduction of paper shrinkage. The paper is provided in 45 x 64 cm sheets, so that 4 magazine sheets can be printed per each paper sheet. The shrinkage occurs during the finishing stage, and causes on average losses of 2%. The study considers paper losses in the impact assessment evaluation. Following **Error! Reference source not found.** shows the amount of consumed paper.

Table 22. Quantity of paper used for a magazine

Quantity of Coated paper	Unit in g
Weight in final product	100.4
Weight of sheet used	132.5
Weight of total paper used, printing shrinkages included	135.1

Inks

Inks are the second material considered in the raw materials stage. The inks used in offset printing are fatty inks with a base of oil. The respective inventory data have been obtained from an ink supplier.

The ink consumption varies depending on the ink type and the printing area. It varies between 1–5 g/m^2, according to ink suppliers consulted. Coating, images and colours differ across magazine types and influence the final ink consumption. Table 23 shows the ink consumption for average printing areas.

Table 23. Ink used for magazine copy

Units	Ink g/ m^2 paper	m^2 printed paper	g ink consumed
Inside paper	3	0.87	2.62

Inks manufacturing

Manufacturing of fatty inks contains varnish or lacquer production, dispersion of pigments, three-cylinder mill grinding, additives and packaging. The composition of inks, as used in this study, is described in Table 24 while Table 25 shows a dataset for ink production**.** Offset inks have assumed to have the average composition.

Table 24. Average composition of inks

Compound	Percentage	Description
Pigments	14.0%	According to their chemical nature, pigments are divided into inorganic and organic pigments
Binders	28.5%	Resins are used as binders
Solvents	53.5%	They are used to dissolve the binders; they regulate the

		viscosity of the ink. Solvents include mineral oils, aliphatic and aromatic hydrocarbons, ketones, esters and alcohols.
Fillers	5.0%	They include optical brighteners, anti-drying, waxes, surfactants, foaming agents, etc.

Table 25. Ink production dataset

Components		Quantity (kg)
Solvents	Light fuel oil	0.475
	Palm/Soya oils	0.05
Pigments	Carbon black	0.07
	Polyethylene terephthalate, granulate, amorphous	0.07
Binders	Bitumen, at refinery	0.095
	Alkyd resin, long oil, 70% in white spirit	0.19
Filler	Limestone, milled, loose	0.05

4.8.2.2 Manufacturing

4.8.2.2.1 Pre-press

Manufacturing starts with the design phase. At this stage multimedia devices are operated, therefore, electricity consumption represents the core inventory part. The study also considers energy for lighting and air-conditioning.

Since a print run of 2,000 copies has been assumed, electricity consumption had to be divided into 2,000. It is calculated using data as obtained from statistics (IDAE) (Table 26). The study excludes pre-printing equipment manufacturing from the impact evaluation.

Table 26. Electricity consumption in the design stage

	Total consumption in creation stage	Consumption for each magazine copy
Electricity	89 kWh	0.0445 kWh

<u>Plate manufacturing and graving</u>

For sheet fed offset printing, firstly an aluminium printing plate is graved. Then, the plate is wet by a soaking solution and the ink is applied using rollers. Finally, the plate transfers the image to a rubber blanket cylinder (intermediate element), which prints the image on the paper. Throughout this production step graving of the plate is the most important activity. The standard plate has a size of 515 x 730 x 0.3 mm. Consequently, 4 magazine pages can be engraved on each plate (1 paper sheet).

The magazine is supposed to be printed in 4+4 ink offset printing. According to this printing technique, the plate must be engraved for each of the four basic colours: black, cyan (blue), magenta (red), and yellow. One plate is used for each colour, considering a 4x4 inks printing system. So for each set of 28 pages, printed following this technique, 28 plates are needed. Considering a print run of 2,000 copies, 0.014 plates are allocated to each copy. The plates have to be prepared in a two stage procedure which encompasses:

- Plate production, carried out in the plate manufacturing facility.
- Plate gravure, performed in a graving facility.

<u>Plate production</u>

Plate production is included in the study. The most widely used plates are made of electro-grained aluminium coated with a slim layer of term-sensitive varnish which normally contains silver halide. The process can be further subdivided into graining, anodising and emulsifying. As manufacturers provide no primary data, the dataset for aluminium manufacturing (EU average) has been obtained from Ecoinvent. Hence, the offset plate is assumed to consist in 68% virgin aluminium.

<u>Plate graving process</u>

The graving process is carried out by a computer, applying the computer to plate technique (CtP). According to it, the images are graved on the plate using laser. CtP facilities consist in different devices connected to a computer, such as a scanner, a console for temporary storage of pages, an interpreter, a positioning testing device, a preproduction device that includes a plate maker and a networker of all these electronic elements[47].

Once graved the plate is washed by the developer which removes the emulsion not affected by the laser. The replenisher allows for recirculating the developer and reducing the wastewater amount. The plate washing process has an average duration of 3 minutes, and consumes 0.44 kWh per plate. The process inputs and outputs are reflected on Table 27.

Table 27. Plate graving dataset

	Inputs			
	For each plate		**For each magazine copy**	
Electricity	0.44	kWh	0.0062	kWh
Plate	1	unit	0.014	unit
Developer	0.003	l	4.3750E-05	l
Replenisher	0.025	l	3.5000E-04	l
	Outputs			
Engraved plate	1	unit	0.014	unit
Liquid waste (regenerator, developers, and plate sensitive layer)	0.028	l	0.0004	l

<u>Developer:</u> It is considered that 20 litres of developer are necessary every 2 months, according to gathered primary data. As graving a plate lasts 3 minutes and assuming 8 working hours per day, 0.003325 l developer per plate are used (density: 0.164 kg/l). The developer composition and its specifications have been collected from commercial developer’s safety datasheets (Figure 38).

Table 28. Plate developer composition

	Composition (%)	**g /plate**
Total developer	100%	0.003325
Disodium metasilicate	10%	0.000333
Sodium octanoate	5%	0.000166
Sodium hydroxide	0,5%	0.000017

[47] BATsGRAPH report “BATs implementation in the European printing Industry”

Replenisher: The replenisher is a solution with a high alkaline content which regenerates the developer solution, prolonging its life. Considering 3 minutes process cycle and 8 working hours a day, 0.025 l/plate is used. The replenisher composition and specifications have been collected from commercial developer's safety datasheets and presented in Table 29.

Table 29. Plate replenisher liquid composition

Composition		g /plate
TOTAL		0.025
Disodium metasilicate	10%	0.0025
Sodium octanoate	5%	0.00125
Sodium hydroxide	2%	0.0005

Waste

The liquid waste generated during cleaning has to be treated as hazardous waste. An amount of 20 litres per week is anticipated, according to graving operators. Hence, an amount of 0.028 litres of liquid waste is generated per plate.

Emissions

The developer solution might contain alcohols that could emit volatile organic compounds.

4.8.2.2.2 Printing

During the core printing process, a dumping solution, containing isopropyl alcohol and water, is applied to the plate followed by ink. Due to wetting, the ink is attached to the lipophilic parts while kept away from the hydrophilic. The plate transfers the image to a rubber blanket cylinder (intermediate element) which prints the image on the paper. Once the paper is printed, it is being dried with cold or hot air to stabilise the ink. For the printing process, a standard press consisting in four parts has been considered. It has a production capacity of 6,000 sheets per hour. Considering 7 sheets per magazine, the printing time per copy is 4.2 sec (Table 30).

Table 30. Inputs of printing process per functional unit

		Amount		Observations
Inputs	Paper	135.12	g	Considered in material production stage
	Ink	2.62	g	Considered in material production stage
	Engraved plate	0.014	unit	Considered in graving plate stage
	Fountain solution	0,0012	l	Consumption: 100 litres every 600.000 printings
	Rubber	0.017	g	Consumption calculated from annual blankets printing house consumption (weight of blanket: 1kg/blanket)
	Electricity	0.0021	kWh	Consumption calculated from annual printing house consumption
	Water	0.0013	L	Consumption calculated from annual printing house consumption
Outputs	Aluminium	4.263	g	0.014 plates (Recycling)
	Paper	2.65	g	Shrinkage during printing (Recycling)
	Empty ink cans	-		(Disposal)
	Rubber	0.017	g	(Disposal)
	EMISSIONS			Some organic solvents contained in the

			fountain solution and inks are evaporated during the printing and drying processes.

Fountain solution: The fountain solution is used to wet the plates and allow for the ink to only cover the graved areas. A consumption of 100 litres each 600,000 sheet has been determined. Consequently, 0.0012 litres are consumed per copy (Table 31).

Table 31. Fountain solution composition

Composition	**Percentage**	**l /plate**
Total		*0.0012*
Damping solution (commercial)	4%	0.00005
2-butoxyetanol	1.20%	0.0000140
propano-1,2-diol	0.80%	0.0000093
Water	92%	0.001073
Isopropyl alcohol (IPA)	4%	0.000047

A screening has also been performed examining the impacts of the offset printing machine. Its life duration is assumed 20 years. The results note insignificant impact fluctuations (0.1%–0.7%) across the impact categories. As contribution is less than 1%, printing machinery has been not included in the analysis.

Cleaning

Cleaning is carried out when the print run is accomplished and a colour change is necessary. Machinery cleaning activities can be included in the printing process, but in the study, they are analysed separately to better assess their environmental load. Machine cleaning is an automated process integrated in the functionality of the machine. It is performed with rap rollers wet with a mixture of solvent and water. The raps are disposed of as waste once used whereas the consumption of washing agents has been decreased as a consequence of automatic washing systems. Additionally, raps and specific cleaners are used for manual cleaning of special parts of the machine or to eliminate ink excess on the plates. These particular rags are assumed to be cleaned and reused. Table 32 summarises the cleaning process dataset.

Table 32. Inventory of cleaning process

		Amount	**Observations**
Inputs	Solvent	0.001 g	1 kg per 1 000 000 copies
	Degreasing	0.0005 g	0.5 kg per 1 000 000 copies
	Rags	0.001 g	1 kg per 1 000 000 copies
	Concentrated cleaner	0.001 g	1 kg per 1 000 000 copies
	Water		
Outputs	Dirty rags	0.001 g	1 kg per 1 000 000 copies
	Solvents	-	Solvents are supposed to be treated with rags

4.8.2.2.3 Finishing

Once the magazine is printed, finishing is performed. The most usual finishing process is binding which includes cutting, folding and stapling. The material and electricity consumption during these activities are depicted in Table 33.

Table 33. Inputs for finishing stage

		Amount	Observations
Inputs	Electricity	0.00017 kWh	Data from finishing companies
	Staples (Iron)	0.076 g	Data from finishing companies

4.8.2.3 Packaging

Some magazines are packaged with plastic film to protect the product. It is done especially for subscripted magazines. Nevertheless, this type of packaging is not considered in the LCA study whereas only the distribution packaging (boxes) is included. It is assumed 50 magazines are packaged together in a corrugated board box.

4.8.2.4 Distribution

The publications are distributed, via marketing channels, to the retailer or directly to final consumer. A straightforward distribution system is assumed, where the magazine is transported from printing house to the final sale point (newsstand). Other distribution types, such as subscription, are not considered. Additionally, a certain amount of magazines might remain unsold and therefore returned to the manufacturer. Nevertheless, the current LCA does not reflect this effect due to the lack of data. Finally, an average distribution of 220 km has been assumed.

4.8.2.5 Use

It has been assumed that a magazine has a lifetime of 3 months. During this phase no environmental loads has been considered, as magazine read does not lead to additional environmental impacts.

4.8.2.6 End of life waste management

When the magazine is heavily damaged or the content is outdated, the user chooses to dispose it off. The LCA analyses end-of-life waste management scenarios, elaborating those impacts. Therefore, Eurostat data have been used as a reference. The European recycling rate for paper in Europe was the 69 % in 2010[48]. The remaining amount is landfilled.

4.8.3 Impact Assessment of magazine

In this section, the environmental impacts throughout the life cycle are being assessed using the ILCD impact assessment method. The most representative impact categories are displayed in Table 34.

The environmental analysis identifies hotspots and finds out the most influential parameters of modelling. Figure 71 shows the contribution of each life stage in the impacts categories. The results determine raw materials production has the highest environmental load across all impact categories. Plate manufacturing follows while the distribution activities are in the third place.

The percentage contributions show analogous trend across the impact categories. Raw materials production reaches the highest load at the land use impact category (93%) while the respective low is observed at water depletion (45%). The impacts are mainly caused by the high paper content in the final product.

[48] European Recovered Paper Council. Final monitoring report 2010.

Table 34. Selected Impact categories

Impact categories selected	**Units**
Climate change	kg CO_2 eq
Ozone depletion	kg CFC-11 eq
Human toxicity, non-cancer effects	CTUh
Photochemical ozone formation	kg NMVOC eq
Acidification	molc H+ eq
Freshwater eutrophication	kg P eq
Freshwater eco-toxicity	CTUe
Land use	kg C deficit
Water resource depletion	m^3 water eq
Mineral, fossil & ren resource depletion	kg Sb eq

Plate manufacturing and distribution also have relevant impacts in all impact categories. On the other hand, the processes of cleaning (including cleaning), finishing, and plate graving and magazine waste treatment have low contributions to impact whereas the use phase has, as expected, no loads. It should be noted that the low environmental impacts of the printing processes might be explained due to the specific primary data used. They are obtained from a manufacturer which applies good environmental practises and is EMAS certified. Moreover, pre-printing activities have higher contribution in comparison to printing and post-printing in this particular case.

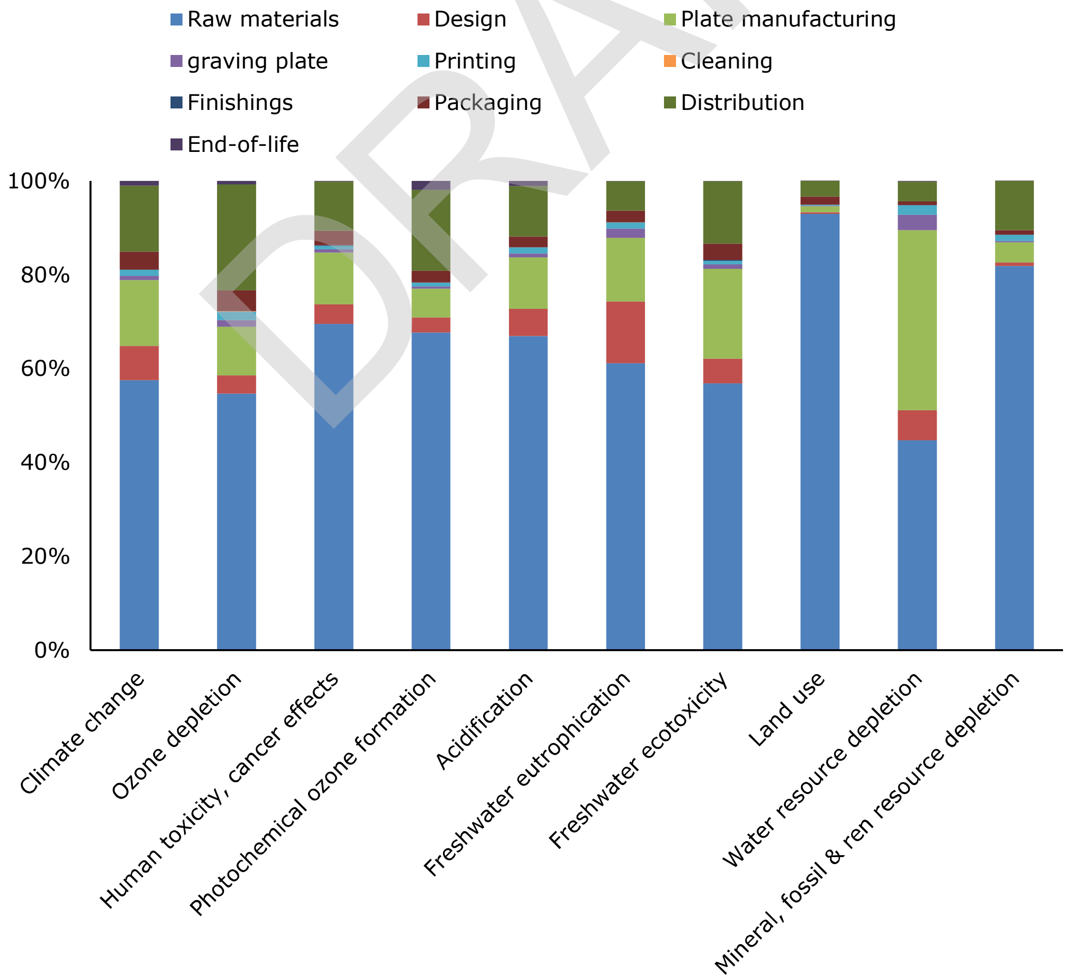


Figure 71. Distribution of environmental impacts among categories and life stages

Table 35. Environnemental Impact categories values

Impact category	Total	Raw materials	Design magazine	Plate manuf.	Graving plate magazine	Printing + cleaning	Finishes	Packagin g	Distribution	Waste treatment
Climate change (kg CO2 eq)	2,97E-01	1,71E-01	2,17E-02	4,17E-02	2,48E-03	3,97E-03	2,34E-04	1,12E-02	4,19E-02	2,94E-03
Ozone depletion (kg CFC-11 eq)	2,64E-08	1,44E-08	1,03E-09	2,73E-09	3,67E-10	4,99E-10	1,11E-11	1,16E-09	5,96E-09	1,88E-10
Human toxicity, cancer effects (CTUh)	1,31E-07	9,13E-08	5,40E-09	1,45E-08	9,60E-10	9,17E-10	2,32E-10	4,02E-09	1,38E-08	1,18E-10
Photochemical ozone formation (kg NMVOC eq)	1,40E-03	9,46E-04	4,49E-05	8,56E-05	5,97E-06	1,17E-05	7,64E-07	3,43E-05	2,42E-04	2,61E-05
Acidification (molc H+ eq)	1,95E-03	1,30E-03	1,13E-04	2,14E-04	1,54E-05	2,59E-05	1,20E-06	4,34E-05	2,10E-04	2,08E-05
Freshwater eutrophication (kg P eq)	1,40E-04	8,59E-05	1,84E-05	1,90E-05	2,78E-06	1,83E-06	1,23E-07	3,38E-06	8,82E-06	8,80E-08
Freshwater ecotoxicity (CTUe)	2,57E+00	1,46E+00	1,36E-01	4,92E-01	2,44E-02	2,01E-02	4,12E-03	8,96E-02	3,41E-01	1,85E-03
Land use (kg C deficit)	3,06E+00	2,85E+00	1,03E-02	4,10E-02	2,34E-03	6,41E-03	1,77E-04	5,25E-02	1,02E-01	4,44E-05
Water resource depletion (m3 water eq)	4,30E-01	1,92E-01	2,73E-02	1,65E-01	1,41E-02	8,61E-03	1,97E-04	3,28E-03	1,83E-02	4,63E-04
Mineral, fossil & ren resource depletion (kg Sb eq)	1,04E-05	8,52E-06	7,97E-08	4,45E-07	2,83E-08	1,44E-07	3,07E-09	9,79E-08	1,09E-06	7,79E-10

4.8.3.1 Environmental impacts of raw materials

Raw materials encompass the magazine's core constituent's paper and ink. As already shown, this stage indicates the most important loads in the life cycle. Most of the impacts are associated with the paper (98% of the total raw materials impacts). Inks have a much lower load due to the small amount used per magazine copy. Nevertheless, ink impacts should not be neglected considering the production volumes at European level.

This study performs a comparability analysis for recycled and virgin paper. Figure 72 shows that recycled paper is environmentally preferable regarding acidification, eutrophication, human toxicity and photochemical oxidation. On the opposite it indicates higher loads at abiotic depletion, global warming and ozone layer depletion. Those impacts are caused by the De-inking process and waste generated from manufacturing.

Although the impacts of paper recycling, in some cases, are higher than woodfree paper, in general the recycling advantages outweigh the impacts. For instance, some paper manufacturers already recycle fillers which were previously sent to landfill causing major environmental issues. It also should be noted that this study considers energy recovery from the incineration of produced by-product during the paper making process. These savings contribute towards lower environmental impact of woodfree paper at some impact categories.

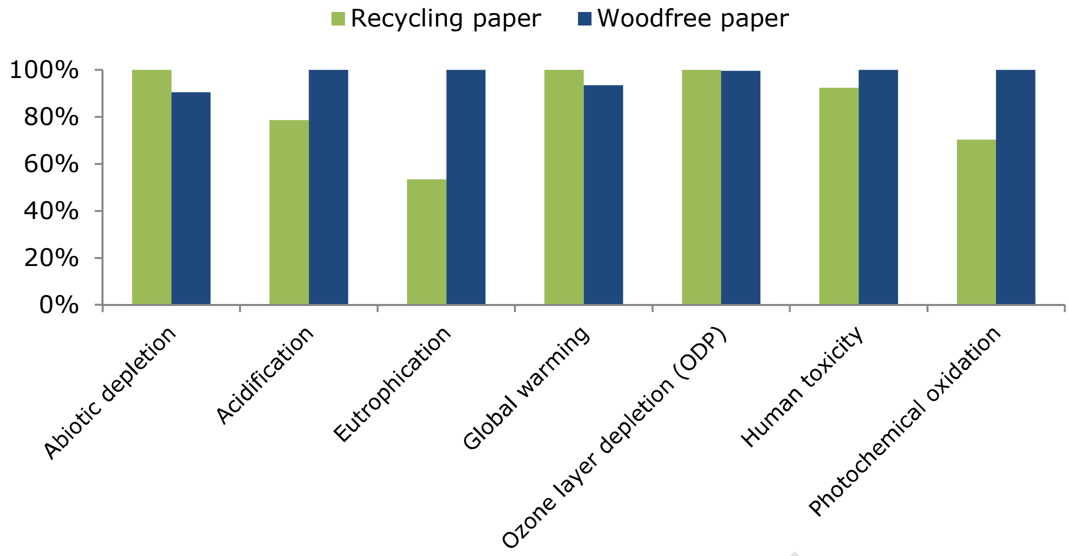


Figure 72. Comparison between recycled and non-recycled paper

4.8.3.2 Environmental impacts of manufacturing

Pre-printing

Plate production has on average 18% of the total magazine impacts. These are sourced to aluminium production as shown in Figure 73.

