WHITE PAPER

LCA of General Commercial Print

HP Indigo vs. Offset printing

Table of contents

Sustainability is imperative for any business

According to the United Nations, the global temperature has already risen 1.1º C above pre-industrial levels, with glaciers melting and sea levels rising. The impact of climate change also includes flooding and drought, displacing millions of people, sinking them into poverty and hunger, denying them access to basic services – such as health and education – expanding inequalities, stifling economic growth, and even escalations in occurrences of conflict. By 2030, an estimated 700 million people will be at risk of displacement by drought alone, and about one-third of global land areas will suffer at least moderate drought by 2100 (UN, 2022)*[1] Taking urgent action to combat climate change and its devastating impact is therefore critical to saving lives and livelihoods, and key to meeting the 2030 Agenda for Sustainable Development and its seventeen goals. Sustainability has become imperative for every business sector as more people become aware of the impact of their actions on the environment. Everyone is accountable: governments, businesses, and consumers. The print industry is no exception. The importance of sustainability has only risen in recent years. Technological innovations in the print industry have been driving manufacturing processes and products, making them strive towards more sustainability. Understanding the right fit for these sustainable printing technologies and implementing the necessary changes will steer Print Service Providers (PSPs) toward more responsible paths, resulting in more thriving businesses.

This white paper is based on a peer-reviewed full LCA report completed in December 2023, and aims to highlight the environmental sustainability facts as well as differences between analog printing technology and HP Indigo digital print production.

HP Indigo sustainable impact strategy

HP Indigo is one of the world's leading digital printing solution providers for the graphic arts industry. Founded in 1977, the company develops advanced technology to drive digital print growth which enables Print Service Providers (PSPs) and brands to become market leaders. Our high-tech digital presses are designed to meet today's and tomorrow's needs for printing sustainably, personably, securely, and immediately. HP Indigo creates lasting value by integrating sustainable solutions into the entire value chain, from sourcing materials to the printed product to recycling, using digital attributes to propel a more sustainable future. Our objectives, synchronized with the greater HP family, are detailed in the HP Sustainable Impact Report. We at HP Indigo also promote a net-zero carbon emission goal, aiming to create a fully regenerative economy while engineering the industry's most sustainable portfolio of products and solutions. Throughout the entire process of product design, production, and delivery, we aim to lower our carbon footprint, reduce the amount of energy we expend and waste we produce, and recycle our materials from the start to the end-of-life of both our printed products and the machines that produce them. For more information about HP Indigo and sustainability, please visit HP Indigo's sustainability portal at https://www.hp.com/us-en/industrial-printers/indigo-digital-presses/environment-sustainability.html

HP Indigo LEP digital printing technology

FIGURE 1: HP INDIGO 120K DIGITAL PRESS

The HP Indigo Liquid Electrophotography (LEP) imaging process starts with a charging unit that generates a uniform current to the entire surface area of a reusable Photo Imaging plate (PIP), followed by the writing head discharge PIP, where it creates a latent electrostatic image. HP Indigo ElectroInk is negatively charged but being the most positive in comparison to the surfaces, so it attracts a less positive image area on the PIP. When the Binary Ink Developer (BID) contacts a latent electrostatic image on the PIP, inked images are developed on the PIP. HP Indigo LEP technology is a thermal offset digital printing process, in which each color separation (i.e., impression) is transferred from the PIP onto a heated blanket. The heated blanket then causes the pigment-carrying particles within the HP Indigo ElectroInk to melt and blend into a smooth film. As this warm film contacts the cooler substrate, it solidifies quickly and adheres firmly to the substrate with almost no change in dimension or shape. HP Indigo LEP technology achieves high print quality because ElectroInk is dried before it is applied, and the image is defined on the blanket rather than on the media. One of the key advantages of digital printing with an HP Indigo Digital Press is the ability to make each page different. While offset printing uses static plates, with digital printing you can create plates for each “page” that is printed. What this means for HP Indigo users is that each page that comes out of the press can be different without changing the imaging plate, thus significantly reducing individual setup costs and setup waste as well. The reduced waste translates into a lower environmental footprint.

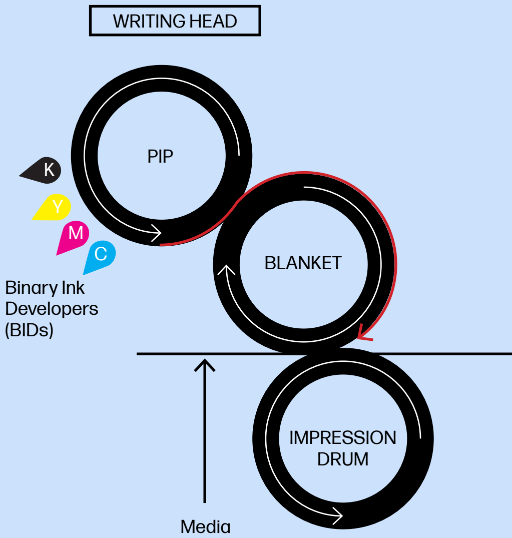


FIGURE 2: HP INDIGO LEP TECHNOLOGY (FOUR COLORS, INDIGO SERIES 5 BASIC CONFIGURATION)

Precise dot placement of HP Indigo LEP technology enables support to Enhanced Productivity Mode (EPM), which is an HP Indigo technology that converts CMYK color to CMY. The operation takes place in the HP DFE RIP using proprietary color management algorithms. Essentially, the black ink is simulated using the cyan, magenta, and yellow channels (i.e., three impressions). This amounts to a 33% gain in productivity on press, and lowers environmental impact by saving the energy consumption of four color impressions per sheet.