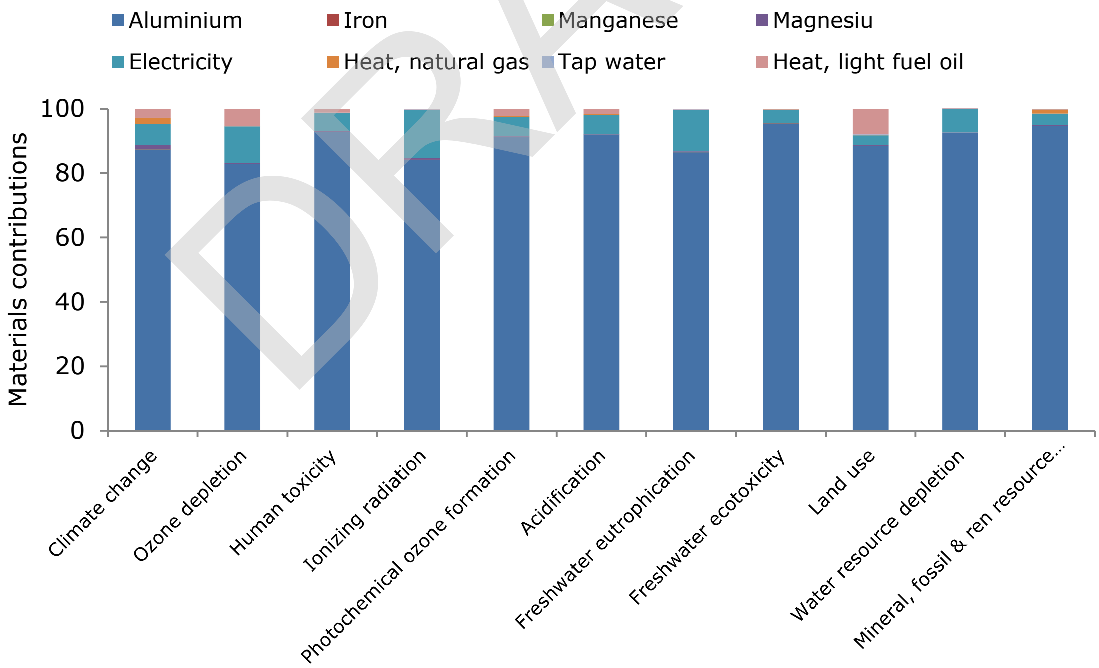


Figure 73. Environmental impacts from plate manufacturing stage

On the contrary, the graving step shows low impacts. That can partially explained due to improvements in the graving technology. For example, the CtP technique has reduced the use of chemicals considerably. Electricity consumption (55%–99%) is the major contributor at that activity (Figure 74). Liquid waste has notable contribution, especially at toxicity or climate change. Chemicals used as replenisher has also noteworhty impact whereas the developer indicates much lower loads.

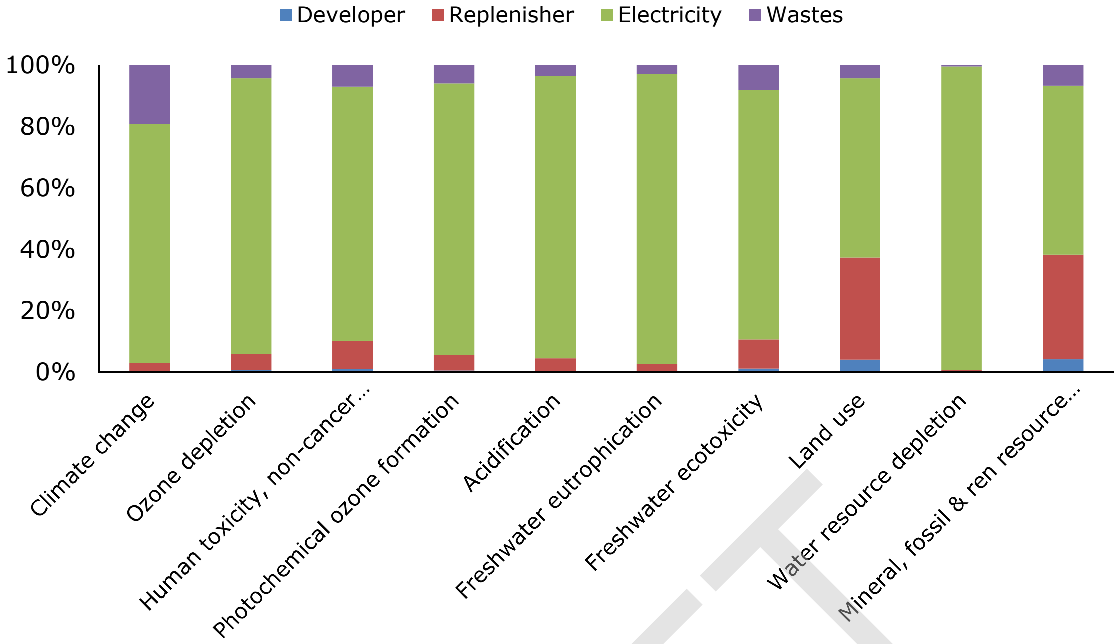


Figure 74. Environmental impacts of plate graving

Environmental impacts of printing process

Printing is an important step in a magazine production. However, in this particular study, it has lower environmental impact in comparison to other stages. Figure 75 displays waste during printing is the most relevant issue followed by electricity consumption. Finally, the use of printing-related auxiliaries is relevant at some impact categories. Particularly, the fountain solution affects ozone layer depletion.

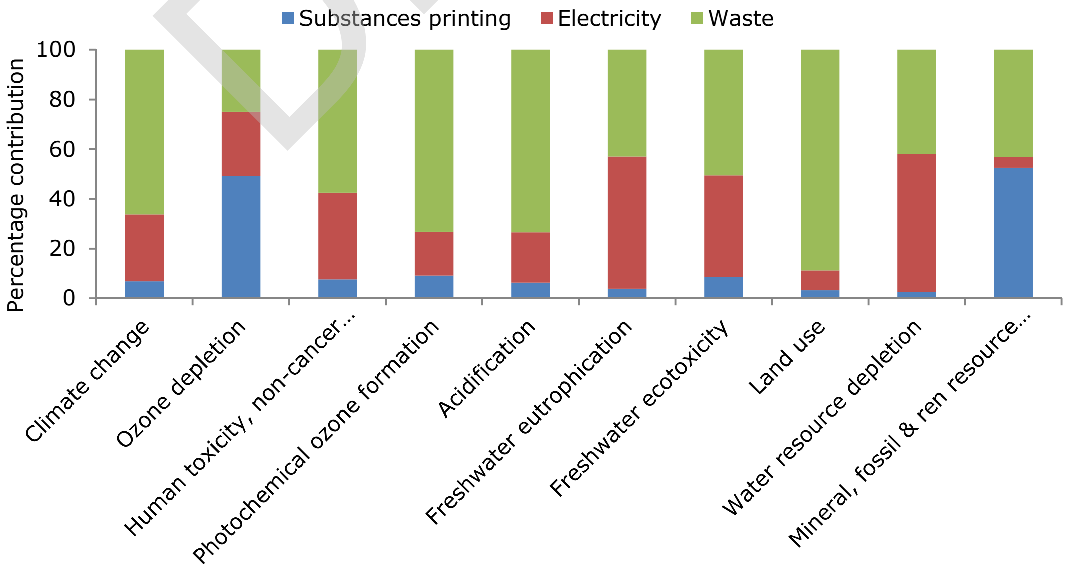


Figure 75. Environmental impacts from the printing stage

4.8.3.3 Environmental impacts of end-of-use stage

A comparative analysis has been carried out applying three different end-of-life waste management scenarios:

- Baseline: 18% of waste is incinerated and 72% recycled
- Recycling scenario: all paper is recycled
- Incineration scenario: all paper is incinerated

The incineration scenario reveals the highest impacts. If the magazine is not recycled, its environmental loads are higher (1%-13%) than the baseline while the recycling scenario performs 1%–6% better compared to baseline. That concludes recycling is the most environmentally friendly waste management option.

4.8.4 Conclusions and improvement suggestions

This LCA study evaluates the environmental performance of a magazine throughout its life cycle.

The results found raw materials as the main hotspot (45%–93%) while the paper production is the most relevant activity. Apart from virgin paper production, the study concludes that recycled paper has environmental advantages over non-recycled paper. It also recommends optimisation of the recycling process, especially the de-inking step.

Furthermore, it advocates vegetable inks present environmental advantages in some impact categories since made from renewable resources. Nevertheless, clear environmental benefits for vegetable inks cannot be stated from the impact assessment. The results suggest decisions in the design phase, such as magazine format and colours choice are very important to the final impacts since they determine the amount of paper, ink and auxiliaries in the production.

During manufacturing, plate production and graving are significant activities (2%–38%), with the former to perform much better than the latter. Therefore, the plate production procedure should be considered for impacts mitigation.

Printing is less important at that particular study. Its impacts are mainly sourced to electricity consumption. This fact highlights the importance of implementing good environmental practices. Cleaning and finishing activities have minor impacts.

The distribution stage contributes between 3%–23% of the total while the use phase does not generate any environmental loads. Finally, the end-of-life waste management impacts are caused by the non-recycled fraction.

Concluding, this study emphasises the importance of the design phase on the total life cycle impact.

Based on the results, improvement measures are recommended. To reduce the environmental impacts, it is important to firstly focus on the design step and secondly improve other activities. Hence, the study supports following:

- Use of recycled paper when possible.
- Reduction of the amount of inks while promoting environmentally friendly patterns.
- Reduction of the auxiliaries' quantity, such as the isopropyl alcohol or solvents, during printing and cleaning.
- Introduction of energy efficiency measures in the producing facilities.
- Choose of environmentally certified suppliers.
- Design demand-oriented print runs to avoid overcapacity and stocks.

- Design more efficient distribution networks.
- Raise environmental awareness among consumers to increase recycling rates and promote use of magazines beyond the considered life period.

4.9 Books life cycle assessment

The study provides a comprehensive life cycle assessment of a book providing with hotspot and activities evaluation. The LCA has been carried out in the frame of the European Life project 'Greening books' and is executed by LEITAT together with El Tinter and Simpple. Book manufacturers and suppliers of the printing sector have collaborated by provided primary data.

The goal of this LCA study is to identify the potential environmental impacts of a standard book printed in Europe throughout its life cycle. This study adopts a cradle to grave perspective considering raw materials production, book manufacturing, and use and end-of-life waste management. The offset printing method is assumed, as it is considered as the most common book printing technique.

The functional unit is defined aiming at representing a standard book, as sold in Europe. The main function of a book is to contain and preserve information for a specific period of time. Apart from its function, the functional unit also depends on the book format and is defined as follows:

> "The function is to contain a concrete amount of written information that can be read for a period of 30 years. A book of 96 pages is assumed with paperback cover and with a page size of 15 x 21 cm, printed in 1 ink for 2/3 parts and in 4+4 inks in 1/3 parts. A print run delivers 1 000 copies"

Further specifications of the functional unit are represented in Table 36.

Table 36. Characteristics of the book studied

Characteristics	Units
Total paper surface	3.15 m^2
Printed surface*	1.91 m^2
Pages	96 pages
Page format	15 x 21 cm^2
Book weigh	152.36 g
Colour printing system	4 + 4 inks (1/3) and 1 ink (2/3)
Life duration	30 years
Print run	1 000 copies
Printing system	Offset

*The printed surface is calculated based on the central part of each page, withdrawing the margins, the printing surface is of 11.6 x 16.6 cm^2 per page.

Regarding editing, a single editorial process has been considered. To assign its environmental loads to functional unit, a single print run of 1 000 copies is assumed. Consequently, one time processes, such as design or plate graving, have been divided into 1,000. Infrastructure and manufacturing machinery is excluded form scope. The impact of recycling process is assigned 100% to the producer of the recycled material. It has been considered that two third of the pages are print using a single ink (text printing) and one third with 4+4 ink (for covers and images). It should be noted that primary data have been obtained from a manufacturer which applies good environmental practises and is EMAS certified.

A straight forward distribution channel is assumed, where the book is transported from editorial to the final sale point. Other distribution types, such as institutional distribution or book returns are excluded.

4.9.1 System definition and boundaries

The system studied can be divided into the following life cycle stages

Raw materials production: Paper and inks production have been considered in this stage since there are the main constituents.

- Paper: Paper is the main component of a book. To assess its relative impact contribution and compare environmental impact of different paper types, a sensitivity analysis is carried out using recycled and non-recycled paper.
- Inks: Together with paper, ink is the other main material considered in this stage. Inks are used in the offset printing technique are fatty inks with a base of oil. Hence, two types of inks have been analysed, mineral oils inks and vegetable oils inks.

Manufacturing: Sheet fed offset printing has been selected in modelling as it represents a standard book printing method. The manufacturing stage can be subdivided into three main steps:

The pre-printing step includes:

- Creation and design: This phase includes writing (300 hours), correcting (20 hours), design (16 hours) and layout (40 hours). At this stage multimedia devices are used which consume electricity to operate. The study considers the latter together with the electricity used for lighting and heating.
- Plate production: Commonly used plates are made of electro-grained aluminium coated by a slim layer of term-sensitive varnish.
- Plate graving: The process is performed using. Once graved the plate is washed by the developer, which removes the emulsion layer from the plate in the areas not affected by the laser.

The printing process consists of:

- Printing: During printing, the engraved plates are first wet in a dumping solution which contains isopropyl alcohol and water, and then ink is applied. The ink is retained in the lipophilic parts of the plate and kept away from the hydrophilic. The plate transfers the image to a rubber blanket cylinder (intermediate element), which prints the image on paper. Once the paper is printed, it is dried with cold or hot air, to stabilise the ink.
- Cleaning: Machine cleaning is done when the printing is finished or when a colour change is necessary. In this stage the raps, solvents and cleaner and degreasing substances have been included.

Post-printing (finishing): Once printing is accomplished, the finishing step starts. This includes folding, sewing, gumming and covering.

Packaging

It is assumed that the product is packaged in cardboard boxes which contain 50 books.

Distribution

Two kind of distribution systems can be differenced: Institutional distribution (from the editorial to institutions), and commercial distribution (from the editorial to the distributors, who prepare packs with different books and send these packs to the different bookstores).

Use

It has been assumed that a book has a life time of 30 years. During this phase no environmental loads are anticipated since reading does not require any additional activities.

End-of-life waste management

At that end stage, book waste management options and their respective impacts are evaluated. Other scenarios, such as donation or re-sale are not considered. As waste product, waste paper has been considered. To analyse the end-of-life impacts, Eurostat data are implemented which consider a paper recycling rate of 72% in 2015[49].

[49] Confederation of European Paper Industries (http://www.cepi.org/topics/recycling)

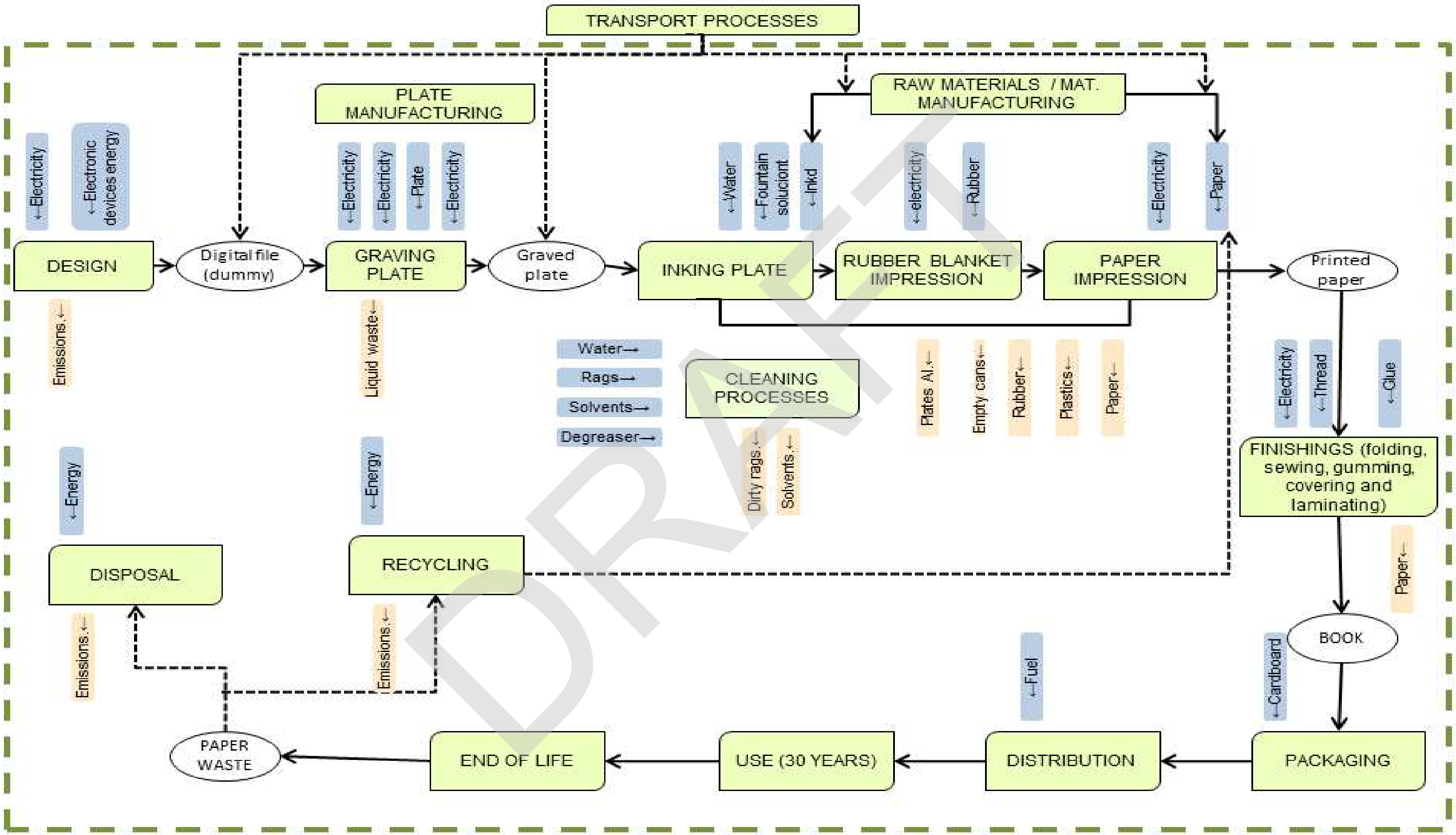


Figure 76. Flowchart of book system

4.9.2 Life Cycle Inventory

Life cycle inventory (LCI) involves the compilation and quantification of inputs and outputs for a product system throughout its life cycle. To compile the inventory, diverse sources of information have been used. Information from manufacturers and suppliers has been gathered to model the manufacturing processes (Table 37). Primary data have been obtained from Spanish suppliers, such as paper suppliers and ink manufacturers. In the case primary data not available, the study considers inventory databases and literature. The Ecoinvent 3 database is the main source of secondary data. It should be noted that datasets which correspond to central European countries data are adopted to compile the inventory.

Table 37. Summary of inventory for a book

Production stages	Inputs		Outputs	
Raw materials	Offset paper 90 gr.	158.63 g	-	
	Coated paper 250 gr.	24.48 g	-	
	Ink	3.96 g	-	
Creation and design	Electricity	0.094 kWh	-	
Plate graving				
Plate production	Aluminium	8.53 g	-	
	Iron (Fe)	0.03 g	-	
	Magnesium (Mg)	0.02 g	-	
	Manganese (Mn)	0.005 g	-	
	Electricity	0.01 kWh	-	
	Fuel oil	0.02 MJ	-	
	Water	0.11 l	-	
Plate graving	Developer	8.75E-05 l	Liquid waste	0.00079 l
	Replenisher	7.00E-04 l	-	
	Plates Al + Ag	0.028 un	-	
	Electricity	0,012kWh	-	
Printing	Engraved plate	0.028 un.	Aluminium plates	0.028 un.
	Fountain solution	0.002 l	Paper (shrinkage)	3.59 g
	Rubber	0.024 g	Rubber	0.024 g
	Electricity	0.0029 kWh	COVs	
	Water	0.0017 l	-	
Cleaning	Solvent	0.001 g	Solvents	
	Degreasing	0.0005 g	Dirty rags	0.001 g
	Rags	0.001 g	-	
	Concentrated cleaner	0.001 g	-	
Finishes	Electricity	0.0002 kWh		
	Vegetal thread	0.05 g		
	Glue	1 g		
	Polypropylene	0.63 g		
Packaging	Board	15.9 g		
Distribution	Lorry transport	220 km		

4.9.2.1 *Raw Materials production*

Paper is the main constituent of a book. Hence, two paper types have been reflected as the most commonly used:

- Inside paper: Non-coated paper with a weight of 90 g/m^2.
- Cover paper: Coated paper with a weight of 250 g/m^2.

The page format (15 x 21 cm) represents the standard size that allows effective reduction of paper shrinkage, therefore, used in Books. The paper is provided in 45 x 64 cm sheets. Consequently 6 sheets (45x64 cm) are used for the inside part (as the book is doubled-page printed). For the cover, 0.33 sheet is used per copy, as in a sheet 3 covers are printed.

During printing, on average, 2% of the paper is lost due to shrinkage. Losses been added to the final amount of used paper. Impacts due losses are included in the printing phase. In the following Table 38 the amount of paper is described.

Table 38. Amount of paper used for a book

	Weight in final product (g)	**Weight of total paper used (g)**
Non coated (inside)	136.08	158.63
Coated (cover)	16.28	24.48
Total paper	152.36	183.11

Further assumptions concerning paper are as follows:

- It has been considered that book is made exclusively by recycled paper
- Inside part: Recycled paper from De-inking process
- Cover: Coated paper originated from De-inking processes

Fibres can be recycled several times depending on the paper grade, but not indefinitely[50]. Therefore, there is a continuous need to feed the inflow of recovered fibre with paper products made of virgin pulp for three main reasons: strength and cellulose fibre deterioration, quality, and availability of waste paper (since around 19% of the paper cannot be recycled). Depending on strength and length of the wood, paper is can be recycled between five and seven times before discarded. Due to this fact, it is assumed that 1/6 is made from virgin fibres whereas the rest 5/6 from recycled.

For defining the different types of paper, average processes from European Database (Ecoinvent) have been used. In order to have more reliable and specific data, some parameters have updated with data obtained from paper suppliers: Arjowiggins, Fedrigoni Group, TorrasPapel and StoraEnso.

- Fine non-coated paper (woodfree): For the non-recycled paper the grade "Woodfree uncoated paper" has been selected, which is the most important category, apart from newsprints. Woodfree means that at least 90% of the fibres are sourced to chemical pulp.
- Coated woodfree paper: This type is one or even both sides coated with kaolin or calcium carbonate, and it is used for all kind of printing and graphic purposes.
- Recycled with De-inking - paper: This sort stands for paper where no wood fibres are used. It is produced following the next production steps: De-inking and pulping of paper, paper machine, on-site energy production and gas cleaning and wastewater treatment.

[50] http://www.paperforrecycling.eu/questions-answers/

- Recycling with De-inking - coated paper: Some papers manufacturers produce recycled coated paper from 100% recycled fibres. Coating minerals such as kaolin or calcium carbonate has been added to the process.

In general it can be concluded that energy and water consumption are lower for recycled paper than woodfree. Coated and non-coated papers mainly differ in the amount of fillers used. For recycled papers, more chemicals are used, during bleaching, and effluents generated than for woodfree paper.

Inks

The inventory regarding inks is similar to those of magazines. The inventory description is summarised in the respective section for magazines.

4.9.2.2 Manufacturing

4.9.2.2.1 Pre-printing

The initial phase of manufacturing is the creation and design of the book. This phase can be divided into writing, correcting, design and layout. Energy consumption of multimedia devices and those for lighting and heating are included in the inventory.

Since a print run of 1 000 copies have been assumed, the consumptions of electricity have been divided into 1 000. The electricity consumption has been calculated based on average energy consumption as obtained from statistics in offices (IDAE) (Table 39).

Table 39. Inputs for the design stage

	Energy consumption in creation stage (kWh)	Energy consumption per unit (kWh)
Electricity	94	0.094

Plate manufacturing and graving

Sheet fed offset printing has been chosen as the standard method for book printing. The standard aluminium plate, used in sheet fed offset printing, has a size of 515 x 730 x 0.3 mm. Thus, 8 book pages are engraved on each plate.

One third of the book (32 pages) is supposed to be printed in 4+4 ink offset printing. Hence, the plate must be engraved for each of the four basic colours: black, cyan (blue), magenta (red), and yellow. So for each 32 pages printed in 4x4 inks printing system, 16 plates are needed. The other two thirds of the book (64 pages) are supposed to be printed with one ink. Consequently, 8 plates are needed for this part. The cover is printed in 4x4 inks, thus, for each cover 4 plates are needed (Table 40).

Table 40. Units of plates used in each part of the book

	Pages	Plates	Colours	Total plates
1/3 parts book 4+4 inks	32	4	4	16
2/3 parts book 1 ink	64	8	1	8
cover	2	1	4	4
Total plates book (Print run)				28
Total plates per copy				0.028

A total of 28 plates are needed for printing a book. Considering a print run of 1000 copies, an amount of 0.028 plates is allocated to each copy. In this stage two phases are included:

- Plate production, done in the plate manufacturer plant.
- Plate gravure, done in a graving company plant.

Plate production

Plate production inventory is included in the study. The most widely used plates are those made by electro-grained aluminium, coated by a slim layer of term-sensitive varnish. The latter normally contains silver halide, or other metals such as Fe, Mg and Mn (Table 41). As no primary data are provided by manufacturers, an Ecoinvent dataset is implemented. The offset plate used in the pre-press was assumed to contain 68% virgin aluminium, according to the Ecoinvent database.

Table 41. Plate manufacturing inventory

	Per each plate (g)	Per each book copy (0.028 plates)
Components		
Aluminium	304.52 g	8.53 g
Iron (Fe)	0.90 g	0.03 g
Magnesium (Mg)	0.54 g	0.02 g
Manganese (Mn)	0.16 g	0.005 g
Other metals	-	-
Inputs - resources		
Water	3.93 l	0.11 l
Light fuel oil	0.93 MJ	0.02 MJ
Natural gas	0.93 MJ	0.02 MJ
Electricity	0.38 kWh	0.01 kWh

The packaging of the plates is excluded. During the manufacturing process, energy and water consumption have been included while manufacturing equipment is excluded. Waste generated during plate manufacturing is not included due to lack of data.

The graving process is similar to those of magazines, therefore, not further explained in this paragraph. The same applies for the developer, replenisher, printing waste and emissions.

4.9.2.2.2 Printing

A standard press machine with 4 bodies is assumed for printing. The press machine has a production capacity of 6 000 printed sheets per hour. The press cycle for each book copy is 0.1233 minutes (7,4 seconds). Further inventory data are displayed in Table 42.

Table 42. Inventory of printing process (for functional unit)

		Amount		Observations
Inputs	Paper	183.11	g	Considered in material production stage
	Ink	3.96	g	Considered in material production stage
	Engraved plate	0.028	unit	Considered in graving plate stage
	Fountain solution	0.002	l	Consumption: 100 litres every 600.000 printings
	Rubber	0.024	g	Consumption calculated from annual blankets printing house consumption (weight of blanket:1kg/blanket)
	Electricity	0.0029	kWh	Consumption calculated from annual printing house consumption

		Amount		Observations
Outputs (Waste)	Water	0.0017	l	Consumption calculated from annual printing house consumption
	Aluminium	8.526	g	0.028 plates (Recycling)
	Paper	3.59	g	Shrinkage during printing (2%) (Recycling)
	Empty ink cans	-		
	Rubber	0.024	g	Disposal
	Emissions			Some organic solvents contained in the fountain solution and inks are evaporated during the printing and drying processes.

A consumption of 100 litres fountain solution each 600,000 sheet printings have been determined. Consequently 0.002 litres are consumed per book copy (Table 43).

Table 43. Fountain solution composition

Composition	Percentage	l /plate
Total		0,002055
Damping solution (commercial)	4%	0.00008
2-butoxyetanol	1.20%	0.000025
propano-1,2-diol	0.80%	0.000016
Water	92%	0.001891
Isopropyl alcohol (IPA)	4%	0.000082

The gum solution, a sub stance usually applied in the plates to avoid oxidation has not been included in the inventory. Empty ink cans have been not considered due to the small amount generated. Printing machinery has been excluded for the analysis. However, a screening analysis has been carried out, assuming 20 years lifetime. Results show 0.1%–0.9% impact variation depending on impact category. As this contribution is less than 1%, printing machinery impacts are excluded.

As above-mentioned, the machine cleaning activity also belongs to the printing process. Its inventory is depicted in Table 44.

Table 44. Inventory of cleaning process

		Amount	Observations
Inputs	Solvent	0.001 g	1 kg per 1 000 000 copies
	Degreasing	0.0005 g	0.5 kg per 1 000 000 copies
	Rags	0.001 g	1 kg per 1 000 000 copies
	Concentrated cleaner	0.001 g	1 kg per 1 000 000 copies
	Water		
Outputs	Dirty rags	0.001 g	1 kg per 1 000 000 copies
	Solvents	-	Solvents are supposed to be treated with rags

Empty packages of cleaning products are not included in the study.

4.9.2.2.3 Finishing

Once the magazine paper is printed, the finishing process applies. It includes folding and stapling operations. The inventory of the total is depicted in Table 45.

Table 45. Inventory of finishing stage

		Amount	Observations
Inputs	Electricity	0.0002 kWh	Data from finishing companies
	Vegetal thread	0.05 g	–II–
	Glue	1 g	–II–
	Polypropylene	0.63 g	–II–

4.9.2.3 Packaging

It is assumed that the product is packaged in a way that 50 books are packaged together in a corrugated board box. The box has a size of 45 x 33 x 25 cm and the board density is 1000 g/m^2, so that the box weight is 795 g (Table 46).

As each box contains 50 books, therefore, 0.02 box units are allocated in the functional unit.

Table 46. Inventory of packaging stage

			g/box	g/book copy
Inputs	Corrugated board	Corrugated board, recycling fibre, double wall, at plant	795	15.9

4.9.2.4 Distribution

An average distance of 220 km has been taken into account based on European market a van is assumed as transport mean.

4.9.2.5 Use

The use phase indicates no specific inventory as it is assumed for reading no extra materials are necessary.

4.9.2.6 End of life

Paper is the most recycled product in Europe which is the global leader in paper recycling. The European paper recycling rate was the 72 % in 2015. The rest 28% stands for landfill.

4.9.3 Life Cycle Impact Assessment

The impact assessment in based on the ILCD methodology. The chosen impact categories are shown in Table 47.

This analysis identifies the hot spots of a book and the parameters causing the biggest impacts. Figure 77 displays the activities contribution across the impact categories.

Raw materials production is the main hotspot contributing 24%–80% of the total. Paper in more relevant than inks as its amount is higher than the respective of inks.

The printing process indicates low impact shares mainly due to the implemented primary data. They have been obtained from a manufacturer which applies good management practises and implements EMAS. In contrast the average Ecoinvent dataset for printing shows higher impacts.

The results suggest raw materials production is the main hotspot, followed by plate manufacturing and distribution (

Table 48). Impact contributions illustrate similar trends across the impact categories.

Table 47. Selected Impact categories

Impact categories selected	**Units**
Climate change	kg CO_2 eq
Ozone depletion	kg CFC-11 eq
Human toxicity, non-cancer effects	CTUh
Photochemical ozone formation	kg NMVOC eq
Acidification	molc H+ eq
Freshwater eutrophication	kg P eq
Freshwater ecotoxicity	CTUe
Land use	kg C deficit
Water resource depletion	m^3 water eq
Mineral, fossil & ren resource depletion	kg Sb eq

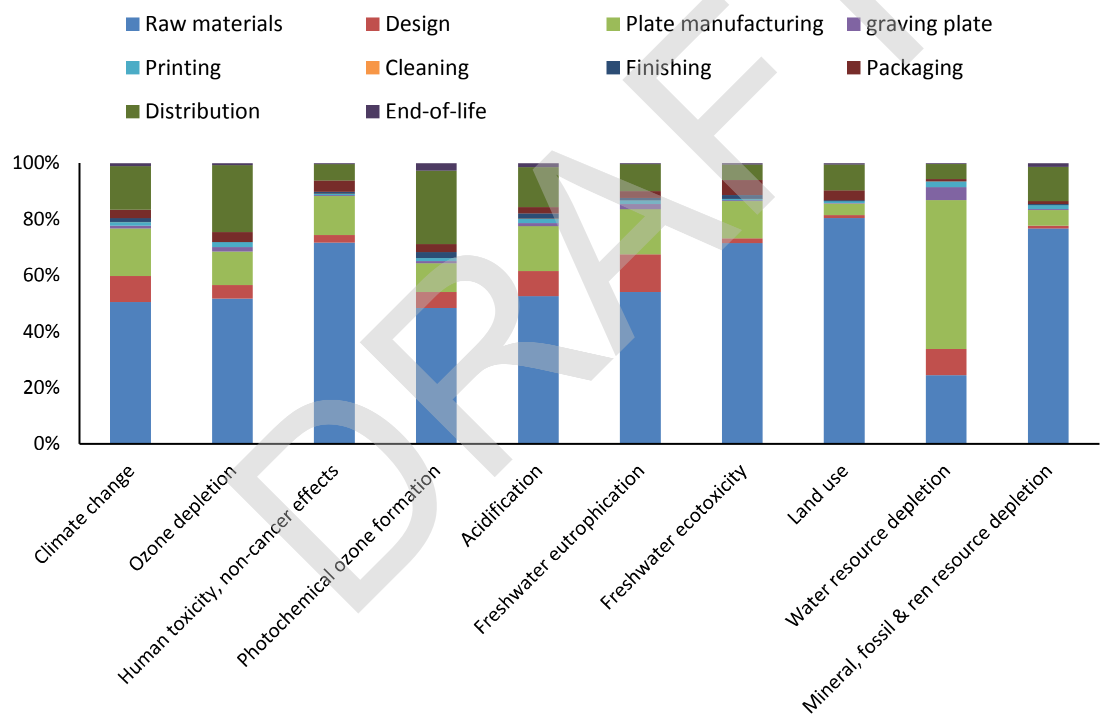


Figure 77. Distribution of environmental impacts among categories and life stages

Table 48. Environmental impact category results

Impact category	Total	Raw mat.	Design	Plate manuf.	Plate grav.	Printing	Finishes	Packaging	Distribution	Book waste
Climate change (kg CO2 eq)	4.94E-01	2.50E-01	4.58E-02	8.35E-02	4.97E-03	6.50E-03	1.52E-02	2.99E-05	6.66E-03	7.63E-02
Ozone depletion (kg CFC-11 eq)	4.56E-08	2.36E-08	2.17E-09	5.46E-09	7.34E-10	7.82E-10	1.57E-09	2.77E-11	4.55E-11	1.09E-08
Human toxicity, non-cancer effects (CTUh)	1.02E-07	7.31E-08	2.77E-09	1.42E-08	2.76E-10	5.68E-10	4.00E-09	3.51E-12	7.14E-10	5.99E-09
Photochemical ozone formation (kg NMVOC eq)	1.68E-03	8.13E-04	9.49E-05	1.71E-04	1.19E-05	1.94E-05	4.65E-05	1.10E-07	3.52E-05	4.41E-04

Impact category	Total	Raw mat.	Design	Plate manuf.	Plate grav.	Printing	Finishes	Packaging	Distribution	Book waste
Acidification (molc H+ eq)	2.67E-03	1.40E-03	2.38E-04	4.28E-04	3.08E-05	4.27E-05	5.90E-05	3.35E-07	4.80E-05	3.82E-04
Freshwater eutrophication (kg P eq)	3.19E-05	1.73E-05	4.23E-06	5.14E-06	6.23E-07	3.94E-07	7.77E-07	4.04E-09	2.78E-07	3.05E-06
Freshwater ecotoxicity (CTUe)	5.70E-01	4.07E-01	9.36E-03	7.61E-02	1.16E-03	3.66E-03	3.06E-02	7.38E-05	7.39E-03	3.13E-02
Land use (kg C deficit)	2.01E+00	1.62E+00	2.18E-02	8.20E-02	4.69E-03	1.08E-02	7.13E-02	1.20E-04	6.06E-03	1.86E-01
Water resource depletion (m3 water eq)	6.21E-01	1.52E-01	5.77E-02	3.30E-01	2.82E-02	1.33E-02	4.46E-03	9.94E-06	7.03E-04	3.33E-02
Mineral, fossil & ren resource depletion (kg Sb eq)	1.61E-05	1.23E-05	1.68E-07	8.89E-07	5.66E-08	2.28E-07	1.33E-07	1.37E-10	7.69E-08	1.99E-06

The outcomes are in line with the LCA screening while impacts distributions follow the same scheme as in published LCA studies. The global warming potential for the current functional unit is 0.494 kg CO_2eq., lower than the average in the literature (0.92–5.45 CO_2eq.). This can be explained due to the implemented primary data which are obtained from an EMAS certified manufacturer.

4.9.3.1 Environmental impacts of raw materials

As seen above, this stage has the most significant environmental load. Paper is the main contributor (Table 49). Inks have considerably lower impact shares than paper mainly due to the small amount used in the printing process. However, inks have relevant contribution in the categories on freshwater eco-toxicity, land use and ozone depletion.

Table 49. Impact contributions of paper and inks

Impact category	PAPER	INKS
Climate change	97%	3%
Ozone depletion	94%	6%
Human toxicity, cancer effects	97%	3%
Human toxicity, non-cancer effects	99%	1%
Particulate matter	97%	3%
Ionizing radiation HH	97%	3%
Ionizing radiation E (interim)	97%	3%
Photochemical ozone formation	96%	4%
Acidification	96%	4%
Terrestrial eutrophication	97%	3%
Freshwater eutrophication	97%	3%
Marine eutrophication	94%	6%
Freshwater ecotoxicity	89%	11%
Land use	92%	8%
Water resource depletion	97%	3%
Mineral, fossil & ren resource depletion	95%	5%

Considering the total European book production, inks environmental impacts should not be neglected. This study compares mineral-oil and vegetable-oil inks to identify possible mitigations. It can be seen in Table 55 vegetable inks show lower impacts than mineral oils inks throughout many impact categories, such as abiotic depletion and ozone layer depletion (Figure 78).

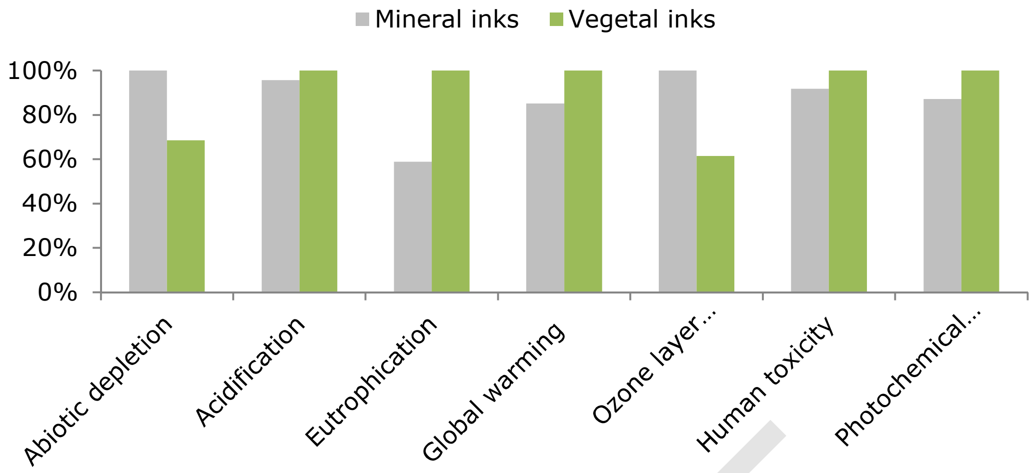


Figure 78. Comparison between environmental impacts for mineral and vegetable oils inks

Sensitivity analysis is carried out to evaluate the influence of the ink type to the final product. The results advocate, impacts to not be sensitive to ink types (Figure 79).

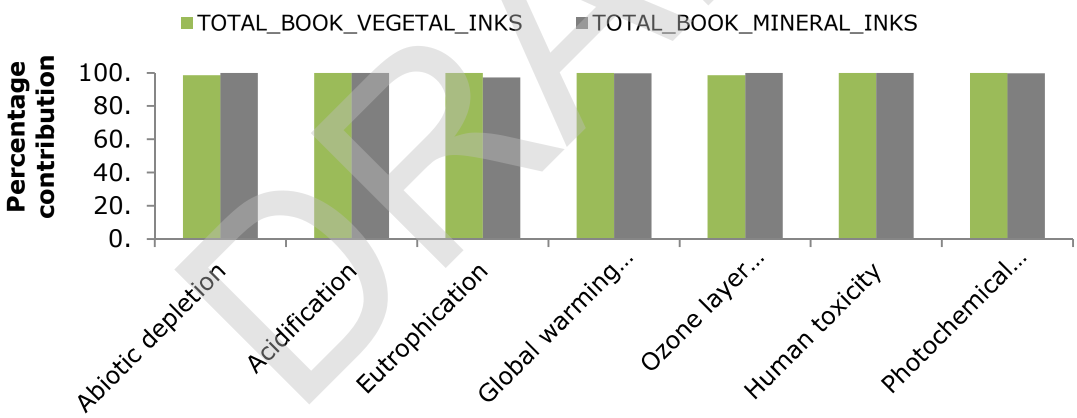


Figure 79. Comparison between environmental impacts for mineral and vegetable oils inks books

By using vegetable inks, minor environmental savings could be achieved in only in some categories:

- Abiotic depletion: 1% of savings
- Ozone layer depletion: 1% of savings
- The rest of impact categories show variations from 0.1% to 3% in favour of mineral inks.

These differences are not significant. Nevertheless, further investigation and more reliable and updated data of renewable oils are needed to assess this parameter.

Comparison between woodfree paper and recycling paper

Sensitivity analysis is also performed for recycled and non-recycled (woodfree) paper. The outcomes show recycled paper is environmentally preferable in some impact categories, such as acidification, eutrophication, human toxicity and photochemical oxidation. On the opposite, recycled paper has higher impacts in abiotic depletion, global warming and ozone layer depletion Figure 80.

The impacts of the recycled paper are attributed to the De-inking process. Although, the recycling process contributes to higher impacts, in some impact categories, the benefits of recycling are significant. For example, filler recycling mitigates environmental loads of landfilling.

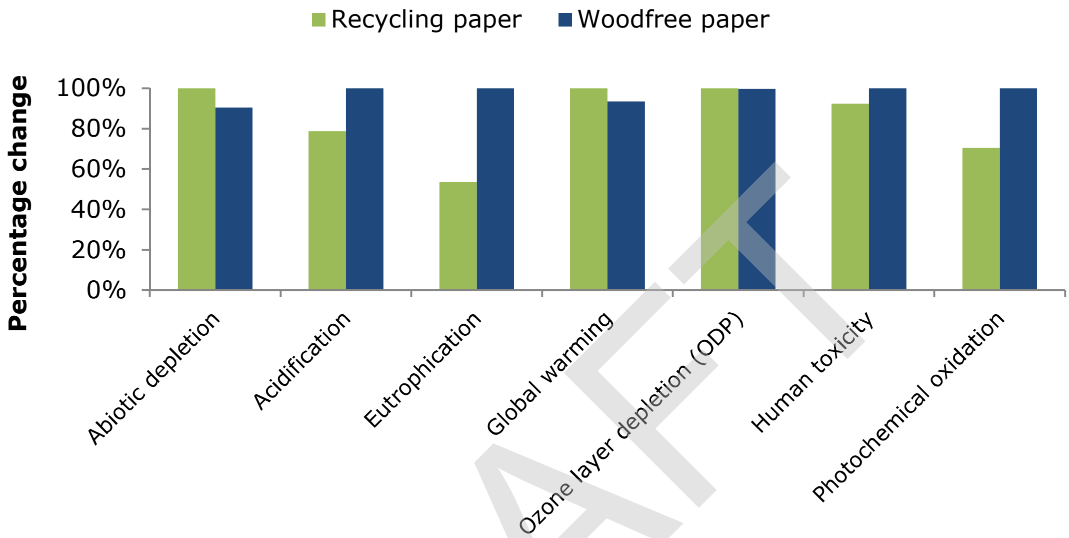


Figure 80. Comparison between recycling and non-recycling paper

To examine how the choice of the paper type affects the environmental impact of a book, two product systems have been compared (Figure 81). The first reflects a book made exclusively by recycled paper while the second by virgin fibres. The impacts of the recycling process, in both systems, are counted in the end-of-life stage, but in the case of the book made by recycled paper, the savings benefit the raw materials stage.