The new HP Indigo 120K Digital Press is a flagship model of HP Indigo Series 5 commercial printing press portfolio, and the world's most productive B2 digital printing solution. Equipped with a single print engine and true digital non-stop full color print capabilities, it can print 6,000 B2 sheets per hour in EPM (simplex) mode, 4,500 B2 sheets per hour in CMYK (simplex) mode, and 2,250 B2 sheet per hour in duplex mode. The energy consumption per sheet of the HP Indigo Series 5 presses, including Indigo 100K and Indigo 120K, have been reduced by 80% compared to the previous generation of HP Indigo presses.*2

FIGURE 3: PRINTING ENGINE OF THE INDIGO PRESS - 7 COLORS

Offset printing technology

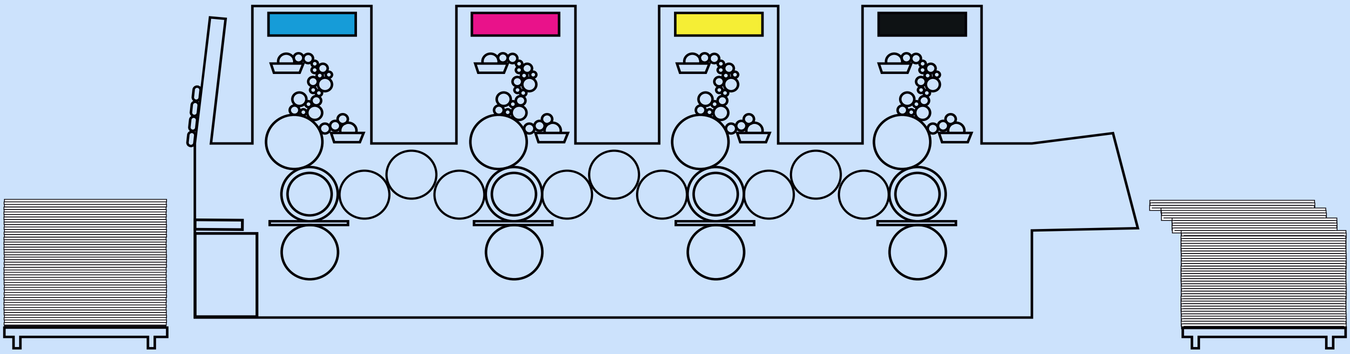


FIGURE 4: NON-PERFECTING 4 COLOR (CMYK) SHEETFED OFFSET PRINTING PRESS

Offset printing technology, also known as lithography, is the most prevailing method of mass-production commercial printing. The latest generation of sheetfed offset presses can reach machine throughputs of 18,000 sheets per hour. Offset press users can choose throughput mode according to the job and daily production plan. Offset printing technology first creates the images on metal plates via an offline CTP (Computer-To-Plate) process. The surface of the plates is treated to make image areas attract oil-based ink and non-image areas attract water to repel the oil-based ink. The plates for each color are then mounted onto a plate cylinder in the press. The plate first passes through wet rollers, and then ink rollers apply oil-based ink to the plate. The oil-based ink sticks to the image while water on the non-image area repels it. Finally, inked images are transferred to rubber blankets and then to the print media. The print media which is mostly paper does not come into direct contact with the printing plates. The plates used in offset printing are thin and lightweight, and therefore easy to manually mount on the plate cylinder. Offset printing has evolved over the years; the latest offset presses analyzed in this LCA study are equipped with highly-automated plate-loading systems, which significantly reduce the time taken for plate changes.

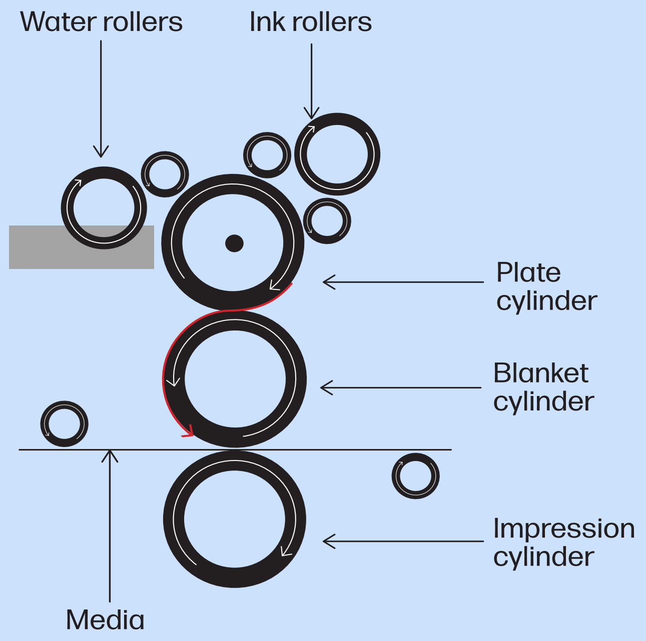


FIGURE 5: OFFSET PRINTING TECHNOLOGY (ONE COLOR PER PRINT TOWER)

Thermal CTP is the largest product segment of offset printing plates, which replaced the time-consuming chemical plate-making process from film. And yet, CTP is still a stand-alone "off press" procedure, and the finished offset printing plates must be transported to and mounted on the offset printing press. The most widely used type of offset plate is aluminum-based, due to its durability and long-lasting quality, as the media and printing plate do not come into direct contact with each other. Despite the long lifespan of aluminum offset plates, their reuse rate in commercial printing jobs is typically as low as one time use.