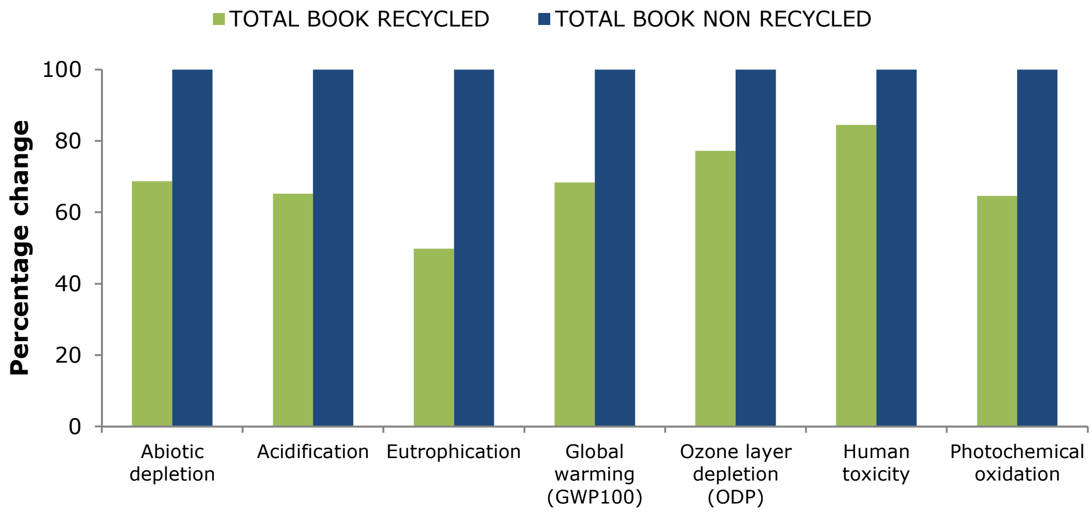


Figure 81. Comparison between recycled and non-recycled paper book

The analysis has proved the books made books made by recycled paper perform environmentally better than those of virgin paper. The next Table 50 highlights savings and the impact mitigation when book made by virgin paper serves as the baseline.

Table 50. Environmental Impact saving for a recycled-paper book

Impact categories	Units	Savings	% of saving respect non-recycled paper
Abiotic depletion	kg Sb eq.	0,0012	31%
Acidification	kg SO_2 eq.	0,0010	35%
Eutrophication	kg PO_4^{-3} eq.	0,0003	50%
Global warming (GWP100)	kg CO_2 eq.	0,1696	32%
Ozone layer depletion (ODP)	kg CFC-11 eq.	0,0000	23%
Human toxicity	kg 1,4-DB eq.	0,0831	15%
Photochemical oxidation	kg C_2H_4	0,0001	35%

4.9.3.2 Environmental impacts of Manufacturing

<u>Plate production and graving process</u>

Plate production step has impacts in the different ranging between 4%–53% of the total. These impacts are mainly due to aluminium production, the main constituent of plates as shown in Figure 82.

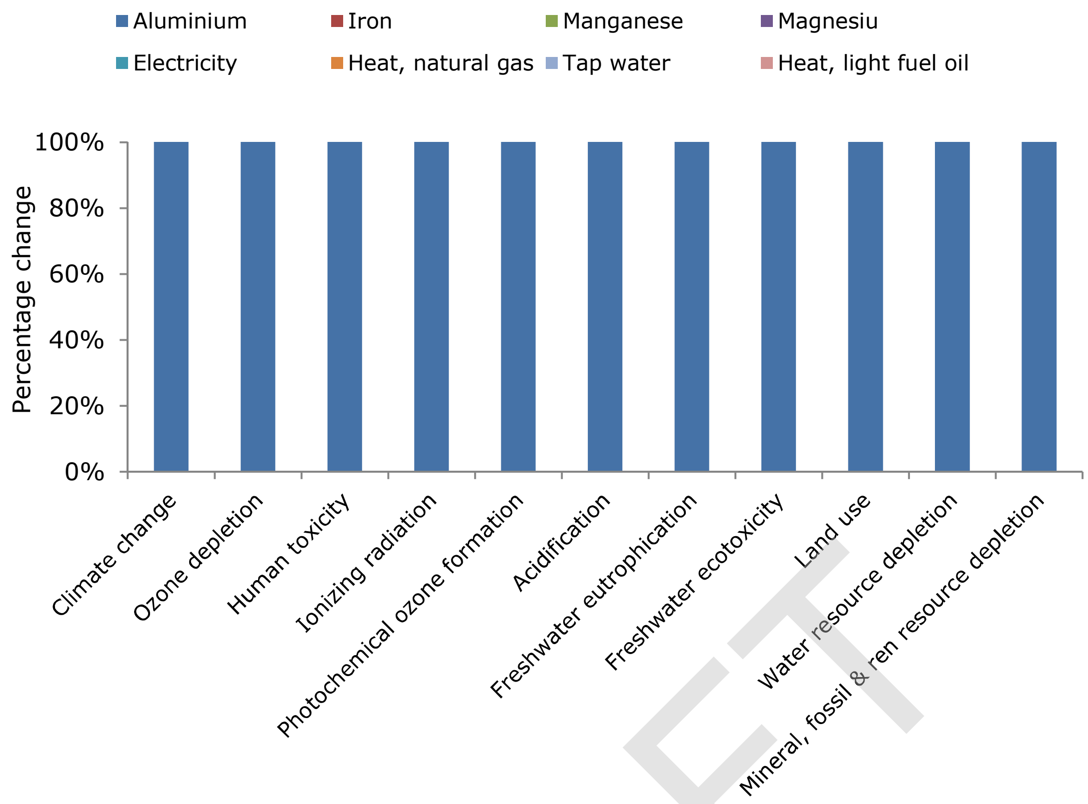


Figure 82. Environmental impacts from plate manufacturing stage

Plate graving has a low impact due to use of more advanced technologies, such as computer to plate graving. A high percentage is sourced to electricity consumption (55%–99%). Liquid waste has noteworthy contributions, especially in climate change (19%). The replenisher has also relevant impacts (2%–34%), whereas the developer shows insignificant contributions (Figure 83).

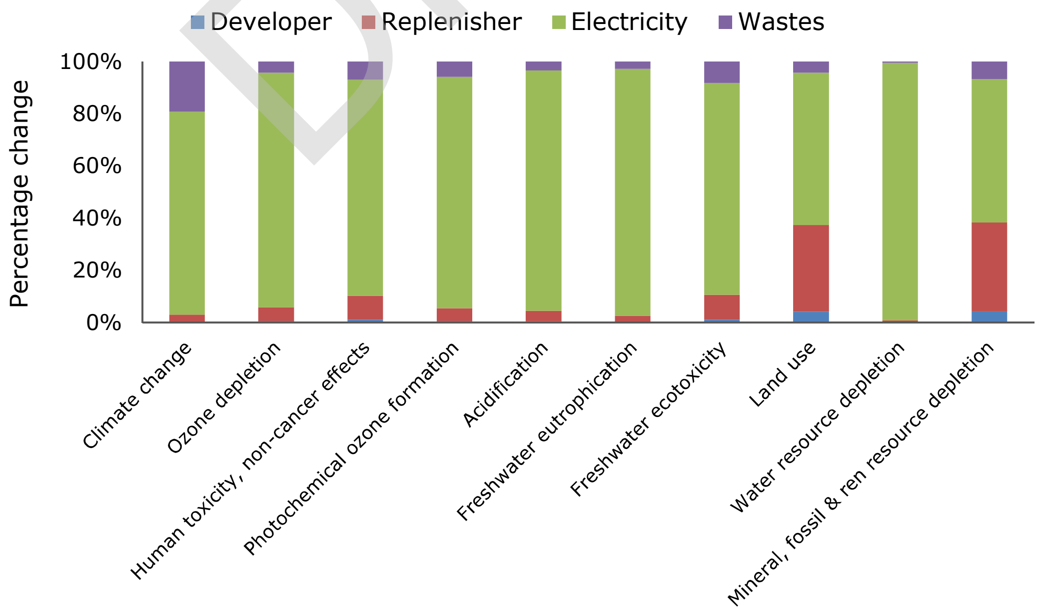


Figure 83. Environmental impacts from graving plates stage

Environmental impacts of printing process

Printing is the core part of book manufacturing. Figure 84 it portrays the major part of the impact comes from the generated waste and electricity consumption followed by substances, such as fountain solution and rubber.

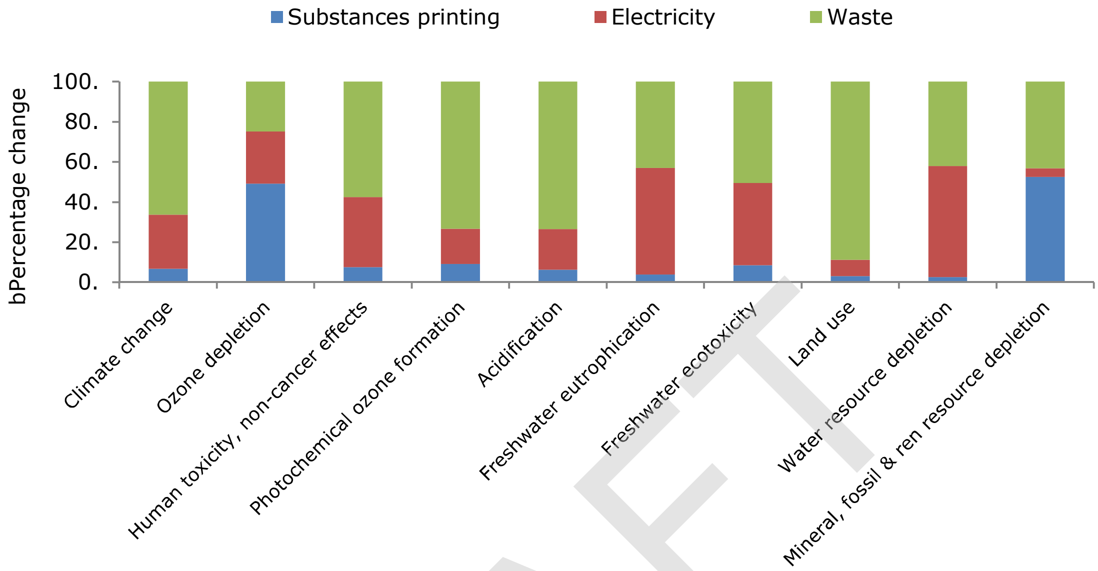


Figure 84. Environmental impacts from the printing stage

Environmental impacts of finishing process

Impacts from finishing process are due with a high percentage to the adhesives. Other materials, such as yarn and polypropylene have also loads, however, negligible. Electricity consumption of finishing has low contribution.

4.9.3.3 Environmental impacts of end-of-use stage

Three different end-of-life waste management scenarios:

- Baseline: 18% of waste is incinerated and 72% is recycled
- Recycling scenario: all wasted paper is recycled
- Incineration scenario: all wasted paper is incinerated

The outcomes advocate the incineration scenario has the biggest impact. If a book incinerated, the environmental loads are higher (1%–13%) than the baseline. On the contrary, they are 1%–6% lower when the recycling scenario applies.

4.9.4 Conclusions and improvement suggestions

The results of the assessment suggest raw materials production is the main hotspot (24%–80%) while paper substrate production is the most important activity. The study also advocates that decisions in the design stage, such as paper type, format and book size could influence the impacts considerably since they can determine the amount of paper and ink used.

Throughout manufacturing, plate production and graving are also relevant steps in a book life cycle (4%–53%). Printing has a relative low importance in that particular case as primary data are obtained from manufacturers which apply good environmental practises. That indicates the importance of implementing good environmental practices to improve the environmental performance of processes. Cleaning and finishing have minor impacts.

The distribution stage has noteworthy impact shares (5%–26%). During the use phase on environmental impacts are generated while in the end-of-life stage, additional impacts are caused mainly by the incinerated or landfilled waste fraction.

Based on results of life cycle impact assessment, this study proposes improvement measurement, specifically at the design stage, yet without to compromise environmental optimisation across the other stages of the life cycle. The most relevant improvements are as follows:

- Promote and use recycled paper.
- Use vegetable oil inks whenever possible.
- Ink amount reductions.
- Reduction in the amount of substances during printing and cleaning, such as the isopropyl alcohol or solvents.
- Energy efficiency measurements in the installations during design and printing.
- To choose environmentally certified supplies.
- Design demand-oriented print runs to avoid overcapacity and stocks.
- Design more efficient distribution networks.
- Enhance environmental awareness among consumers promoting book sharing, and recycling activities.

4.10 Additional information for relevant parameters

Additional information, besides LCA studies, is gathered to address specific aspects of environmental relevance.

4.10.1 Inks

Based on the best scientific data and calculations available by the European ink industry's association (EuPIA), a rough estimation of CO_2 emissions per a typical ink is 100-200 g CO_2/kg of ink. Studies carried out by authorities, such as the UK's Carbon Trust or the German Printing and Media Industries Federation (BVDM), concluded that the ink contribution to global warming potential of a printed article varies between 1%– 3%. This variation depends on the ink type, printing processes, and print run. These studies confirms that the ink, regardless of its composition, makes a very small contribution to the carbon footprint[51,52].· On the other side, although, inks have a low environmental load due to the small amounts used, they can be very relevant for the working environment.

Considering a holistic perspective, ink can cause impacts at various stages of the life cycle (Figure 85).

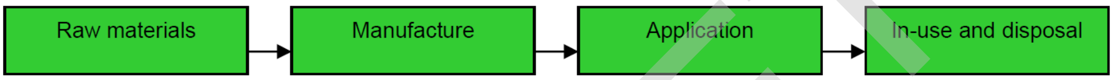


Figure 85. Life cycle stages potential affect from ink environmental impacts

The following Figure 86 provided an overview of the environmental impact of inks used in different printing technologies. It can be observed that non particular technology is "the best" from an environmental impact perspective.

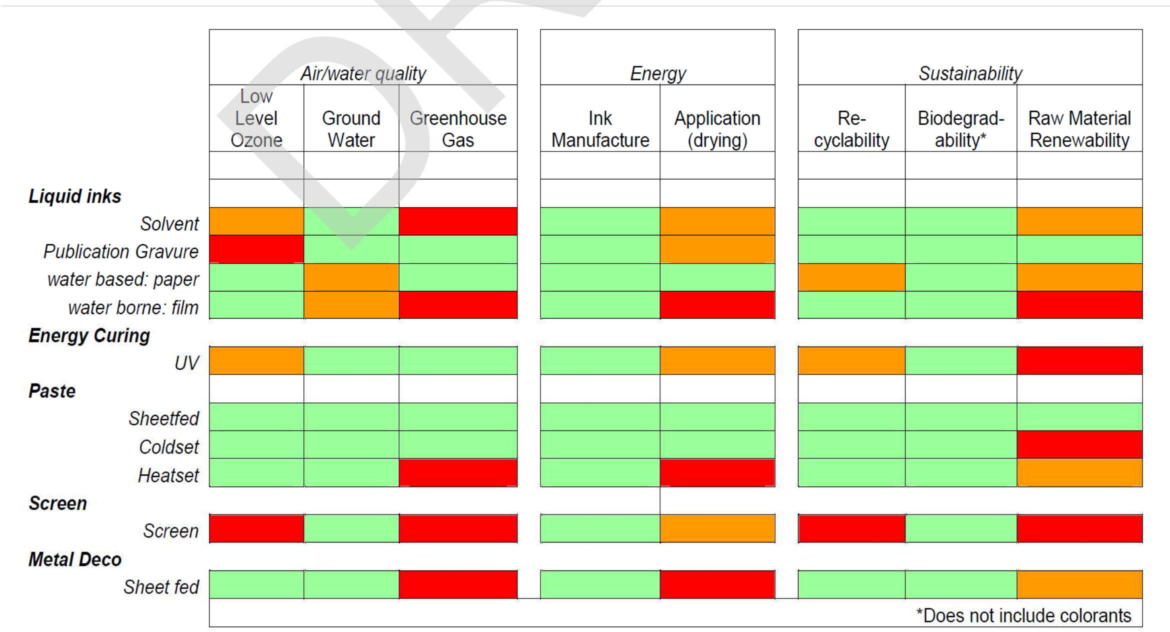


Figure 86. Inks environmental relevance across different printing techniques

[51] EUPiA. Carbon footprint of a reference ink. http://eupia.org/index.php?id=3&tx_edm_pi1%5BshowUid%5D=5&cHash=dfc8377791f18a86bed5918607de3808

[52] European Printing Inks Association. ENVIRONMENTAL IMPACT OF PRINTING INKS. March 2013

4.10.1.1 Comparison between mineral-oil and vegetable-oil based inks

Although the impacts of inks to the final product are quite low, the study compares two types of inks since at European level the total impact might be significant. Two types of offset inks have been analysed, mineral oils inks and vegetable oils inks. Inventory data are obtained from the 'greening books' project. Due to data limitations, it is assumed the inks undergo the same manufacturing procedure, composition of constituents and printing performance. The only difference lies in the origin of oil. Mineral oils inks are based on mineral-oils obtained from petroleum while vegetable oil inks use vegetable oils, such as rapeseed or palm oil (Table 51).

Table 51. Inventory for 1 kg ink

		Mineral oil inks	Vegetable oil inks	Quantity	
Components	Solvents	Light fuel oil	Rapeseed oil	0.475	kg
		Palm/Soya oils	Palm/Soya oil	0.05	kg
	Pigments	Carbon black		0.07	kg
		Polyethylene terephthalate, granulate, amorphous		0.07	kg
	Binders	Bitumen, at refinery		0.095	kg
		Alkyd resin, long oil, 70% in white spirit		0.19	kg
	Filler	Limestone, milled, loose		0.05	kg

As result of the assessment, Figure 87 shows vegetable inks have lower impacts than mineral oils inks in abiotic and ozone layer depletion. On the opposite, they indicate higher impacts in the rest of impact categories.

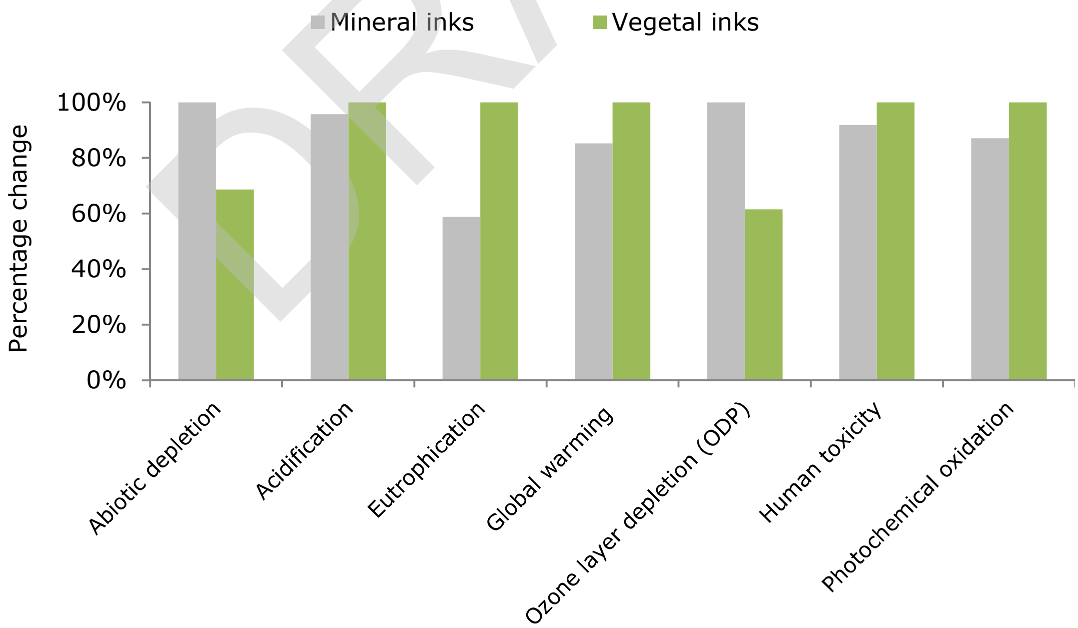


Figure 87. Comparison between environmental impacts for mineral and vegetable oils inks

4.10.1.2 Hazardous substances

EuPIA elaborated an "Exclusion List for printing inks and related products". Initially focused on health and safety in the work-place, it has now been extended to cover environmental protection issues.

Toxic heavy metals and other regulated elements

Four heavy metals (cadmium, hexavalent chromium, lead, mercury) are recognised as hazardous to human health and are covered by the EuPIA list. Substances which contain these heavy metals are not deliberately used to make inks or related products as far as it concerns EuPIA members. If the latter are used then their concentration has to be kept below the level that trigger toxic effects. In addition, other metallic elements, such as (tri-organo) tin compounds, are subject to specific environmental protection controls.

Aquatic effects

For technical and/or economic reasons, certain inks, which are classified as hazardous to the aquatic environment, might be used in products. Those inks are classified and labelled in accordance with the relevant EU legislation. When used, in accordance with environmental regulatory requirements and industry guidelines, these compounds will not be released into the aquatic environment.

Atmospheric effects

Nitrogen oxides react in the presence of sunlight to photochemical smog while organic solvents emissions can accelerate this effect. Experimental data show that solvents, typically used in inks, photo-degrade rapidly in the atmosphere into water and carbon dioxide, and are not significant contributors to lower atmosphere ozone. Nevertheless, solvent emissions are strictly controlled.

A wide range of measurements is undertaken to reduce the effects of inks and printing process on the environment, including:

- Chlorinated hydrocarbons, which are known to be harmful to organisms due to the bio-accumulation effect, are prohibited in ink manufacturing.
- Aromatic fractions are reduced or substituted by low aromatic-content solvents. This applies not only to heat-set inks solvents and mineral oils, but also to mineral oils for cold-set inks and hydrocarbon solvents used in packaging inks.

N-vinyl caprolactam (NVC)[53]

N-vinyl caprolactam (NVC) replaces n-vinyl pyrrolidone as a safer alternative, particularly due to its very low volatility which is interpreted in low emissions.

4.10.1.3 Inks manufacturing

Inks manufacture is not an impact hotspot, according to its categorisation in a number of EU and national environmental laws. Potential emissions of VOCs and pigment/extender dusts to atmosphere might be of concern. However, manufacturing processes are subject of control according to the national Environmental Permitting Regulations. Emissions of volatile compounds in flexographic and gravure inks are kept below a minimum, while emissions are fully recovered. Pigment dust is captured by filters. Odour traps are fitted on high temperature varnish manufacturing vessels. Untreated discharges to water are prohibited. Additionally, the ink manufacture is not regarded as an energy-intensive sector.

[53] http://eupia.org/uploads/tx_edm/2015-03-11_EuPIA_Customer_Information_Note_NVC.pdf

Application of inks

Electronic colour control systems allow for greater efficiency of inks. In certain circumstances, ink dispensing systems can be effective in reducing excess mixed ink.

4.10.1.4 Emissions to air and soil

Volatile Organic Compounds (VOCs) contribute to atmospheric photochemical reactions. Organic solvents for heat-set, flexographic, gravure, non-impact digital and screen printing inks are sources of VOCs. Further potential sources are:

- Organic solvent-containing founts in offset printing
- Press cleaning in offset printing processes.
- Pre-press production of flexographic plates.

Under the current requirements of the Solvent Emissions Directive, and national regulations, emissions of VOCs to atmosphere have to be controlled and kept under defined limits. Emissions control includes their recovery or destruction and can be achieved in a number of ways.

- Recovery: Adsorption (scrubbing), adsorption/desorption, condensation.
- Destruction: Catalytic thermal oxidation, thermal oxidation, biological scrubbing.

In large-scale flexographic and gravure printing, thermal oxidation is the most common emission destruction technique. In publication gravure inks, where the solvent is primarily toluene, it is subject of recovery. The recovery efficiency should exceed 98%. Under normal conditions there is no release of inks to soil or to ground water.

4.10.1.5 Energy

The energy requirements in application processes represent only part of the overall energy usage, and are ink technology and process dependent.

4.10.1.6 Process wastes

Electronic colour control systems allows for greater efficiency of ink applications and so reducing waste. Moreover, best practices for cleaning solvents have lowered their wastage. Alternatively, process wastes are managed efficiently following recycling plans. Empty, dry ink containers are not hazardous waste. Therefore, they can be managed by waste management companies.

4.10.1.7 Ink waste treatment

Recycling of paper is now common and the associated de-inking processes well-established. Issues in the UV and water based ink technologies have been well documented and are subject of continuing research. Recycling excludes printed paper in contact with food. Reuse of inks, due to their post-printing condition is not technically feasible. On the opposite, incineration as a waste treatment option is a common solution

4.10.2 Energy consumption

According to some LCA studies, printing is the second most energy relevant stage (17%) after the energy used for producing the paper substrate (79%)68. A reduction between 3%–8% of the total environmental could be achieved by 20%–50% energy reduction in printing operations.

Average market values for energy consumption, according to Nordic Ecolabel[54], are presented in Table 52.

Table 52. Energy consumption

Printing method	Average energy consumption (kWh/tonne)
Sheet fed offset (except packaging and offset printing of envelopes)	1253
Cold-set, news print	365
Cold-set, forms	997
Cold-set rotation (except news print and form printing)	825
Heat-set rotation	965
Rotogravure printing	864
Flexographic printing (except envelope production)	486
Digital printing	2799
Offset printing, envelopes	436
Envelope production with flexography	552
Offset, packaging	1564

Generally, digital printing requires higher consumption of energy consumption. Sheet-fed offset printing follows while and the method with lowest energy consumption is coldest printing.

4.10.3 Waste

It is estimated that the average substrate wastage is 17% and accounts for 4%–16% of the print house turnover. Thus, any waste minimisation measurements will not only improve the environmental impacts, but also have economic benefits. To improve paper wastage, the paper type size has to fit the type of the final product. The type and size of paper more suitable for specific print methods are pointed out in Table 53.

Table 53. Paper suitability

Name	Paper size (mm)	Suitable for	Trim
SRA3	450 x 320	Litho with bleed	15%
RA3	430 x 305	Litho no bleed	5%
A3+	427 x 305	Digital with bleed	4%
A3	420 x 297	Digital no bleed	0%

4.10.4 Recyclability and de-inkability

Recyclability is crucial for the environmental performance of paper. Recyclability in turn is linked to de-inkability[55]. De-inking at industrial scale is highly complex since it needs to consider and address diverse types of inks, and also to remove impurities and unwanted

[54] Nordic Ecolabelling: Printing companies, printed matter, envelopes and other converted paper products. Background document for ecolabelling. December 2011

[55] http://pub.ingede.com/en-GB/methods/

substances. The key de-inking steps are the detachment of the ink film from the paper, ink fragmentation and removal from the pulp slurry.

To evaluate recyclability of printed paper products, general requirements were given in the EN ISO 17025:2005 standard[56]. Methods for recycling are also specified in the updated publications of the International Association of the De-inking Industry (INGEDE)[57] and the European Recovered Paper Council (ERPC)[58]. In the case of inks and varnishes, the INGEDE Method 11 'Assessment of Printed Product Recyclability - De-inkability Test 2012' applies. In the case of non-water-soluble adhesives, the INGEDE Method 12 "Assessing the Recyclability of Printed Products - Testing of Fragmentation Behaviour of Adhesive Applications of 2009" can be followed.

The European Recovered Paper Council (ERPC) adopted this assessment scheme, the so called 'De-inkability scorecard', to promote eco-design of printed products aiming further to ensure recyclability and promote sustainable production. The scheme is designed to allow printers, publishers and suppliers to identify which types of printed paper have the best recyclability when they are deinked. Five parameters – luminosity, colour, cleanliness, ink elimination and filtrate darkening – are considered in the INGEDE Method 11.

Flotation is the most widely used technique for ink removal while households are the main providers of wasted paper for de-inking. Wasted paper goes to de-inking plants which produce deinked pulp from newsprint, publication and other printed and written papers. These paper types are usually pulped in an alkaline environment so the ink can be removed by flotation. Typically, the ink collector is a fatty acid based substance. This process has been developed for offset and gravure inks which are roughly more than 95 % of the market. On the opposite, flotation is not efficient for water based inks, yet they are less niche product. Other papers, suitable for de-inking, are medium and high-quality paper grades sourced from offices. However, most of the printed products end up in household waste collection systems and are treated as household wasted paper.

<u>Effect on recycling of printing inks, varnishes, toners and inks</u>

The ability to remove inks and varnishes from paper depends on various factors including the ink/varnish type, printing technology and conditions, and the surface of the paper.

Vegetable inks harden more quickly than mineral inks, and therefore are much more difficult removable from the fibres. Their removal necessitates more energy while causes higher losses.

Silfverberg and Sørensen highlighted recycling constrains of UV inks and varnishes. The reason for that is the less favourable properties of UV inks, and the higher energy requirements in the de-inking plant whereas the resulted paper quality is lower in comparison printing with conventional inks. UV printing inks and varnishes are used for specific customer orders, such as long durability products or gloss and colour reproduction. UV printing inks adhere to the paper fibres, therefore, their removal is challenging. A further attitude of UV inks is that they may form flakes of certain particle sizes which are problematic for separation. That results to the so called speck-lings on the finished paper.[54]

<u>De-inking of Flexographic Printing inks[59]</u>

The extent of flexographic printing of newspapers could impose a major risk for European recycling targets. Flexography started as printing technique for low quality paper grades

[56] Conformity assessment: General requirements for the competence of testing and calibration laboratories
[57] www.ingede.org
[58] www.paperrecovery.org
[59] http://www.ingede.de/ingindxe/flexo.html

e.g. corrugated boxes printing. Nowadays, modern flexography is capable to achieve high quality printing for all types of paper including coated packaging. The low quality of recycled flexographic printed matter, such as newspapers is caused due to difficulties to deink flexography printed material achieving high quality. It should be noted that newspapers are made by 80%–100% recycled paper.

De-inking digitally printed matter

Digital printing has many advantages, such as overprint reduction, accuracy, no storage costs etc. However, digital printing has some disadvantages compared to conventional offset and gravure printing. Digitally printed matter is harder de-inkable. Thus, sending even small quantities of that type to the paper mill, it might affect the quality of the produced pulp. Moreover, water-based inks (e.g. water-based ink for inkjet) dissolve in the recycling process and may affect the pulp colour.

Finishing processes and their effect on recycling

During the recycling phase, paper bunches up at the plastic part of the lamination film. The created lumps are relatively large and thus easily removable during the de-inking process. However, laminated paper cannot be recycled. Furthermore, wax is used for paper or coating or board manufacturing, delivering greater wet strength. Though, the waxed material can generate the same type of sticky substances as adhesives, showing a similar attitude in the recycling process as hot melt glue (Grafiska Miljörådet 2000).

Adhesives influence on recycling

Ideally, collected paper should contain only staples and no adhesives, yet that is not the case, therefore, test results should proof they have not adverse effect on recycling. Following adhesives are used in printing.

Hot melt adhesives become liquid at high temperatures whilst they get solid at room temperature. These adhesives form large particles in the recycling process and are not critical according to INGEDE's requirements (Putz et al 2004).

PUR or polyurethane glue is supplied as single or double component glue and differs from hot melt glue which hardens permanently by means of a chemical reaction, among others, with isocyanates. Some PUR adhesives are classified as R40 (carcinogenic in category 3) whereas others are excluded from this categorisation. PUR adhesives form even bigger particles than hot melt adhesives, hence they are easily removable.

Water-soluble adhesives cause problems in the recycling process because they dissolve and cannot be strained out. In water circulation systems, widely used in the paper industry today, water soluble adhesives can build up and cause problems.

Toner inks, used in photocopiers and laser printers, impose difficulties for office paper recycling, yet difficulties in De-inking office papers are well known. There is major obstacle to disperse the thermoplastic binders used in laser and xerographic inks while sorting and separation of this paper type is not cost effective. The later represents a key factor for efficient De-inking and production of printing and writing paper from recovered office paper. Developing effective De-inking agents is a challenge while understanding the interactions between toner inks and De-inking agents is crucial for increasing efficiency of the recycling process.

Environmental impact of de-inkability processes

Since de-inkability depends on various parameters, two scenarios are carried out to evaluate possible impact variations. The best case scenario considers a high luminosity limit (72.5) and the worst case low (33.5). Printed products with luminosity lower than

33.5 are not de-inkable, and therefore not recyclable[60]. To assess the impact of the two scenarios, following data has been considered[60]:

Table 54. Scenarios used to assess de-inkability

	Units	Best case	Worst case
Energy consumption	(kWh/kg of pulp)	0.3	0.27
Chemicals consumption			
NAOH	(g/kg of pulp)	13	5
Silicate		40	10

The environmental impacts of the two scenarios are presented in Figure 88. If the product is easily de-inkable, the environmental impacts are reduced by 60% at the impact categories mineral, fossil and renewable resource depletion, compared to the worst case scenario, while climate change and acidification impacts are 22% lower.

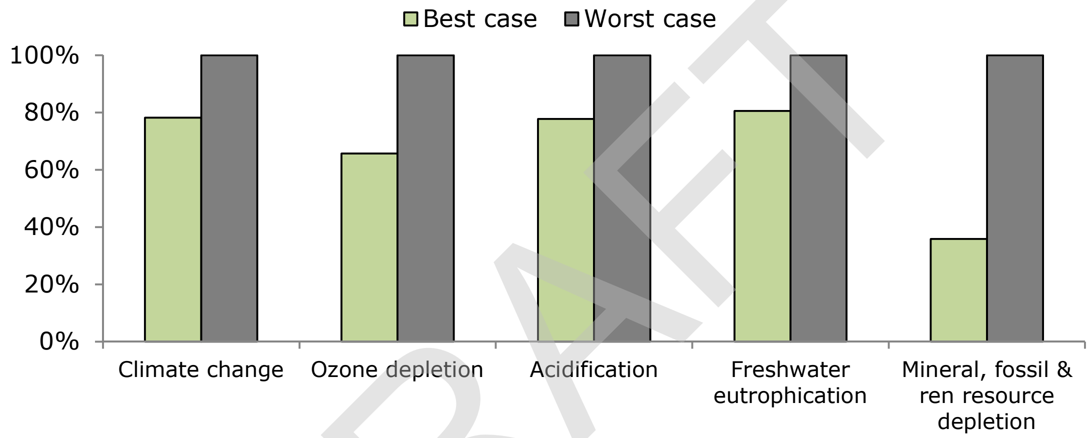


Figure 88. Comparison of different scenarios for de-inkability

To assess the entire environmental impacts of the de-inkability process, the subsequent waste treatment was also assessed. The deinked pulp is recovered and sent to recycling facilities whereas residues need to be treated as hazardous waste. These are fragments of paper fibres and pigments which are removed during the process. Three different scenarios have been assumed representing various efficiency rates of the process:

- 60% of the paper pulp is recycled and 40% remains as hazardous waste
- 70% of the paper pulp is recycled and 30% remains as hazardous waste
- 80% of the paper pulp is recycled and 20% remains as hazardous waste

[60] Eco-design for recycling: Criteria for sustainability (December 2014). EcoPaperLoop project

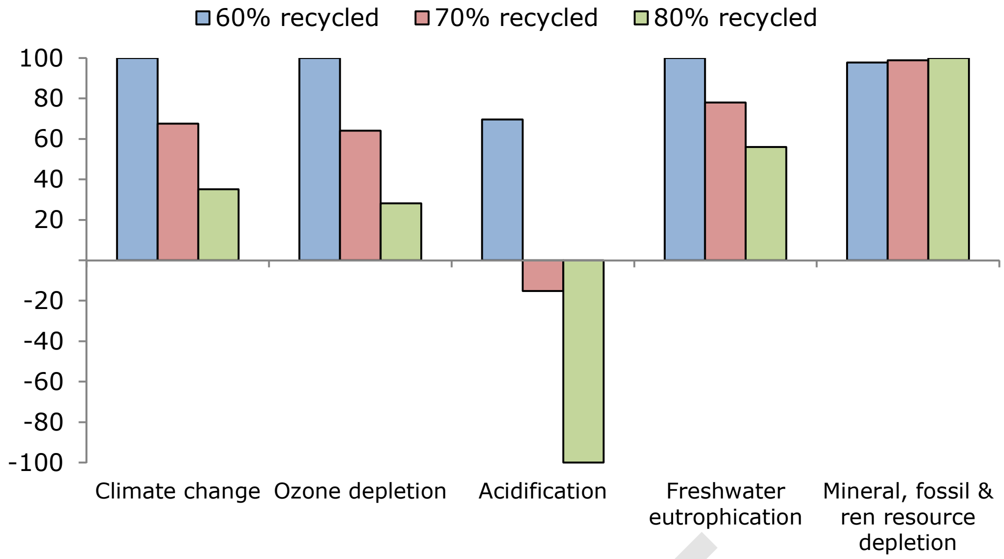


Figure 89. Comparison of different efficiency of de-inkability processes

4.10.5 Emissions to air and water

At inventory level, some LCA studies[61] reported emissions to air (NOx, SO2, TSP and VOC) and emissions to water (COD, Ntot, Ptot, TSS). NOx emissions originate from deliveries to customer (28%), other transport activities (14%), direct emissions from pulp and paper manufacturing (14%) and energy consumption in pulp and paper manufacturing (13%). SO_2 emissions are sourced to energy consumption in pulp and paper manufacturing (31%) and printing (19%). Chemicals, auxiliaries and fuels for pulp and paper manufacturing and for printing contribute to 16% and 23% respectively. Particulate emissions (TSP) originate from multiple life cycle stages. Most of the VOC emissions are sourced to printing houses (~70%). In addition, VOC emissions occur in manufacturing of chemicals (printing ink and isopropanol) and fuel production (propane and natural gas).

Regarding emissions to water, the chemical oxygen demand (COD), total nitrogen (Ntot), total phosphorus (Ptot), total suspended solids (TSS) and adsorbable organic halogen compounds (AOX) were included in the inventory. When released to water, nitrogen and phosphorous emissions cause eutrophication. Pulp and paper mills are the biggest contributors to COD (74%), Ntot (28%) and TSS (76%).

TSS emissions (total suspended solids) from pulp and paper mills can include small fibre fragments, fillers and coating substances. Nitrogen and phosphorous emissions originate from the wastewater purification process at the mills. Another major contributor is manufacturing of printing ink, which produces the largest share (83%) of the phosphorous and nitrogen emissions (72%) in addition, to 25% of COD and 21% of TSS emissions. AOX emissions originate mainly from pulp and paper manufacturing.

[61] Pihkola et al, 2010

VOCs emissions

In Germany, the total VOC from surface treatment activities using organic solvents were estimated at 224,750 t in 2010 (Figure 90). They covered by the VOC Solvents Directive (1999/13/EC) and the Industrial Emissions Directive (IED 2010).[62].

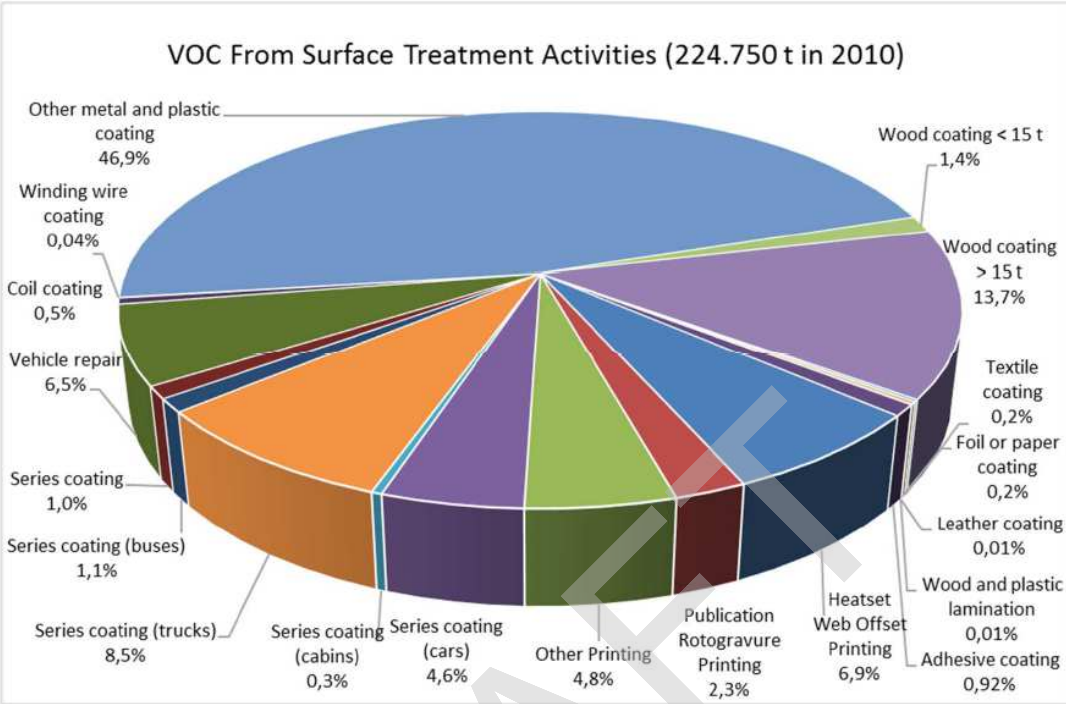


Figure 90. Estimated percentage of VOC Emissions from surface treatment activities using organic solvents in Germany including Non-IED Activities
Source: Ökopol 2016

Emissions of volatile organic compounds mainly originate from the use of organic solvents and alcohol in dampening solutions. Heat-set inks contain mineral oils which are considered as VOCs when they reach the afterburner. Washing agents and the dampening solution, include isopropyl alcohol (IPA) which contributes by 95% at photochemical ozone formation (Johansson 2002). Drivsholm et al (1996, 1997) suggest paper accounts for more than 50% at photochemical ozone. Other VOC sources within manufacturing can include pre-press and the finishing activities.

The main source of VOC emissions in the printing house is the press-room where three main points of VOCs emissions are identified as follows:

1. Inks: Many of them are solvent based. Their evaporation dries the ink on the substrate. The amount of solvent emitted from the drying ink varies from 5%, in a non-heat-set lithographic process, to 100% in flexographic and heat-set.
2. Cleaning: Excess of inks in presses has to be removed to ensure the inks don't dry on the rollers and ink wells. Often the chemicals used for cleaning contain high percentages of solvents.
3. Fountain solution: It is used in lithographic printing to ensure that oil does not stick to the non-image area of the blanket. Traditionally, isopropyl alcohol is used to control the properties of the fountain solution. The use of IPA makes the fountain solution the primary source of VOC emissions in lithographic facilities.

[62] Ökopol GmbH, on behalf of the German Environment Agency. Best Available Techniques (BAT) in Europe in Surface Treatment Activities Using Organic Solvents - Final Report. TEXTE 20/2017

The VOC Solvents Emissions Directive is the main policy instrument for the reduction of industrial emissions of volatile organic compounds (VOCs) in the European Union[63]. It covers a wide range of solvent using activities, e.g. printing, surface cleaning, vehicle coating, dry cleaning and manufacture of footwear and pharmaceutical products. The VOC Solvents Emissions Directive requires installations in which abatement activities are applied. The facility shall comply either with the emission limits, set out in the Directive, or with the requirements of the so-called reduction scheme. The Directive sets out emission limits for VOCs in waste gases at maximum levels for fugitive emissions (expressed as percentage of solvent input) or total emission.