In essence, offset printing technology is analog technology that requires a custom printing plate for each impression, unlike in digital printing technology. Thus, commercial printers must deal with a substantial number of offset printing plates in their operation day in and day out such an accumulation significantly impacts the sustainability of commercial print outputs. The state-of-the-art offset printing press can include a perfecting device which enables one-pass duplex printing. A perfecting press that prints a 4-color process (CMYK) on each side of the paper must have at least eight ink towers. Furthermore, commercial PSPs typically add lacquer stations in press configurations, which effects the energy consumption of the printing process. A perfecting offset press is a more expensive, sizable machine with a larger footprint than a non-perfecting offset press, but it can support higher print productivity. It is worth noting that both press types require the same number of offset plates to process the same job. Changing plates correspond to the media waste in each setup. This LCA study uses the non-perfecting offset press as a baseline for analysis and the perfecting press for sensitivity analysis. Offset printing technology accommodates a variety of large paper sizes, including B1 format (707 mm x 1,000 mm) which fits eight A4 sheets, and B2 (500 mm x 707 mm) which fits four A4 sheets. This LCA studied the state-of-the-art B1 and B2 offset presses that were commercially available on the market during the study period.

Printing inks

Oil-based ink is a popular choice for sheetfed offset printing for General Commercial Printing (GCP) applications. In essence, ink is made of three main ingredients: Pigment, which is the colorant; Modifier, which controls the drying of the ink as well as other properties such as scuff and fade resistance; and Vehicle, which is the liquid that holds the colorant particles and carries them onto the paper. There are two types of vehicles used in offset inks: synthetic vehicles, which are liquids resulting from the mixture of chemicals and plant-derived vehicles such as soy oil or linseed oil; and vegetable oil-based ink which have become increasingly popular because of the market's sustainability demands. Nevertheless, Volatile Organic Compound (VOC) emission is an inherent environmental concern when using oil-based ink, regardless of the type of oil used in the offset printing ink. VOC emissions from an offset printing press mainly stem from the hot air dryer, dampening aids used in the fountain solution, and cleaning solution. Add-on control technology can reduce the amount of air pollution introduced into the environment.

Drying is one of the most important properties of printing inks. The dryness level of ink can delay print outputs from moving to the post-printing process and effect time for commercial shipment of printed products. The first phase of the drying process for oil-based offset ink is Setting. In the Setting phase, vehicles of the ink are partially evaporated by a hot air dryer or penetrate the paper, thus the surface of the ink layer solidifies, and then print outputs can be stacked. This ink film may undergo an additional ink hardening process required for finishing processes such as a guillotine. In the Oxidation phase, oils chemically bond with oxygen in the atmosphere, accelerating the ink-hardening process that often occurs in conjunction with absorption. Oxidation can further accelerate by additional drying (e.g. IR) during this phase, but use of more drying power means more energy consumption in the printing process, which makes it less sustainable. In essence, drying speed and the amount of energy used for drying oil-based offset ink is a trade-off relationship.

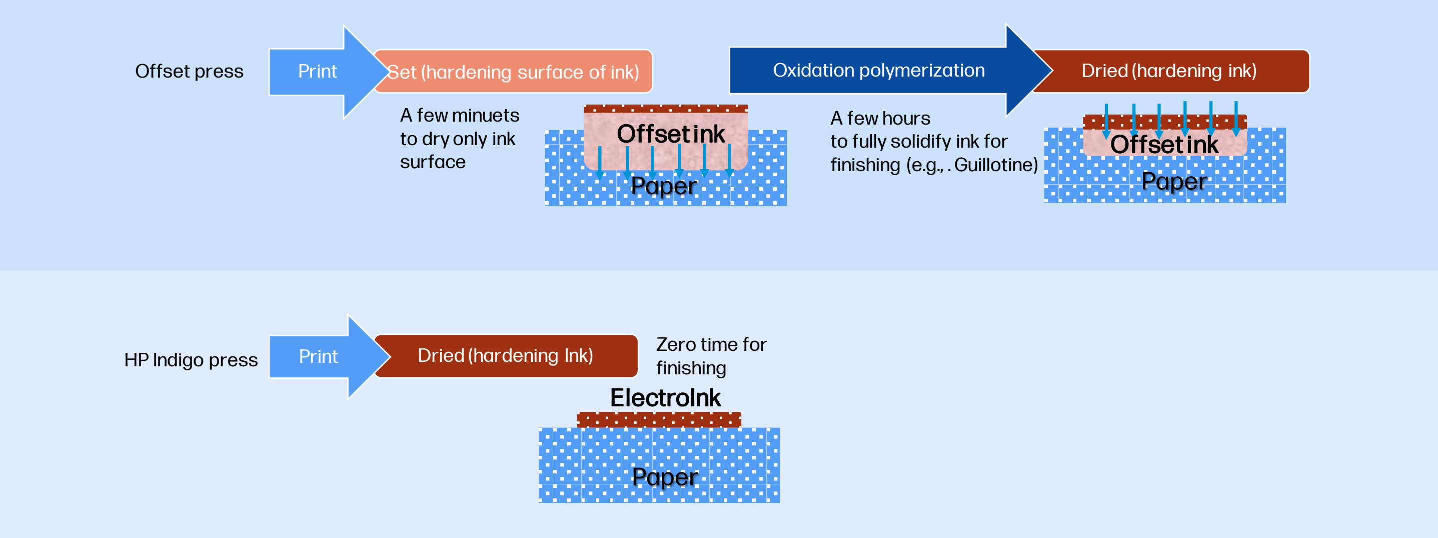


FIGURE 6: HOW OIL-BASED INKS ARE SOLIDIFIED AND READY FOR FINISHING

FIGURE 7: HP INDIGO ELECTROINKS IN RECYCLABLE CARTRIDGES

The carrier liquid used in HP Indigo ElectroInk is a high-purity, virtually odorless, dielectric fluid comprised of low weight hydrocarbon chains. It is commonly used in personal care products. The carrier liquid which evaporates during printing is captured by the dedicated capture and control system which recycles the carrier and returns it to the printing process. Therefore, the HP Indigo Digital Press emits a fraction of the VOCs extracted in conventional printing processes.*3 Furthermore, unlike with offset printing technology, HP Indigo ElectroInk is dried on a blanket rather than on the media. Hence, HP Indigo printed outputs are ready for the finishing process immediately after print.

Life Cycle Assessment (LCA)

LCA is a tool to assess potential environmental impact over the course of the product's entire life cycle, from the extraction of raw materials to the manufacturing, use, to finally the disposal of the product. The most popular LCA applications are the following:

- Analysis of the contribution of the life cycle stages to the overall environmental load, usually with the aim of prioritizing improvements on products or strategic planning
- Comparison between products for improvements or product marketing. (i.e., Comparative LCA)

Four phases of an LCA study

1) Goal and scope

Goal and scope aims to define how a product's life cycle will be taken into assessment and to what end that assessment will be serving.[*4]

2) Inventory analysis

Life cycle Inventory (LCI) provides a description of material and energy flows within the product system, especially its interaction with the environment, consumed raw materials, and emissions into the environment.

3) Impact assessment

The indicator results of all impact categories are detailed in this step; the importance of every impact category is assessed by normalization and weighting.

4) Interpretation

Interpretation of a lifecycle involves critical review, determination of data sensitivity, and result presentation. Fig. 8 visualizes the four stages under the ISO 14040 guidelines.

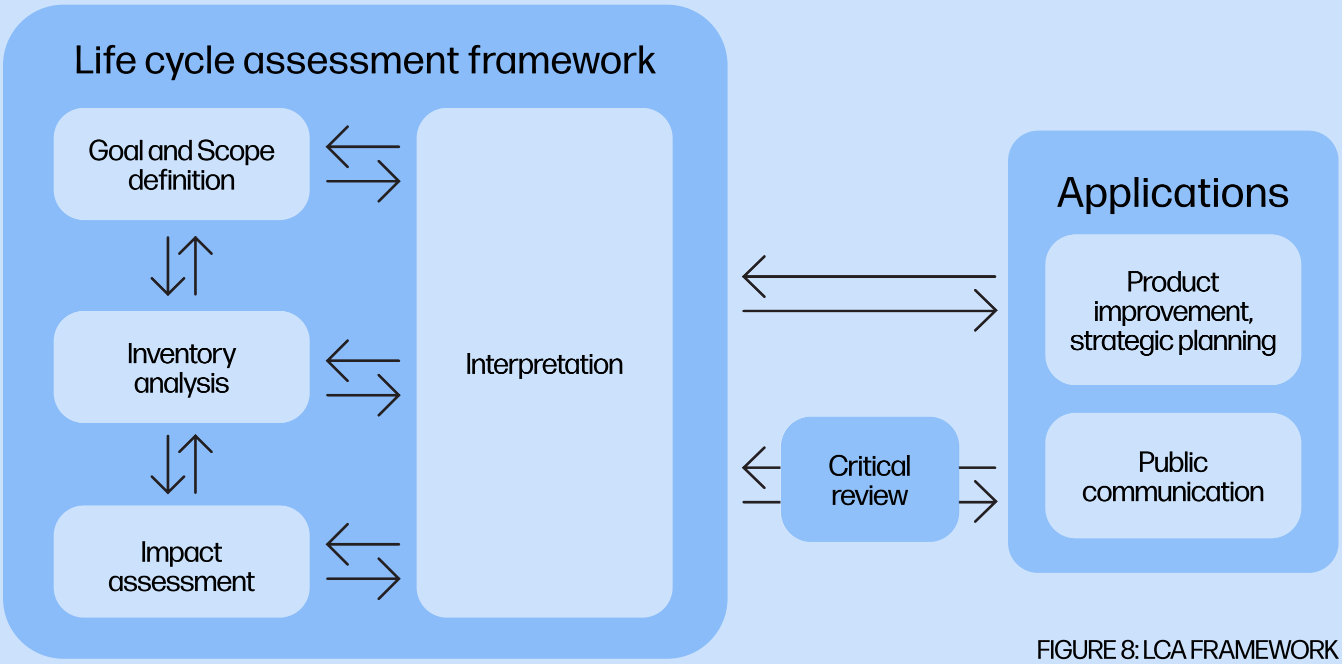


FIGURE 8: LCA FRAMEWORK

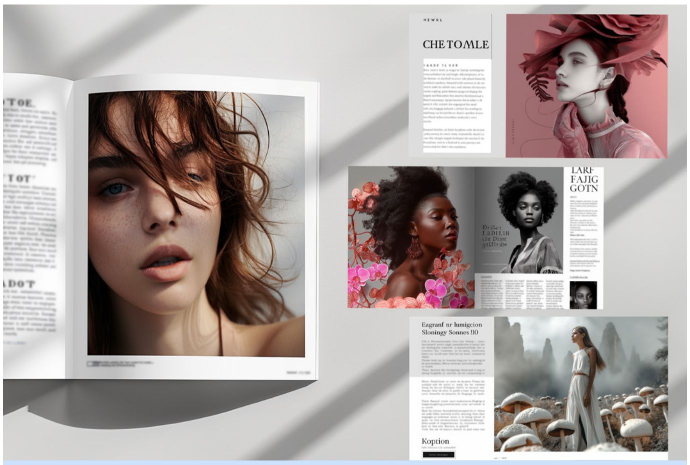
Critical review

A critical review is the ISO 14040 terminology for a peer review, which aims to ensure the LCA study is carried out according to the best practice and international standards. If the LCA study aims to disclose the results to the public, then a critical review is mandatory under ISO 14044.