The solvent-consuming sectors, Directive 1999/13/EC, are provided guidance documents for the substitution of solvents and the development of solvent management plans[64].

- Heat-set web offset printing
- Publication rotogravure
- Other rotogravure, flexography, rotary screen printing, laminating or varnishing units, screen printing on textile/cardboard
- Surface cleaning using substances with R40, R45, R46, R49, R60, R61 or R68
- Other surface cleaning
- Other coating, including metal, plastic, textile, fabric, film and paper coating
- Documents relevant to all sectors or those of general interest not related to a specific sector

The following points suggest good practices for effectively address VOCs emissions:

- Under the UK Printing Solvent Substitution Scheme, solvents are categorised as IA (flashpoint <21°C), IIA (21°C to 55°C) and IIIA (>55°C). The aim is to use IIIAs where possible and eliminate IA solvents.
- Use of solvent-free, water-based wash-up solutions. They are substances, such as vegetable-based surfactants and fruit acids which could replace organic solvents reducing their use.
- Use of water-based inks, UV inks or inks containing lower solvent levels. Water-based gravure, flexographic and screen inks are being improved and are suitable for many printed products. UV inks are already used in flexographic and screen printing.
- Solvents can be recovered from abatement systems and press cleaning. That can reduce costs effectively.
- Installation of abatement equipment to reduce emissions.
- Emissions limits and best available techniques (BAT) for solvent abatement in printing houses can be found in the EU BREF document for surface treatment using organic solvents, Secretary of State’s Guidance for Printworks, PG6/16(04), and in SEPA's process guidance notes.

4.10.6 Environmental impacts of printed products at European level

The EU28's total carbon footprint was equal to 7.1 t CO_2 per person in 2016. Private households emit 24% of the total due to burn of fossil fuels (e.g. heating, private vehicles) while 76% is indirectly emitted across the supply chain. The majority of the

[63] http://ec.europa.eu/environment/archives/air/stationary/solvents/legislation.htm
[64] http://ec.europa.eu/environment/archives/air/stationary/solvents/guidance_en.htm

latter (4.4 t/person) stem from production activities located in the EU. A smaller part, 1.1 t/person, originates from production activities outside the EU.

Table 55. Domestic and imported CO_2 emissions by final use of products (EU, 2016)

Source: Eurostat

In Europe, the average annual consumption of paper products is approximately 155 kg per person. Considering an average GWP of printed paper products at 1.557 kg CO_2/t, this leads to a carbon footprint of 241 kg CO_2/person/year. Scaling up at European level, the GWP rises at 123 Gt CO_2 eq. (EU population at 511.8 m)[65]. The GWP of printed products is not high compared to other products, nevertheless, considering the annual GWP at European level; improvements can drive towards environmental impact mitigations.

4.11 Environmental sustainability conclusions

The environmental impact of printing products and processes are analysed in this report. A screening LCA has been carried out including three magazines, four newspapers, three books, and one leaflet. The results, obtained from section 5.1, are compared to those obtained from literature in the following Table 56.

Table 56. Environmental sustainability conclusions

Product		Carbon footprint kg CO_2/unit	Life Cycle Stage					
			Raw Materials	Pre- press	Printing Production	Packaging	Transport	End-of-life
Magazine	Average LCA Screening	0.45	48.7%	-	26.8%	2.4%	10.4%	11.7%
	LCA case study	0.30	58.3%	7.3%	16.0%	3.7%	14.4%	0.3%
Book	Average LCA Screening	2.52	41.8%	-	37.5%	11.9%	7.8%	0.9%
	LCA case study	0.49	50.5%	9.3%	20.6%	3.1%	15.5%	1.1%

65 https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_and_population_change_statistics

Summarising the life cycle stages contribution, the raw materials production contributes to more than 40% of the total impact, mainly due to energy consumption in the paper mill. Mitigations at that stage might be achieved using higher amounts of recycled paper.

Despite the pre-press stage is not well covered in the literature, this study advocates the environmental relevance of that specific stage. Consequently, decisions made during the design phase are important to the final environmental profile of the product.

Energy consumed and chemicals used during the production phase are the most important contributors to the environmental impact of production stage. Transport has a contribution between 7%-15%. Finally, packaging and end-of-life are not a relevant in most of the cases, yet in some products they could indicate contributions higher than 10%.

Summarising, key aspects are presented in the following Table 57. These have been classified according to their relevance in the environmental profile of a printed paper product.

Table 57. Key parameters identified by life cycle stage

Environmental aspects		Description	Relevance
RAW MATERIALS			
Substrate	Origin	Use of recycled fibres	High
	Energy consumption	Energy consumed during the pulp and paper production	
	Certification	Consider other type I ecolabels, regional ecolabels or other standards	Medium-high
Inks	Origin	Preference for vegetable inks or water-based inks instead of mineral base inks	Medium-high
Adhesives	Recyclability	Adhesives accepted in the recycling process	Medium-high
	Best available techniques	Use of methods with less environmental impact: dispersion adhesives, hot-melt adhesives...	
Other chemicals	Toxicity	Use of chemicals with lower toxicity to the environment and higher biodegradability	Medium
	Best environmental performance	-	
PRE-PRESS			
Design	Eco design strategies	Selection of some parameters such as grammage of paper	Medium
PRODUCTION			
Emissions	Emissions to air	NOx, SO_2, TSP and VOC	Medium
	Emissions to water	Chemical oxygen demand, total nitrogen and phosphorus, total suspended solids	
Energy and water consumption	Energy sources	Use of renewable sources of energy	High
	Energy consumption	Energy consumed during the printing process	
	Best environmental practices	Implementation of an annual energy reduction goal	
	Water consumption	Water consumed during the printing process	Medium
Waste	Inks and toners	Collection and treatment of inks and toners	Medium- low
	Washing agents	Collection and treatment of washing agents	
	Unsorted waste control	Avoid unsorted waste	
	Waste water	Treatment methodologies of waste water	
PACKAGING			
Packaging	Quantity	Avoid unnecessary packaging: eliminate, reduce or replace the packaging of the product	Medium

	Materials	Use of more sustainable options	Low
Transport			
Transport	Efficiency	Efficiency of the transport method, less fuel consumption	Medium
	Optimization	Planning of the delivery route	Medium-high
USE			
Lifespan	Reuse	Expand the lifespan of the products	Medium
END-OF-LIFE			
Consumer information	Lifespan	Information regarding the importance to expand the lifespan of the products	Low
	Recyclability	Information regarding the best waste sorting method	
Waste treatment	Recyclability	Ensure the recyclability of the product	Medium- low

4.12 Circular economy approach for printed paper products

The circular economy concept promotes production and consumption systems where products and services are traded in closed loops (**Error! Reference source not found.**). It also endorses proactive actions, such as the product design phase, aiming to retain resources and mitigate environmental impacts considering a life cycle approach. Opposite to the linear economy model, circular economy aims to maintain and extend the value of products and materials. Moreover waste and resource use are minimised, and recycling is encouraged.

Sustainable practices are well established in the printing industry in response to corporate social responsibility (CSR) concerns and recycling obligations. This applies not only in manufacturing but extents across the supply chain.

The life cycle of the final product is composed of a series of value-adding steps, from the extraction of raw materials up to the end of the product's life. The circular economy scheme proposes the product's end of life is recoupled from the previous life cycle stages.

This scheme is particularly suitable for the pulp and paper sector, thanks to the possibility of producing paper and packaging from used paper products. However, as fibre quality worsens in recycling, fresh fibres are always needed in the recycling loop. Inks and toner recycling may constitute of further constrain.

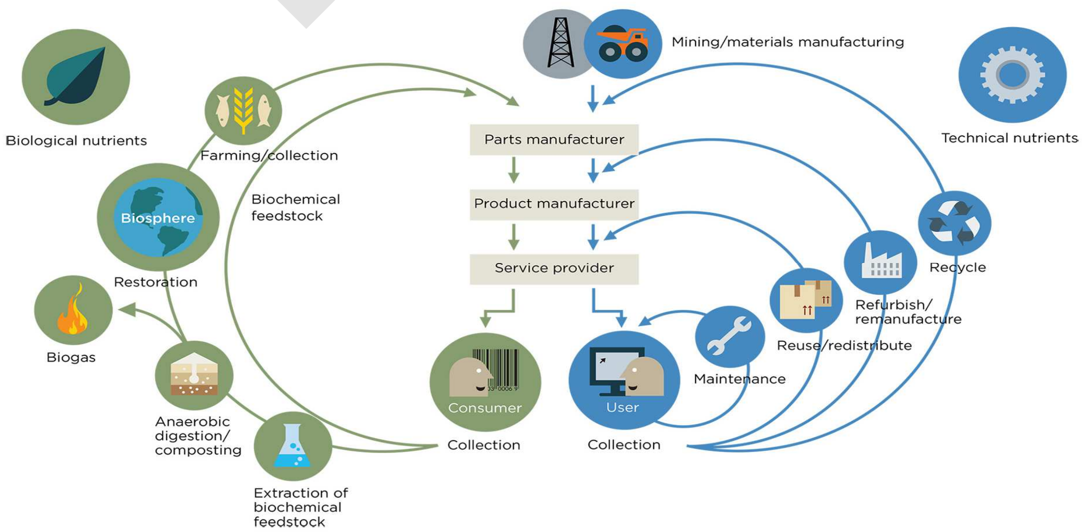


Figure 91. Scheme of circular economy principles

Source: Ellen MacArthur Foundation

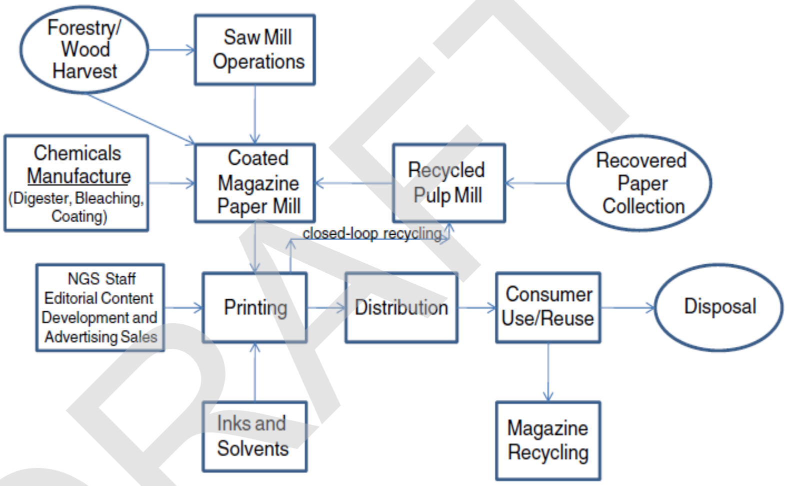
The core principles of the circular economy applied to paper products are[66, 67]:

- Product reuse, easy disassembly and recycling are considered in the design phase.
- Rethinking of paper product function (Type of information, demand from consumers, end-user target, number of copies, lifetime).
- Eco-Design choices should contribute towards impacts mitigations.
- Optimisation of paper/board size to fit standard industry production sizes and thus reducing wastage.
- Optimize the paper weight.
- Pay particular attention to layout.
- Limit the use of coloured (tinted) graphic paper.
- Limit the addition of non-paper components and accessories, and the use of wet-strength papers.
- Make sure any non-paper product components or accessories are compatible for recycling.
- Match appearance (e.g. brightness, specks, thickness) to the minimum requirements.
- Preserve and enhance natural resources by managing stocks and balancing renewable resource flows. Improve resource use and preserve value across the value chain.
- Compliance with an internationally acknowledged certification scheme regarding sustainable fibre sources.
- Use of recycled raw materials.
- Use of non-toxic and non-hazardous substances. Replacement, as far as possible, of substances of concern in the whole product chain.
- Production related impacts should be identified, evaluated and potentially mitigated.
- Increase efficiency of the printing processes.
- Use easily de-inkable inks.
- Customer oriented production.
- Limit the use of adhesives and UV varnishes.
- Select suppliers committed to the environment (EMAS certified suppliers).
- Communicate product environmental performance.
- Choose the most efficient distribution and delivery methods.
- Improve resources by promoting reuse and recycling.
- Product life extension.

[66] Design and Management for Circularity – the Case of Paper. World Economic Forum. January 2016.
[67] Unlocking the circular economy in the print industry. Quocirca 2017

ANNEX

I. LCA case studies as result of the screening process

Item 1	**Information**
Title	**Life cycle carbon footprint of the National Geographic magazine**[68]
Authors	Terrie K. Boguski
Year	2010
Type of publication	Life cycle carbon footprint. *Greenhouse Gas Protocol, A Corporate Accounting and Reporting Standard* also provided guidance.
Scope	Magazine. The use of 0%, 5%, and 10% recycled fibre content in the coated magazine paper is evaluated in this study.
FU	**1,000 kg** of National Geographic magazines produced and delivered to consumers
System boundaries	
Assumptions	Open-loop recycling (allocating burdens between the virgin and recycled products) is an alternative allocation method. A sensitivity analysis was not performed on the allocation method for recycled fiber content because recycling did not significantly affect the study results for energy or GHG emissions when comparing 0%, 5% and 10% recycled fiber content scenarios. For the magazines that are recycled at end of life, all initial production burdens for the magazines are allocated to the magazine, while the product system using the magazines as raw material is allocated the burdens for collection, reprocessing, and ultimate disposal of the material. A sensitivity analysis for this method of allocation and open-loop recycling allocation is presented in the report.
Data sources and quality	• Data from the paper supplier, printer, and National Geographic Society were collected directly for this study. • Data collected are from 2006-2008. • US data are used for this study.
Impact categories/ methods	Carbon footprint. Emissions from: • Combustion of fuels directly consumed in process and transportation steps. • Combustion of fuels and transmission losses to produce and deliver purchased electricity.

[68] Boguski, T.K.(2010). Life cycle carbon footprint of the National Geographic magazine. *The International Journal of Life Cycle Assessment*, *15*(7), 635-643.

	• Precombustion of GHG emissions. • GHG emissions from unit processes that emit non-fuel-related GHGs.
Results	The study showed that the life cycle of the National Geographic magazine produces about 0,82kg of carbon dioxide equivalents per life cycle of the average magazine. 70% of the impact is due to the coated magazine paper; on the other hand, printing operations, solvent manufacture for inks, and transportation by the printer account for about 26% of the total GWP. Total GWP for magazines made with paper containing 0%, 5% and 10% recycled fiber content is: 2384, 2370 and 2357 kg CO2 equivalent, respectively. The use of recycled fibers is not significant if the environmental GHG are analysed.
Main conclusions	Opportunities for improving the carbon footprint of a magazine are more likely to be found within the manufacturing and printing of the paper.

Item 2	**Information**
Title	**Screening environmental life cycle assessment of printed, web based and tablet e-paper newspaper**[69]
Authors	Åsa Moberg, Martin Johansson, Göran Finnveden and Alex Jonsson
Year	2007
Type of publication	LCA Screening
Scope	The aim of the study is to describe the potential environmental impacts of three studied product systems: printed newspaper, web based newspaper and tablet e-paper newspaper*
FU	The consumption of newspaper during one year by one unique reader: 131 newspaper/year
System boundaries	Newsprint DIP containing, transportation of paper (train, lorry), pre-press (electricity, gumming, offset plate, plate developer), editorial work (electricity), printing (electricity, ink, isopropanol, cleaning agent, water), distribution (transport, diesel), reading, incineration with energy recovery, landfill, recycling of fibre
Assumptions	<u>Transportation of paper</u>: assumed distances (400km by truck and 1600km by train), European average. <u>Distribution</u>: assumed vehicle van 3.5tonnes, payload 2 tonnes and local use. Data from an internal STFI-Packforsk database gave estimations on fuel consumption for urban distribution (0.0041 litre fuel/newspaper). <u>Recycled fibre and waste management of post-consumer waste paper</u>: the paper waste streams, based on European statistics on waste paper recovery for 2005 (60% recycling, 30% landfill, 10% incineration). Recycling of newspaper was modelled as closed-loop. Landfill was modelled without energy recovery. Incineration was modelled with energy recovery.
Data sources and quality	• Europe (assumption: the content production, the production of paper, the use phase and the waste management are taking place in Europe) and Sweden. • Data from established databases, such as Ecoinvent 1.2, and internal databases at STFI-Packforsk were used. • Manufacturing: European electricity mix • End-of-life: European waste flows. The time boundary for landfilling of waste paper was set to 100
Impact assessment categories/ methods	• Resources used were characterised using: • Abiotic Depletion Potential • Exergy in resources (abiotic resources and biotic resources) • Energy in resources (non-renewable/abiotic, renewable and total resources)

69 Moberg, Å., Johansson, M., Finnveden, G., & Jonsson, A. (2007). Screening environmental life cycle assessment of printed, web based and tablet e-paper newspaper.

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- Non-toxicological impacts were characterised using:
- Acidification Potential
- Eutrophication Potential
- Global Warming Potential, no biotic CO2 (GWP 100 years)
- Ozone Layer Depletion Potential , steady state
- Photochem. Ozone Creation Potential
- Toxicological impacts were characterised using:
- Freshwater Aquatic Ecotoxicity Potential
- Human Toxicity Potential
- Marine Aquatic Ecotoxicity Potential
- Terrestric Ecotoxicity Potential

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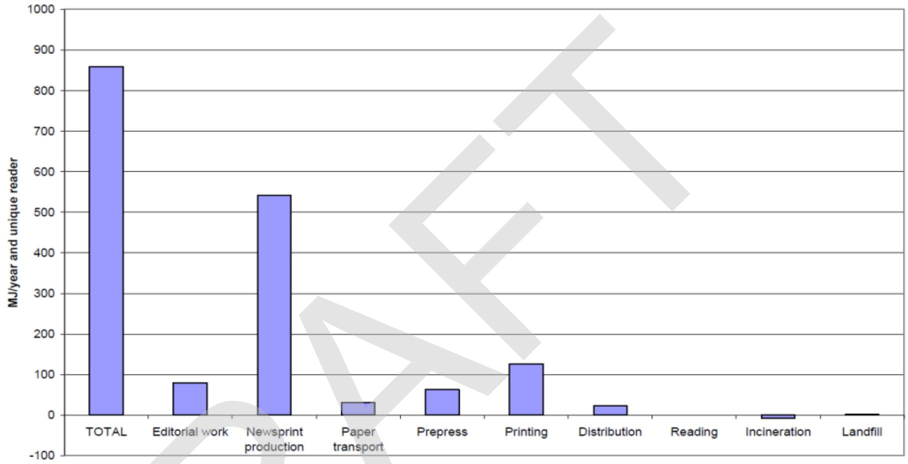
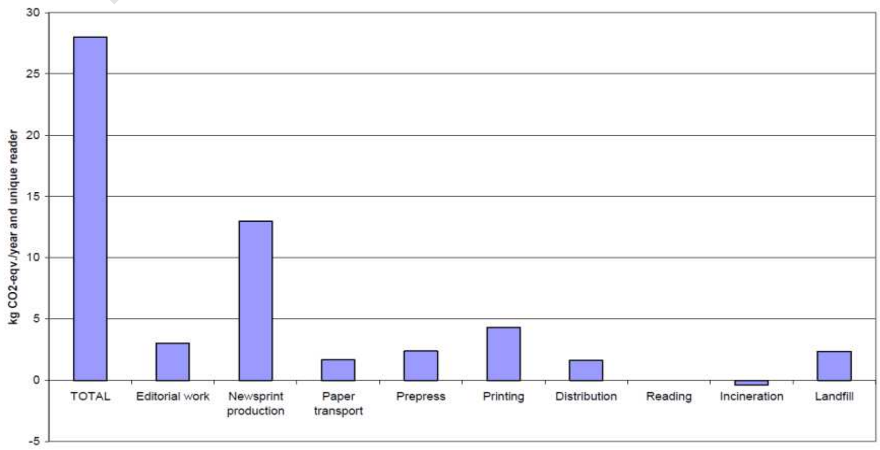
<tr><td>Results</td><td>

The newsprint production was the main activity concerning resource use, followed by the printing of the newspaper.



Total energy used for different parts of printed newspaper life cycle

Concerning the non-toxicological impact categories (global warming, acidification, eutrophication, ozone layer depletion and photooxidant formation) the newsprint production gave rise to the largest impacts in all cases. Printing had the second largest values in all impact categories except the ozone depletion, where distribution and printing resulted in similar values.
The global warming potential of the one year consumption of a printed newspaper was 28 kg CO2-eqv./year.



Global warming potential for different parts of printed newspaper life cycle

For all four toxicological impact categories the result showed that newsprint production gave rise to the highest potential impact. Second was printing for terrestric ecotoxicity and human

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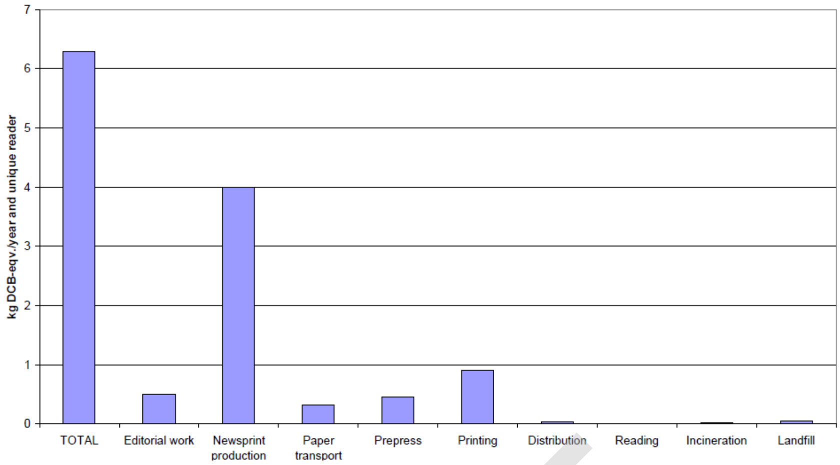
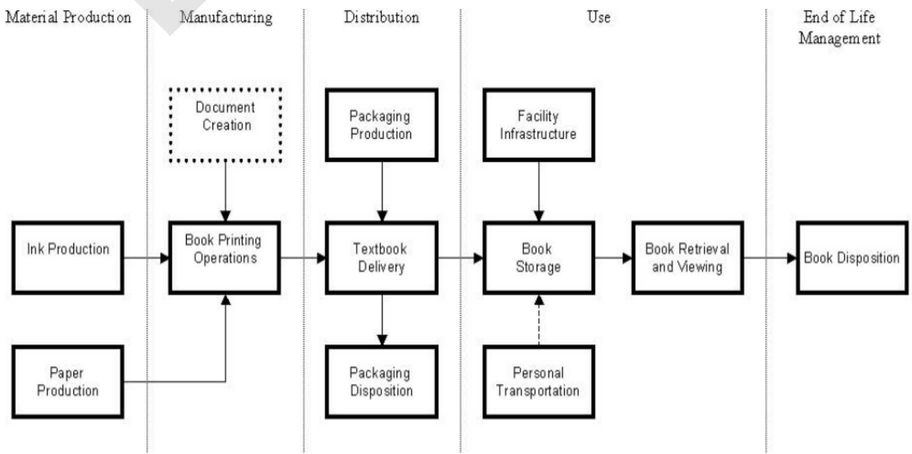
	toxicity. In the freshwater and marine aquatic ecotoxicity impact categories several activities had similar values. Emissions from distribution were lacking to a great extent concerning toxicity.  Human toxicity potential for different parts of printed newspaper life cycle
Main conclusions	The main environmental impact of the printed newspaper was caused by the paper (30-70% of the total environmental impact).