Comparative LCA design overview

LCA is a tool for measuring the environmental performance of various products and processes. A comparative LCA was commissioned by HP Indigo and carried out by the independent sustainability consultant Earth Shift Global, LLC. to bring to the public a scientifically robust and transparent environmental assessment of commercial print outputs using HP Indigo digital printing technology compared with analog printing technologvies.

Goal and scope definition



FULL COLOR CATALOGUE

The first phase of an LCA is to define the goal and scope of the study according to the ISO 14040 and 14044 standards (ISO 2006a; ISO 2006b). The main objectives of this study are the following:

1) Quantify and compare the life cycle environmental impact of printing A4 color Catalogues using the HP Indigo Series 5 technology (including HP Indigo 100K and 120K digital press) and conventional B1, B2 offset printing technologies.

2) Identify the environmental hotspots in the HP Indigo Series 5 digital printing process and conventional B1, B2 offset printing technologies.

3) Explore the potential environmental crossover points for digital and offset printing technologies for A4 color Catalogue printing.

The attributional LCA approach was used for the study. The attributional approach takes an accounting perspective on the system by quantifying the energy and material flows associated with the printing function for all the processes that are active in the life cycle and using average data for processes from the background system like electricity, water supply, and waste treatment.

The full color, multi-page catalogue is one of the most common general commercial print applications produced by HP Indigo Series 5 users. The function of the studied systems is to transfer color images to a paper substrate to produce A4 color Catalogue of varying numbers of pages, such that the quality of the imaging meets the requirements of commercial end users.

Related to the function of the studied systems, the functional unit in an LCA is defined as the quantified performance of a product system for use as a reference unit (ISO 14044, 2006). This facilitates the determination of reference flows for the system being studied.

The functional unit for this comparative study was defined as the printing of 500 color Catalogue containing 160 A4-size pages in each Catalogue (equivalent to 10,000 B2 sheets). The print job contains multiple A4 color pages which were practically imposed and printed on either SRA1 or SRA2 paper according to substrate format supported by each print technology. These functional units were chosen due to an economic break-even point.

In general, digital printing technology has an inherent advantage of first turnaround of finished product because of cutting time for prepress. As for HP Indigo LEP technology, it also has decades of field proven reputation for high print quality equivalent to offset printing technology. Hence, print quality is not a determinant of technology choice between HP Indigo or offset. PSPs typically choose HP Indigo presses for the cost effective, on-demand printing for small quantity orders or multi-SKU jobs which are aggregations of small quantity jobs from the analog printing technology perspective. While digital prints' cost per unit is almost constant, regardless of quantity of products, offset prints start from high initial cost due to tooling (e.g., offset printing plates) and it lowers the cost as quantity increases. It is a common industry understanding that digital and offset print technologies are complementary from an economic standpoint. Therefore, the technology should be choosen according to the size of job. An economic break-even point is reached when the print cost of comparative printing technologies is equal.

Figure 9 shows cost per unit by number of finished product (A4 Catalogue which contains 160 full color pages) with different print technologies in Europe. The economic crossover points for print job size for the HP Indigo Series 5 press and B1 offset press are shown in the range between approximately 500 and 700 pcs of A4 Catalogues. These crossover points explain the rationale of setting 500 pcs of finished product as a functional unit for this LCA study. Although there is no direct connection between environmental impact of prints and production costs of prints, it is nevertheless important to run an LCA with genuine business cases. This LCA study explores the potential environmental crossover points for digital and offset printing technologies with various key TCO parameters such as:

- Quantity of finished products (ranging between 500 to 10,000 pcs)
- Number of offset plates per job. (i.e., number of pages per Catalogue, ranging between 4-208)

The results are shown in section titled SENSITIVITY ANALYSIS, where it is demonstrated whether environmental crossover points can meet beyond economic crossover points.

System boundaries are established in this LCA to include the significant life cycle stages and unit processes, as well as the associated environmental flows in the analysis. This lays the groundwork for a meaningful assessment where all important life cycle stages and the flows associated with each alternative are considered.

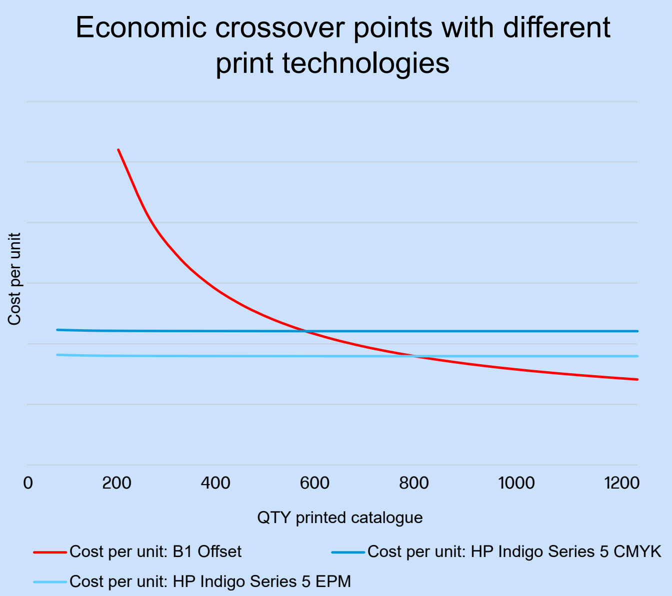


FIGURE 9: ECONOMICAL CROSSOVER POINT OF HP INDIGO VS. OFFSET

Defining the system boundary for the study is essential in all LCAs to ensure clarity in how to attribute the results. Figure 10 shows system boundaries for this LCA which are set for a cradle-to-gate LCA, ranging from raw material extraction to production of the paper substrate, through its use and finally all the way to end-of-life disposal. To meet the objectives of the present study, the system boundary was limited to the manufacturing stage of the life cycle, in particular the printing stage. Downstream distribution, use, and disposal were assumed to be equivalent regardless of printing technology used, and so were excluded from the system boundary.

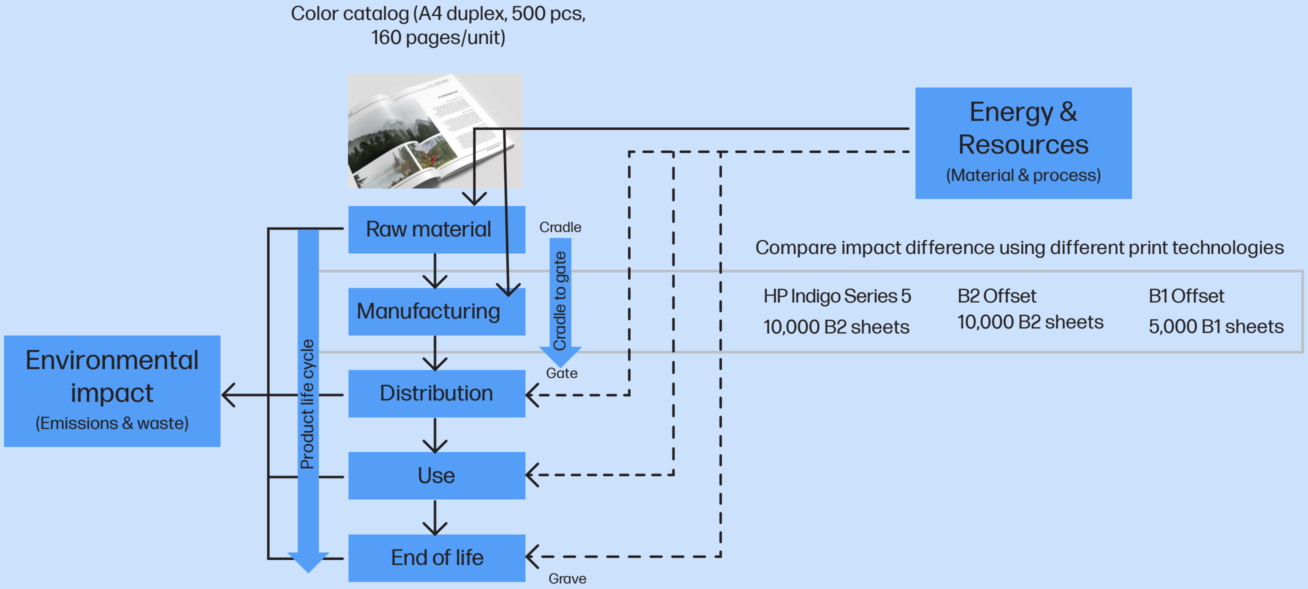


FIGURE 10: COMPARATIVE LCA SYSTEM BOUNDARY

The system description outlines the various sub-systems that comprise the value chain across the life cycle of the product. In this study, the system description is based on the goal and scope of this study—which is to determine and compare the environmental impact of printing using an HP Indigo Series 5 press versus a B1 or B2 sheetfed offset press.

The simplified system diagram for the HP Indigo Series 5 press is shown in Figure 11 and the system diagram for offset presses is illustrated in Figure 12. Note that the main inputs for printing are similar—substrate, ink, and electricity, whereas the consumables used in the HP Indigo Series 5 press are very different from those used in the offset presses. It is important to note that this comparative LCA analyzes the operational or use-phase of the printing presses, and thus accounts for the impact of consumables and inputs required during printing using the respective printing press. Electricity for the print setup and steady-state printing processes were modelled based on the average European electric grid. More than half of color Catalogue print jobs have ink coverage ranging between 30% - 60% (CMYK) according to statistical analysis based on the global install base of HP Indigo Series 5 press. Hence, an average ink coverage of 40% was used as an assumption for the baseline analysis of this study.

Cutoff criteria are often used in LCA practice for the selection of processes or flows to be included in the system boundary. The processes or flows below these cutoffs or thresholds may be excluded from the study. Several criteria are used in this LCA practice to determine which inputs are to be considered, including mass, energy, and environmental relevance.