*Only the information about printed newspaper is included in the sheet.

Item 3	**Information**
Title	**Printed Scholarly Books and E-book Reading Devices: A Comparative LCA of Two Book Options**[70]
Authors	Greeg L. Kozak, Gregory A. Keoleian
Year	2003
Type of publication	ISO 14040 LCA method
Scope	Two different book options: electronic and print*
FU	The function is defined as the actual process of a college student reading 40 scholarly e-books one time using a dedicated e-book reading device. Printed Scholarly Book: Forty 500 page, 7'' x 10'' scholarly books
System boundaries	

[70] Kozak, G.L., & Keolelan, G.A. (2003, May). Printed scholarly books and e-book reading devices: a comparative life cycle assessment of two book options. In *Electronics and the Environment, 2003. IEEE International Symposium on* (pp. 291-296). IEEE.

Assumptions	The document creation and publishing has been excluded from this analysis. Raw materials The user must purchase one scholarly book per class (40 books over 4 years). The average scholarly book has the following attributes: • 500 pages in length > Standard-sized 7” x IO” high-end print run with a basis weight of 60 pounds. • 1” (top and bottom) and 1.25” (left and right) margins with a font size of 10. End-of-life After four years, the user decides to retain rather than resell or dispose of the purchased books. Thus, there is only one user per book and no burdens associated with disposal.
Data sources and quality	LCI data were collected from both primary and secondary sources. Primary data includes data that is directly accessible, plant-specific, and/or measurable from the field. Secondary data, on the other hand, includes data from literature resources or other LCAs, but may be applicable to the product of interest. Data was also obtained through visits to retail establishments and phone interviews with representatives of book/e-book manufacturers, distributors, and retailers.
Impact assessment categories/ methods	• Global warming • Ozone depletion • Acidification
Results	• Global warming: 218 kg CO_2 eq. The conventional book system global warming indicators are driven by the material production and manufacturing stages, which contribute approximately 45% and 30% of the total, respectively. • Ozone depletion: 1,04E-06 kg CFC11 eq. The conventional book system ozone depletion results are driven by the manufacturing stage, which contributes approximately 78% of the total. • Acidification: 1,09 kg SO_2 eq. Conventional book system acidification results are driven by material production and the manufacturing stage, which contribute approximately 45% and 28% of the total, respectively.
Main conclusions	For the conventional book system, LCI results were largely driven by three factors: (1) textbook paper production, (2) the relatively large amount of electricity consumed during book printing operations, and (3) personal transportation. The conventional book system was very sensitive to the number of users per book.

*Only the information about printed book is included in the sheet.

Item 4	**Information**
Title	**The Environmental Impact of Getting the News. A Comparison of On-Line, Television, and Newspaper Information Delivery**[71]
Authors	Inge Reichart and Roland Hischier
Year	2002
Type of publication	LCA- Comparison of different products.
Scope	Quantify the environmental impact of reading the daily news in printed and on-line newspaper and watching it on TV*
FU	1. Reading or watching a single news item: 250 cm2 of newspaper. 2. Reading or watching the daily news entirely: 100g – 280g. Total mass of the newspaper is adjusted according the consideration of 2,3 readers on average per newspaper.
System boundaries	Cradle to grave. Transportation processes and distribution to customers are included in the system boundary.
Data sources and quality	Data information from paper manufacturers complemented with standard LCA inventory data.

[71] Reichart, I. (2002). The environmental impact of getting the news. Journal of Industrial Ecology, 6(3-4), 185-200.

Impact assessment categories/ methods	Two recognized assessment methods: environmental scarcity applicable to Switzerland and Eco-Indicator 99 method applicable to Europe. First method: energy consumption and its related to air emissions and also some emissions to water and land are evaluated. The second method includes many environmental problems (ecotoxicity, human toxicity, land use, etc.).
Results	Paper production has the higher environmental contribution of newspaper impact. Environmental impact for the production phase of newspaper life cycle

*Only the information about printed Newspaper is included in the sheet.

Item 5	**Information**
Title	**Carbon footprint of print products**[72]
Authors	Nors M., Behm K., Dahlbo H., Pajula T., Pihkola H., Viluksela P., Wessman H.
Year	2009
Type of publication	The carbon footprint of print products was calculated through the whole life-cycle. Also a LCA was conducted based on newly gathered life-cycle inventory data.
Scope	• Finnish newspaper, coldset web offset printed • Finnish magazine, heatset we offset printed • Electrophotographic printed product
FU	The most common functional unit, one tone of printed products, has been used in many studies. Other possible functional units are square meters of printed products and tones of paper consumed.
System boundaries	For Carbon Footprint Case Studies: cradle to grave: pulp and paper manufacturing (including harvesting and raw material manufacturing), print manufacturing, distribution. Whole life cycle products: from forest to end-use and disposal or recycling.
Assumptions	Cut-off allocation method was applied in the calculations. Raw materials inputs or process stages that represent less than 1% of the total weight/or impact of the product, can be excluded from the calculations. Carbon footprint-case studies: the carbon sequestration in forests was excluded from the case studies. • Finnish newspaper: the assumption that 79% of the newspaper is recycled, 16% are disposed to landfill, and 5% are incinerated. No emissions are allocated to recycled fibre (and do not have a contribution to the overall carbon footprint). • Printed magazine: 83% of the magazines are recycled, 16% is disposed to a

[72] Nors M., Behm K., Dahlbo H., Pajula T., Pihkola H., Viluksela P., Wessman H. (2009). Carbon footprint of print products. *Results from the LEADER project (Part 1).*

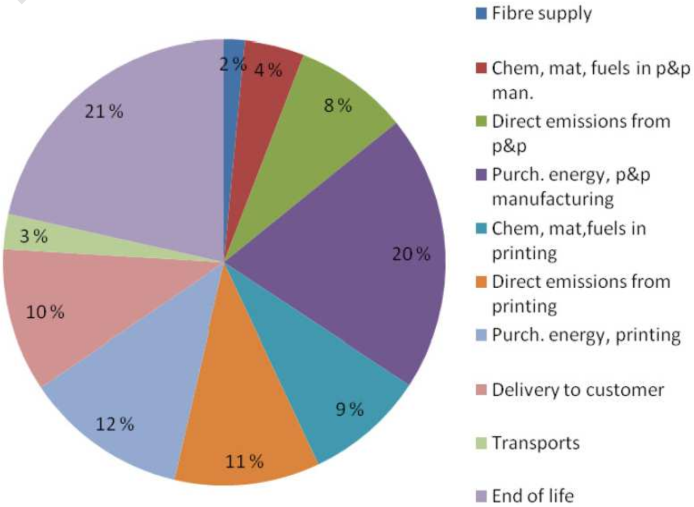
	landfill, and 1% is incinerated.
Data sources and quality	Annual level input and output data was collected from several printing companies participating in the research. Data was collected from the years 2006 and 2007.
Impact assessment categories/ methods	Main interest: energy, material and emission flows in the print products value chain. Life Cycle impact assessment (DAIA 1998): • Climate change • Acidification • Eutrophication • Summer smog • Oxygen depletion
Results	**Finnish newspaper:** The carbon footprint for one ton of printed newspaper varies between 750-940 kg CO2 equivalents. Total carbon footprint per one newspaper: 190g, 152g or 150g depending on the landfill emissions considered. In percentage, the 39% of CO2 emissions are related with purchased energy paper mills, followed by end of life. Fossil fuels for pulps and paper making have also an important contribution: 14%. Most emissions occur from production of purchased energy and raw material manufacturing; improving energy efficiency and use of materials are the most efficient ways to reduce the carbon footprint. If the end of life phase was left out of the calculation, the carbon footprint was approximately 20% smaller. **Printed magazine:** The carbon footprint for one ton of printed magazines varies between 1140-1350kg CO2 eq, 190g-230 g CO2eq per one magazine. 27% of the impact is related with purchased energy printing, fossil fuels for pulp and paper making and end of life have a contribution of 16%. When the end-use phase was left out of the calculation and the life cycle was followed from cradle to customer, the carbon footprint decreases by 16% approximately. **Comparison**: the carbon footprint is different due to the different paper used in the two cases, and the printing method used (in newspaper was coldset offset and in the magazine heatset offset). Other differences are the transport method used, and the percentage of waste management. Life Cycle assessment, electrophotographic printed product: the carbon footprint for one tone of printed publication varies between 1010-1500kg CO2 eq., 200- 300g per one product. 34% of the carbon footprint is caused by fossil fuels used for pulp, paper and board production, chemicals, materials and fuels have an impact of 24%. • The main contributor to acidification is paper and board production, followed by purchased energy for printing. • Paper and board production has also the biggest contribution to eutrophication and oxygen depletion, near 90%. • For summer smog, the main contributor is paper and board production, followed by transport and purchased energy for printing.
Main conclusions	The carbon footprint of newspapers would be over doubled, if all newspaper would be disposed to landfills instead of recycled or burned. Incineration would seem to be the most favourable option, based on the carbon footprint. However, there are many other issues that would be affected, as use of resources.

Item 6	**Information**
Title	**Carbon footprint and environmental impacts of print products from cradle to grave-Heatset offset printed magazine**[73]
Authors	Hanna Pihkola, Minna Nors, Marjukka Kujanpää, Tuomas Helin, Merja Kariniemi, Tiina Pajula, Helena Dahlbo & Sirkka Koskela
Year	2010

[73] Pihkola, H., Nors, M., Kujanpää, M., Helin, T., Kariniemi, M., Pajula, T., ... & Koskela, S. (2010). Carbon footprint and environmental impacts of print products from cradle to grave. *Results from the LEADER project (Part 1). Espoo.*

Type of publication	LCA has been conducted for a newspaper, magazine, and electrophotography printed photobook. Carbon footprint of an advertisement leaflet and hardcover book has been calculated
Scope	The scope is focused on printed media products: newspapers, magazines, books and advertisements. Five case studies: heatset offset printed magazine, coldset offset printed newspaper, sheetfet offset printed book, electrophotography printed photobook, rotogravure printed advertisement leaflet.
FU	1000kg of products, unless otherwise stated.
System boundaries	Cradle-to-grave: from raw materials manufacturing until the disposal of the read magazine. Magazine editorial work was not included in the study.

Assumptions	• Print product: weekly magazine, 56 and 86 pages, 22 x 30 cm
	• Printing: Heatset web offset, 4-colour printed
	• Paper:
	  o Cover: 150 gsm coated fine paper
	  o Inner sheets: 80 gsm LWC paper
	• Circulation: 70 000–80 000
	• Yearly subscription: 48 issues
	• Weight and dryness :170 g and 250 g/issue, dryness 96%
	• Geographical aspects: Paper production, printing, delivery and disposal in Finland
	• Distribution: Delivery to home
	• End-use of product:
	  o Recycling 83%
	  o Landfill 16%
	  o Incineration 1%

Impact assessment categories/ methods	Impact categories assessed in newspaper and magazine (following the ReCiPe methodology): climate change, terrestrial acidification, freshwater eutrophication, photochemical oxidant formation, particulate matter formation, mineral resource depletion and fossil resource depletion.
Results	**Carbon footprint results** If a landfill with higher gas collection efficiency and lower landfill gas emissions is considered, the carbon footprint of one tonne of magazines would be 1351 kg CO2eq, about 11% smaller than in a landfill with higher emissions. In the case of open-loop allocation, it is considered that 40% of the carbon footprint is transferred to the other product system using the recycled fibre as an input for new products. For the best case scenario, the cradle-to-grave carbon footprint for one tonne of magazine is 905 kg CO2eq. The biggest share (21%) of the greenhouse gas emissions originates from landfills. 20% of the emissions are generated by the production of the purchased electricity that is used in paper mills. Fossil fuel combustion at pulp and paper mills (direct emissions) contributes 8% of the total greenhouse gas emissions. Printing in total (direct emissions from printing, production of purchased electricity and raw material manufacturing) accounts for 32% of the total carbon footprint.  Carbon footprint of a magazine

	Life cycle impact assessment results The fibre supply phase has a little impact compared to the other phases. The end-of-life phase may have a significant contribution to the climate change impacts, assuming a high paper degradation rate and low landfill gas collection rate. Results of life Cycle Environmental impact assessment for one tone of magazines The majority of the impacts in the categories climate change, terrestrial acidification and particulate matter formation are due to energy and fuel use in the system. Freshwater eutrophication impacts are caused by the phosphorus emissions from pulp and paper production and the printing ink manufacturing chain. The printing phase can be divided into three life cycle phases. As in pulp and paper production, most of the impacts are due to energy and fuel use. The freshwater eutrophication impacts of chemicals and materials manufacturing and acquisition originate from phosphorus emissions to water from the manufacturing chain of the partly biobased printing ink used in the product system.

Item 7	**Information**
Title	**Carbon footprint and environmental impacts of print products from cradle to grave- Coldset offset printed newspaper**[73]
Authors	Hanna Pihkola, Minna Nors, Marjukka Kujanpää, Tuomas Helin, Merja Kariniemi, Tiina Pajula, Helena Dahlbo & Sirkka Koskela
Year	2010
Type of publication	LCA has been conducted for a newspaper, magazine, and electrophotography printed photobook. Carbon footprint of an advertisement leaflet and hardcover book has been calculated
Scope	The scope is focused on printed media products: newspapers, magazines, books and advertisements. Five case studies: heatset offset printed magazine, coldset offset printed newspaper, sheetfet offset printed book, electrophotography printed photobook, rotogravure printed advertisement leaflet.
FU	1000 kg of newspapers. Carbon footprints were calculated for one newspaper and for a yearly subscription of newspapers based on the assumed weight of the product
System boundaries	Cradle-to-grave approach: from raw materials manufacturing until the disposal of the read newspaper.
Assumptions	• Print product: Newspaper, approx. 48 pages (broadsheet)

	• Printing: Coldset web offset (CSWO), 4-colour printed
	• Paper: 40 gsm newsprint; 60% DIP, 35% TMP, 5% fillers
	• Circulation: Less than 80 000
	• Yearly subscription: 356 issues
	• Weight and dryness: 200 g/piece, 88%
	• Geographical aspects: Paper production, printing, delivery and disposal in Finland
	• Distribution: Direct to home at night
	• End-use of product:
	  o Recycling 79%
	  o Landfill 16%
	  o Incineration 5%

Impact assessment categories/ methods	Impact categories assessed in newspaper and magazine (following the ReCiPe methodology): climate change, terrestrial acidification, freshwater eutrophication, photochemical oxidant formation, particulate matter formation, mineral resource depletion and fossil resource depletion.
Results	**Carbon footprint results** The (cradle to grave) carbon footprint of newspaper is 1066 kg CO2eq/tonne of newspapers: more than one fourth of the emissions come from the production of the purchased electricity used by paper mills, fossil fuel combustion at pulp and paper mills contributes 17%, delivery to customer accounts for about 16% of the total greenhouse gas emissions. Additionally, emissions from landfills have a big impact on the carbon footprint of a newspaper. Carbon footprint varies depending on the landfill assumptions, reducing the total carbon footprint in 16%. **Life cycle impact assessment results** The life cycle phases of pulp and paper production, printing and transport are responsible for the majority of impacts potentially produced by the life cycle of newspapers. The end-of-life phase may have a significant contribution to climate change impacts, if assuming a high paper degradation rate and low landfill gas collection rate The introduction of green grid electricity decreases impacts in all impact categories except for freshwater eutrophication. Results of life cycle environmental impact assessment for one tone of newspapers

Item 8	**Information**
Title	**Carbon footprint and environmental impacts of print products from cradle to grave- Sheetfet offset printed book**[73]
Authors	Hanna Pihkola, Minna Nors, Marjukka Kujanpää, Tuomas Helin, Merja Kariniemi, Tiina Pajula, Helena Dahlbo & Sirkka Koskela
Year	2010
Type of publication	LCA has been conducted for a newspaper, magazine, and electrophotography printed photobook. Carbon footprint of an advertisement leaflet and hardcover book has been calculated

Scope	The scope is focused on printed media products: newspapers, magazines, books and advertisements. Five case studies: heatset offset printed magazine, coldset offset printed newspaper, sheetfet offset printed book, electrophotography printed photobook, rotogravure printed advertisement leaflet.
FU	One book
System boundaries	Cradle-to-retailer: end of life was excluded from examination.
Assumptions	• Print product: o Sheetfed offset printed book, hardcover, sewn o Components: Cover, inner sheets, end papers, jacket o Format: 205 mm x 135 mm o 300 pages • Printing: Sheetfed offset (SFO) • Paper: o Cover: 1300 gsm board (100% defibered pulp from board and unbleached paper) + 150 gsm coated fine paper (11% pine kraft pulp, 34% birch kraft pulp, 50% pigments, 5% binders) o Inner sheets: 90 gsm uncoated fine paper (21% pine kraft pulp, 50% birch kraft pulp, 25% fillers,4% binders) o End papers: 150 gsm uncoated fine paper (21% pine kraft pulp, 50% birch kraft pulp, 25% fillers,4% binders) • Jacket: 150 gsm coated fine paper, water varnish • Weight and dryness: 500 g / book, dryness 96% • Geographical aspects: Paper production, printing and delivery in Finland • Distribution: Transportation to retailers included, transportation to customer excluded • Storage at home: 50 and 100 years
Impact assessment categories/ methods	For the calculation of carbon footprint, all the GHG emissions mentioned by IPCC and in PAS 2050 are considered.
Results	**Carbon footprint results** The cradle-to-retailer carbon footprint of a hardcover book is 1160 g CO2eq, equalling 1.2 kg CO2eq/book. Manufacturing of papers used in the book (inner sheets, cover and end papers) accounts for a total share of 51% and the printing phase for about 46% (production of purchased energy for printing and manufacturing of chemicals, materials and fuels) of the total cradle-to-customer greenhouse gas emissions.

Item 9	**Information**
Title	**Carbon footprint and environmental impacts of print products from cradle to grave-Electrophotography printed photobook**[73]
Authors	Hanna Pihkola, Minna Nors, Marjukka Kujanpää, Tuomas Helin, Merja Kariniemi, Tiina Pajula, Helena Dahlbo & Sirkka Koskela
Year	2010
Type of publication	LCA has been conducted for a newspaper, magazine, and electrophotography printed photobook. Carbon footprint of an advertisement leaflet and hardcover book has been calculated
Scope	The scope is focused on printed media products: newspapers, magazines, books and advertisements. Five case studies: newspapers, magazines, books and advertisements. Five case studies: heatset offset printed magazine, coldset offset printed newspaper, sheetfet offset printed book, electrophotography printed photobook, rotogravure printed advertisement leaflet.
FU	1000kg of photobooks
System boundaries	Cradle-to-customer approach: from raw material extraction until the customer receives the pthotobook in the mail.

Assumptions	• Print product: Digitally printed photobook, hardcover, glue bound, size A4 • Printing: Electrophotography (EP), 4-colour printed • Paper: o Cover: 1300 gsm board (100 % defibered pulp from board and unbleached paper) + 150 gsm coated fine paper + laminate o Inner sheets: 150 gsm coated fine paper (11% pine kraft pulp, 34% birch kraft pulp, 50% pigments, 5% binders) o End papers: 150 gsm uncoated fine paper (21% pine kraft pulp, 50% birch kraft pulp, 25% fillers, 4% binders) • Weight and dryness: 500 g (64 pages) and 800 g (128 pages)/book, dryness 96% • Packaging: Corrugated board box 120 g, plastic wrapping 14 g • Geographical aspects: Paper production, printing and delivery in Finland • Distribution: Delivery to home • Storage at home: 50 years
Impact assessment categories/ methods	Impact categories assessed in newspaper and magazine (following the ReCiPe methodology): climate change, terrestrial acidification, freshwater eutrophication, photochemical oxidant formation, particulate matter formation, mineral resource depletion, fossil resource depletion, human toxicity, terrestrial ecotoxicity and freshwater ecotoxicity impacts.
Results	**Carbon footprint results** The cradle-to-customer carbon footprint of a tonne of photobooks is 2013 kg CO2eq: the paper used in the book has a total share of 44%, delivery to customer produces roughly 20% of greenhouse gas emissions, and the printing phase accounts for about 21%. **Life cycle impact assessment results** Photobook materials, packaging materials and delivery to consumer phases are responsible for the majority of impacts potentially produced over the life cycle of a photobook. The use of small vehicles in delivering small amounts of photobooks is reflected in the relatively high impacts caused by exhaust gas emissions. x Results of life cycle environmental impact assessment for one tone of newspapers The majority of the impacts in the categories climate change, terrestrial acidification and particulate matter formation are due to energy and fuel use in the system. Freshwater eutrophication impacts are caused by the phosphorus emissions from paper manufacturing and the plastic wrapping manufacturing chain.