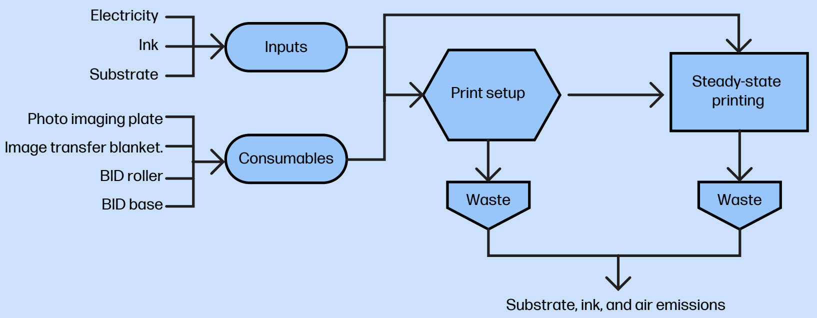


FIGURE 11: MAIN SYSTEM DIAGRAM FOR INDIGO SERIES 5 PRESS

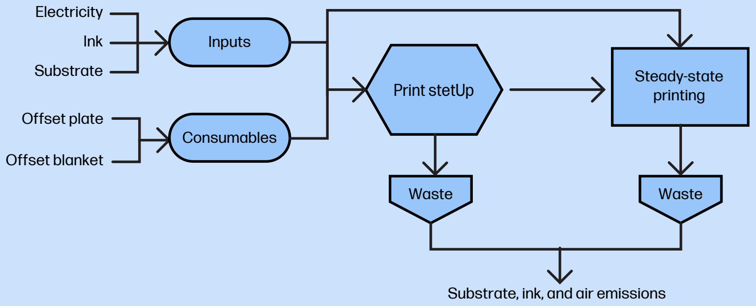


FIGURE 12: MAIN SYSTEM DIAGRAM FOR OFFSET PRESS

Life cycle inventory (LCI)

The second phase of an LCA is to collect Life cycle inventory (LCI) data, which contains the details of the resources flowing into a process and the emissions flowing out of a process to the air, soil, and water. The LCI data for Indigo Series 5 press was collected from HP Indigo R&D, and the LCI data for offset presses was collected from PSPs and industry experts. For secondary energy and materials (e.g., electricity production and, paper production), data was drawn from the life cycle database. Once all the required data was obtained and the associated flows were normalized to the reference flows (based on the chosen functional unit), system modeling was carried out using the commercial LCA software, which enables calculation of life cycle inventories and impact assessments, contribution analyses, parameterization, and related sensitivity analyses.

Impact assessment result and interpretation

Impact assessment methods are used to convert life cycle inventory (LCI) data (emissions to the environment and raw material extractions) into a set of environmental impact. ISO 14044 dictates that the chosen method should be an internationally accepted one. The following paragraphs provide a summary of the LCI results, including both a comparative analysis and contribution analysis to shed light on the hot spots of the studied printing systems.

Relative impact for different printing technologies—baseline result

A key objective of this study was to understand the relative life cycle environmental impact of producing A4-size color Catalogues using an HP Indigo Series 5 press with two different print modes, in addition to state-of-the-art B1 and B2 offset presses. Weighting supports the interpretation and communication of the results of the analysis. In this step, normalized results are multiplied by a set of weighting factors (in %) which reflect the perceived relative importance of the life cycle impact categories considered. Weighted results of different impact categories may then be compared to assess their relative importance.[*5]

A summary of the baseline comparative results is provided in Figure 13 which indicates that the HP Indigo press has significantly lower impact than both B1 and B2 offset presses for all impact categories considered. Impact results for global warming potential, resource scarcity, fine particulate matter formation, and land use were all approximately 60% or more lower than those of B2 offset presses, and approximately 30% or more lower than those of B1 offset presses. Ozone depletion and water use were approximately 30%–40% lower for the HP Indigo, and ecotoxicity as well as human toxicity were both approximately 25% lower for the HP Indigo. It is also worth noting that the HP Indigo prints with EPM show slightly lower impact across all categories compared with HP Indigo prints with CMYK because of shorter printing time.