Item 10	**Information**
Title	**Carbon footprint and environmental impacts of print products from cradle to grave-Rotogravure printed advertisement leaflet**[73]
Authors	Hanna Pihkola, Minna Nors, Marjukka Kujanpää, Tuomas Helin, Merja Kariniemi, Tiina Pajula, Helena Dahlbo & Sirkka Koskela

Year	2010
Type of publication	LCA has been conducted for a newspaper, magazine, and electrophotography printed photobook. Carbon footprint of an advertisement leaflet and hardcover book has been calculated
Scope	The scope is focused on printed media products: newspapers, magazines, books and advertisements. Five case studies: heatset offset printed magazine, coldset offset printed newspaper, sheetfet offset printed book, electrophotography printed photobook, rotogravure printed advertisement leaflet.
FU	1000 kg of advertisements delivered to the consumer
System boundaries	Whole life cycle from raw material production to the end-of-life treatment of the paper product.

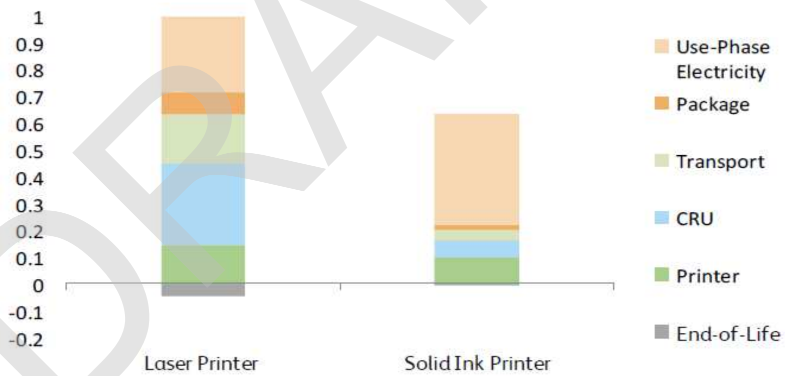
Assumptions	• Print product: Advertisement (unaddressed leaflet)
	• Printing: Gravure 4-colour printing
	• Paper:
	  o 52 gsm SC paper
	  o 49% soft ground wood, 22% softwood kraft pulp, 29% fillers
	• Weight: 20 g/piece, dryness 96%
	• Size: 4 pages of A4, folded (40 cm x 50 cm)
	• Geographical aspects: Paper production, printing, delivery and disposal in Finland
	• Distribution: Directly to home by mail
	• End-use of product:
	  o Recycling 83%
	  o Landfill 14%
	  o Incineration 3%

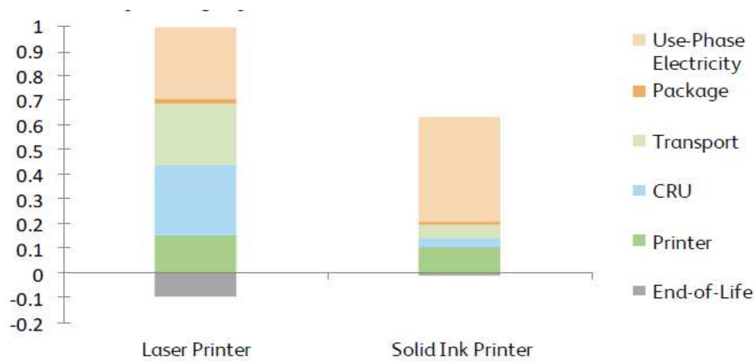
Impact assessment categories/ methods	For the calculation of carbon footprint, all the GHG emissions mentioned by IPCC and in PAS 2050 are considered.
Results	**Carbon footprint results** The life cycle GHG emissions are around 1630 kg CO2eq/tonne per product for the studied gravure printed advertisement case. Pulp and paper manufacturing contributes more than 50% (900 kg CO2eq) of the life cycle GHG emissions, printing activities 20% (320 kg CO2eq), and delivery to customer and end of life around 10% each (160 kg CO2eq each). Different aspects influence in the GHG emissions of printing houses: The paper used for printing has the most significant impact on the gravure printed product's carbon footprint. In actual printing activities, the production of the energy consumed in the process is responsible for 60–70% of the GHG emissions from the printing phase. Thus it is more important to focus on energy efficiency than the selection of chemicals or inks.

Item 11	**Information**
Title	**Life Cycle Assessment of a Solid Ink Printer Compared with a Colour Laser Printer**[74]
Authors	Meagan Bozeman, Victoria DeYoung, Wendi Latko, Chris Schafer
Year	2010
Type of publication	LCA are made according to the ISO 14040 standard.
Scope	This study is intended to quantify the differences in environmental impact between current models of two printing technologies: solid ink and conventional colour laser.
FU	360,000 prints: 7,500 prints per month over a four year life
System	The study includes the use of the device, the packaging and transport of the consumable items

[74] Meagan Bozeman, Victoria DeYoung, Wendi Latko, Chris Schafer (2010). Life Cycle Assessment of a Solid Ink Printer Compared with a Colour Laser Printer.

<table>
<tr><td>boundaries</td><td>and their disposal.

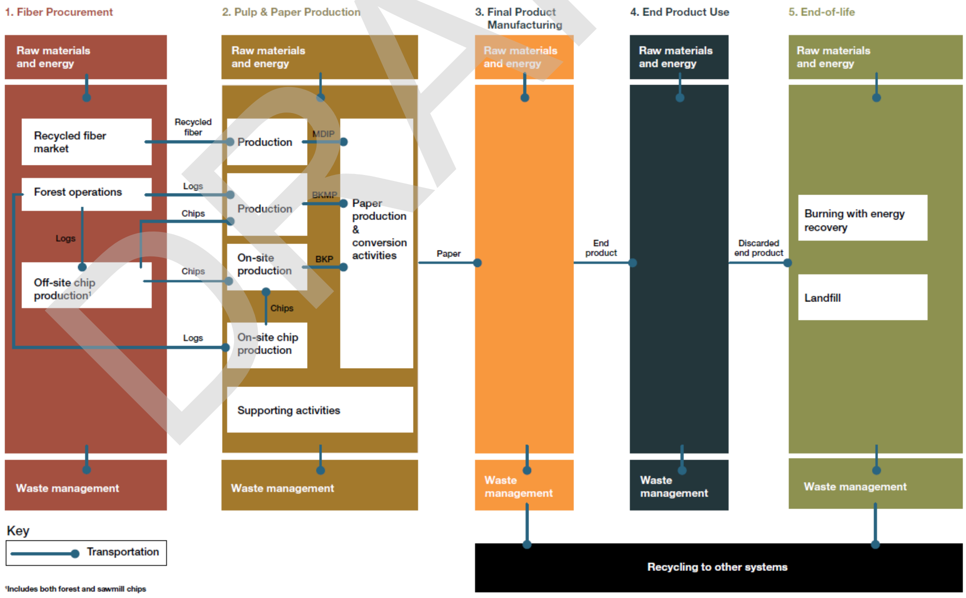
• The laser consumables were: print cartridges, fusers, transfer kits, and toner collection bottles.
• The solid ink printer consumables were: ink and drum maintenance kits.
The impact associated with the manufacture, transport and disposal of the paper were excluded from the analysis.</td></tr>
<tr><td>Assumptions</td><td>• The solid ink printer is manufactured in Penang, Malaysia.
• The laser printer is manufactured in China.
• The print cartridge's was assumed to be manufactured in Tokyo.
• Materials extraction was assumed to occur 100 miles from the parts manufacturing site. The parts manufacturing site was assumed to be 100 miles from the final assembly site.
• It was assumed that 25% of laser consumables were recycled locally.
• It was assumed that ink consumables were not recycled.
• Corrugated packaging for both products was assumed to be 60% recycled content and 40% virgin content.
• It was assumed that 66% of the packaging materials were recycled</td></tr>
<tr><td>Data sources and quality</td><td>Data from manufacturers was used when available. In other cases, data from the SimaPro databases was used.</td></tr>
<tr><td>Impact assessment categories/ methods</td><td>• Cumulative Energy Demand
• Global Warming Potential
• Inventory of post-consumer consumables waste</td></tr>
<tr><td>Results</td><td>Use phase is the most contributor part for both impact categories, for solid ink printer. For laser printer, the Customer Replacement Unit has an important environmental impact contribution.


Relative Contribution of cumulative Energy Demand by Category


Relative Contribution of Global Warming Potential by Category</td></tr>
<tr><td>Main conclusions</td><td>Solid ink printer creates approximately 90% less post-consumer waste than the laser printer. Moreover, solid ink printer was founded to have reduced Cumulative Energy Demand and Global Warming Potential compared to the colour laser printer (30%).</td></tr>
</table>

Item 12	**Information**
Title	**Streamlined LCA of Soy-Based Ink Printing**[75]
Authors	Duane A. Tolle, David P. Evers, Bruce W. Vigon and John J. Sheehan
Year	2000
Type of publication	LCA, following the applicable guidelines described by ISO 14041, in conjunction with the U.S. EPA's (1992) document on Life Cycle Assessment: Inventory Guidelines and Principles.
Scope	The aim of the study was to document the life cycle environmental impact characteristics associated with the use of soy-based inks by evaluating a soy-based ink formula. The scope of this project was to select a typical sheetfed printing system using soy-based ink as a baseline and conduct a streamlined Life Cycle Inventory (LCI) and LCIA to benchmark the life cycle environmental characteristics of this system.
FU	Quantity of inventory items required for printing 645 m^2 (one million in^2) of substrate at 100% coverage (opacity).
System boundaries	The following modules were not included in the LCA: packaging for the printed product, manufacture of paper used for printing, distribution/ transportation of printed matter, burdens contributed by capital equipment and/or by human operators, colour pigments other than black.
Impact assessment categories/ methods	• Smog Creation Potential • Ozone Depletion Potential • Acidification (Acid Rain) Potential • Global Warming Potential • Eutrophication Potential • Carcinogenicity Potential • Human Inhalation Toxicity Potential • Terrestrial (Wildlife) Toxicity Potential • Aquatic (Fish) Toxicity Potential • Solid Waste Land Use Potential • Natural Resource Depletion Potential • PM10 Effect Potential • Water Use Effect Potential
Results	The Soybean Agriculture module contributes 72%, 98%, and 94% of the normalized impact score, respectively, for Eutrophication Potential, Aquatic (Fish) Toxicity Potential, and Water Use Effect Potential. Soybean agriculture is the source of all of the impact potential for these three impact categories included in the Soybean Oil Solvent in Varnish module. The Nuclear Power Generation module contributes 52% of the normalized impact score for Natural Resource Depletion Potential. The tall oil rosin Manufacture module contributes 100% of the normalized impact score for Ozone Depletion Potential. Changes in the percentages of different components in the generic sheetfed lithographic ink formula could reduce the impact score for some impact categories selected; nevertheless it may slightly increase the score for other impact categories: - Reducing the quantity of tall oil rosin used in the formula by replacing it with soy oil could reduce the Ozone Depletion Potential, but it would be likely to increase the impact scores for Eutrophication Potential, Aquatic (Fish) Toxicity Potential, and Water Use Effect Potential (associated with Soybean Agriculture).
Main conclusions	Soybean Agriculture life cycle makes a substantial contribution to the impact potential for three impact categories: Eutrophication Potential, Aquatic (Fish) Toxicity Potential, and Water Use Effect Potential.

[75] Tolle, D.A., Evers, D.P., Vigon, B.W. & Sheehan, J.J.(2000). Streamlined LCA of soy-based ink printing. *The International Journal of Life Cycle Assessment*, *5*(6), 374.

<table>
<tr><td colspan="2">Note: this LCA study has not been considered for average values since this is for USA.</td></tr>
<tr><td>Item 13</td><td>Information</td></tr>
<tr><td>Title</td><td>Printing & Writing Papers. Life-Cycle Assessment Summary Report[76]</td></tr>
<tr><td>Authors</td><td>American Forest & Paper Association</td></tr>
<tr><td>Year</td><td>-</td></tr>
<tr><td>Type of publication</td><td>LCA</td></tr>
<tr><td>Scope</td><td>Evaluate the environmental impact of four North American grades of printing and writing papers:
1) a ream of office paper made of uncoated freesheet;
2) a telephone directory made primarily of uncoated mechanical paper;
3) a catalogue made primarily of coated freesheet;
4) a magazine made primarily of coated mechanical paper.
The scope of this study was a “cradle-to-grave” LCA of four 2006-07 North American industry-average paper products.</td></tr>
<tr><td>FU</td><td>Office paper: The production in the U.S. and Canada, delivery to an average U.S. customer, use and final disposal or recovery of one standard ream of office paper.
Catalogue: The production in the U.S. and Canada, delivery to an average U.S. customer, use and final disposal of standard catalog
Telephone directory: The production in the U.S. and Canada, delivery to an average U.S. customer, use and final disposal of a standard telephone directory
Magazine: The production in the U.S. and Canada, delivery to an average U.S. customer, use and final disposal of a standard magazine</td></tr>
<tr><td>System boundaries</td><td>Cradle-to-grave approach: from raw material extraction to final disposal of paper products. Transport is also included.

</td></tr>
<tr><td>Assumptions</td><td>Office paper: 4% of the fibre needed to produce the office paper comes from recovered fibre, primarily market deinked pulp (MDIP). 71,8% of used office paper is recovered for recycling, 5,2% is burned for energy and 23% is sent to landfills.
Catalogue: 5% of the fibre comes from recovered fibres, primarily MDIP and old newspapers. 32,7% of used catalogue is recovered for recycling, 12,5% is burned for energy and 54,8% is sent to landfills.
Telephone directory: 20% of the fibres come from recovered fibre. 19,1% is recovered for recycling, 15% is burned for energy, and 65,9% is sent to landfill.
Magazine: 2% of fibre from recovered fibre. 38,6% of used magazines is recovered for recycling, 11,4% is burned for energy and 50% is sent to landfill.</td></tr>
<tr><td>Data sources</td><td>The data was collected from 72 mills in the U.S. and Canada, which produced 22.4 million short</td></tr>
</table>

[76] American Forest & Paper Association. Printing & Writing Papers. Life-Cycle Assessment Summary Report

and quality	tons of printing and writing papers in 2006-07: 77 percent of all North American production within that time period. Data are from 2006-2007
Impact assessment categories/ methods	Global warming, acidification, respiratory effects, eutrophication, stratospheric ozone depletion, smog and fossil fuel depletion. Life cycle energy demand, water use and solid waste generation.
Results	**Office paper**: the uncoated freesheet production life-cycle stage is the largest contributor to all impact categories except for eutrophication, for which the largest contribution is the EoL. Truck transportation of the fibre is also a significant contributor to acidification. Fibre procurement (transportation and fuel usage) has a significant effect on smog potential and fossil fuel depletion. Increasing recovery rate from 71% to 85% decreases the carbon footprint by approximately 25%. Eliminating landfill, and replacing with burning and energy recovery, this indicator is reduced by 40%. **Catalogue**: the paper and catalogue production life-cycle stages are the largest contributors to all impact categories except for eutrophication, for which the largest contributor is the paper's EoL. The production of the catalogue also contributes significantly to acidification, respiratory effects, stratospheric ozone depletion, smog and fossil fuel depletion. Increasing recovery from 33% to 50% decreases the carbon footprint by approximately 15%. Replacing landfill by burning reduces the footprint by 40%. **Telephone directory**: the production of the directories is a significant contributor to all impact categories except eutrophication and acidification. The paper life-cycle stage is also an important contributor. Increase in recovery has almost no effect on carbon footprint because the benefits from exporting the burden to subsequent uses and burning with energy recovery are largely compensated by less carbon stored in the system boundary. **Magazines**: production of paper is the life-cycle stage contributing most to all impact categories for magazines except eutrophication and smog. The production of magazines is also an important contributor. Recovery rate increases have almost no effect on carbon footprint because the benefits of exporting the burden are compensated by less carbon stored within the boundary. A cradle-to-gate analysis has been also included: - Uncoated Free: 1,194 kg CO2 eq./ton - Coated Free: 1,469 kg CO2 eq./ton - Uncoated Mechanical: 1,176 kg CO2 eq./ton - Coated Mechanical: 1,393 kg CO2 eq./ton
Main conclusions	The most significant life-cycle impacts for printing and writing papers results from the production of the paper and disposal of used paper at the end-of-life. After fibre, water is the most important renewable raw material used in paper production. It has been shown that electricity consumption and VOC releases associated with printing have important impacts on the results for several indicators. There is an opportunity to improve the quality of the study by collecting specific information for VOCs and industry-average information for both parameters.

Item 14	**Information**
Title	**Life Cycle Analysis in the Printing Industry: A Review**[77]
Authors	Justin Bousquin, Marcos Esterman, Sandra Rothenberd
Year	2011
Type of publication	LCA screening
Scope	Studies related with imaging equipment are studied in this paper (14 studies have been analysed): - 5 printers - 3 cartridges - 2 print products - 2 design methodologies - 2 consumer "calculators"

[77] Bousquin, J., Esterman, M., & Rothenberg, S. (2011, January). Life cycle analysis in the printing industry: A review. In *NIP & Digital Fabrication Conference* (Vol. 2011, No. 2, pp. 709-715). Society for Imaging Science and Technology.

<table>
<tr><td>FU</td><td>Different functional units are used in each LCA study.
Functional units of the studies selected
<table>
<tr><th>Study #</th><th>Product(s)</th><th>Purpose</th><th>Stated functional unit</th></tr>
<tr><td>[1]</td><td>Printer devices</td><td>Internal design tool</td><td>Per image printed. Considers expected life of print system and images printed per month.</td></tr>
<tr><td>[2]</td><td>Solid ink vs. ink jet printer</td><td>Comparative</td><td>25,000 prints/month over a four-year life.</td></tr>
<tr><td>[3]</td><td>Manufactured vs. remanufactured copiers</td><td>Comparative</td><td>12 million copies over a maximum period of 10 years for each life cycle.(1)</td></tr>
<tr><td>[4]</td><td>3,250 imaging devices</td><td>Comparative (End-of-life)</td><td>21.6 tonnes printer waste.</td></tr>
<tr><td>[5]</td><td>Electrophotographic and ink jet printers, copiers and multifunctional devices</td><td>Baseline</td><td>Average daily use pattern (pages/job, number of jobs and idle time, on- and off-mode time).</td></tr>
<tr><td>[6]</td><td>Cartridge remanufacture</td><td>Comparative</td><td>"30,000 copies with 5% average coverage." The duration is 1 year. (2)</td></tr>
<tr><td>[7]</td><td>Cartridge remanufacture</td><td>Comparative</td><td>Printing of 100 usable monochrome one-sided pages. Consistent with Quality Logic study. 6,000 pages in accordance with ISO.(3)</td></tr>
<tr><td>[8]</td><td>Toner</td><td>Baseline</td><td>One metric ton of toner produced - enough to produce an average of 22 million images on A4 with 6% coverage.</td></tr>
<tr><td>[9]</td><td>Magazine</td><td>Baseline</td><td>One magazine, avg weight of 349 g.</td></tr>
<tr><td>[10]</td><td>Flexographic and rotogravure packaging print processes</td><td>Comparative</td><td>Area of imaged plate or printed substrate.</td></tr>
<tr><td>[11]</td><td>No product evaluated</td><td>Design tool development parameters</td><td>Over 5 functional years.(4)</td></tr>
<tr><td>[12]</td><td>Printers (non- specific)</td><td>Design tool</td><td>A unit of information: A4 impression of average area coverage (5-6% per color). 10 million units of information.</td></tr>
<tr><td>[13]</td><td>Personal and office printers</td><td>Cost and CO_2e calculator</td><td>Variable, pages printed per year and printer life.</td></tr>
<tr><td>[14]</td><td>Personal and office printers</td><td>Compare baseline and optimized print scenarios</td><td>Number of images per month; results are annualized.</td></tr>
</table></td></tr>
<tr><td>System boundaries</td><td>Cradle-to-grave process, from the acquisition of the raw materials through production, use, and eventual end-of-life disposition (reuse, remanufacture, recycle, disposal).
Transportation and packaging were lacking high-quality data or ignored in many of the studies. Raw materials acquisition was missing in the greatest number of studies (due to difficulties in obtaining upstream data).</td></tr>
<tr><td>Impact assessment categories/ methods</td><td>1. Energy use
2. Water use
3. Eutrophication
4. Acidification
5. Global warming potential
6. Particulate matter
7. Air emissions
8. Volatile Organic Compounds
9. Toxicity
10. Waste</td></tr>
<tr><td>Results</td><td>Material acquisition stage:
Majority of the environmental impact comes from paper. The pulp and paper industry accounts for a large percentage of the total energy used (surpassing the aluminium industry).
Production:
The production and manufacturing stage has a relatively low impact in the overall LCA.
Use phase:
Several of the print use patterns and assumptions that have already been described are difficult to estimate since there are not only one use pattern.
End-of-life:
The major contributor in this stage is the waste management. However, waste management differs by locality and different results are obtained depending on the management considered.</td></tr>
</table>

	The recycling rates are important to determine the environmental impact, for this reason some sectors of the industry are focused on de-inking (34% more energy is needed in the de-inking process than in the fibre recovery process). **Packaging:** Inclusion of packaging can be significant to the results of some studies, especially when it is included for consumables. **Print consumables**: **Cartridges:** it is important to consider the remanufacture of cartridges, nevertheless only 10-15% of the cartridges are remanufactures. Up to 60% of carbon footprint could decrease due to the remanufactured cartridges. However, others indicated that remanufactured cartridges have a negative impact due to reduced print quality. **Ink and toner:** these components have the potential to contribute to emissions and airborne particulates, they impact on the recyclability of the substrate, and they are derived from process-intensive manufacturing. VOCs and their emissions have become a major concern for commercial print shops in relation to employee health.
Main conclusions	Impacts on toxicity and human health typically get less attention, because regulations already in place for chemicals and outputs that would be a threat to human health. Resource depletion does not receive much attention in the studies, with the exception of energy use. Waste receives a lot of attention considering the high level of uncertainty in end-of-life data. Ink and toner advancements and alternatives have potential to make improvements in less popular impact categories. One such example is the use of soy-based inks

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