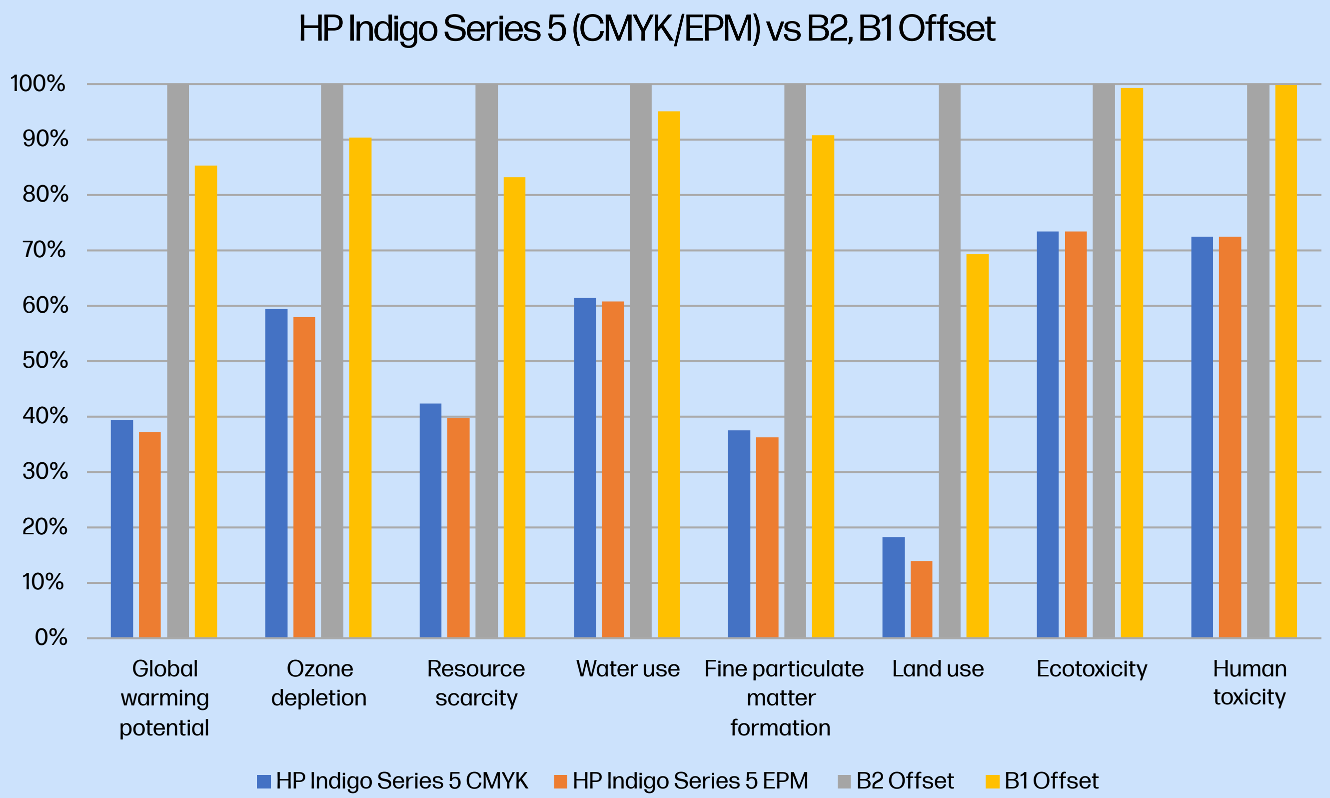


FIGURE 13: RELATIVE IMPACT FOR HP INDIGO SERIES 5 PRESS AND B2, B1 OFFSET PRESSES

The paper substrate is expected to be the primary environmental hot spot regardless of the printing technology that is used. As such, a further comparative analysis is also provided below with the paper substrate excluded, allowing for a more direct comparison of the printers and their respective operations (Figure 14). Results of the comparative analysis with paper excluded show a more notable difference in environmental performance between the HP Indigo Series 5 press and offset presses, with the HP Indigo press showing impact that is 80% lower or more than the B2 offset press and 40% lower or more than the B1 offset press for global warming potential, ozone depletion, resource scarcity, water, use, fine particulate matter, land use, and human toxicity. Human toxicity impacts were essentially zero (or negative) for the HP Indigo with paper excluded, due to an upstream credit in one of the Gabi professional database processes.

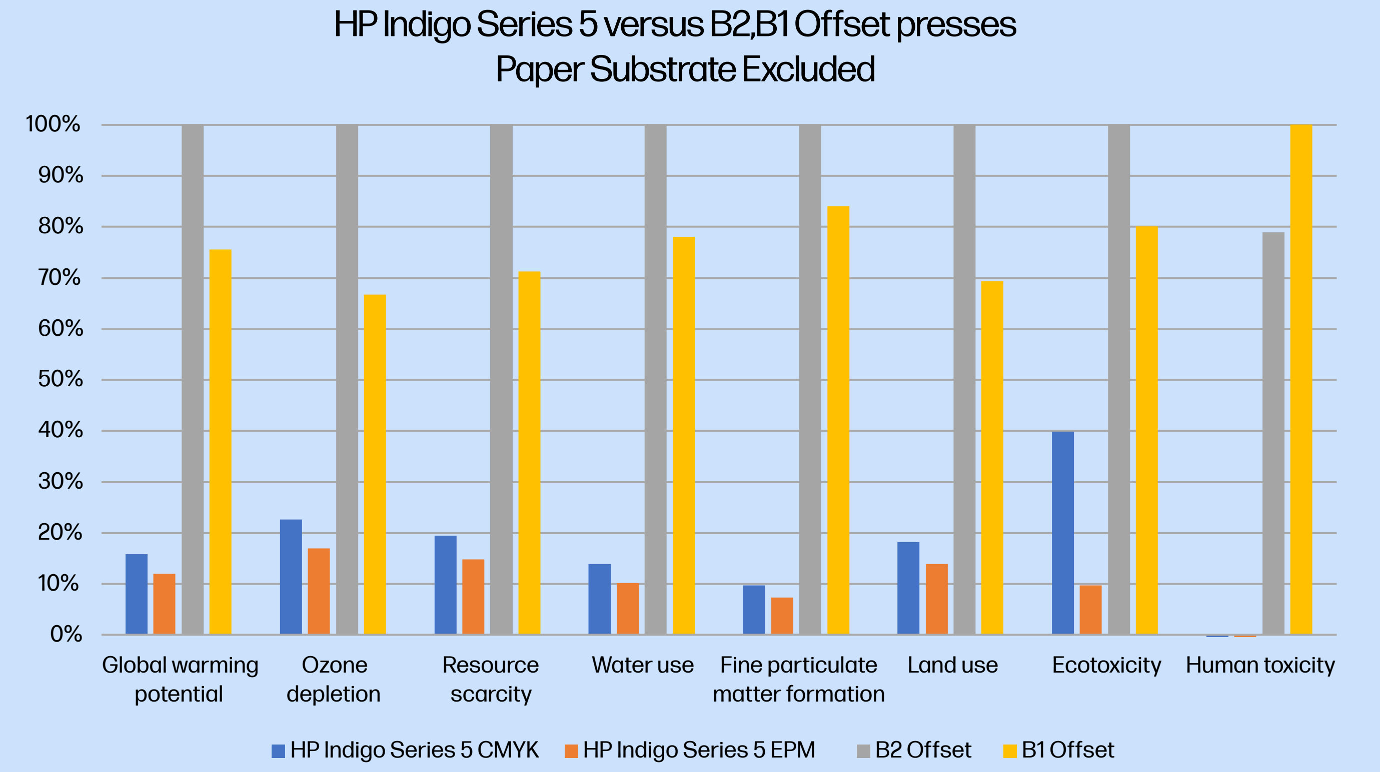


FIGURE 14: RELATIVE IMPACT FOR HP INDIGO SERIES 5 PRESS AND B1, B2 OFFSET PRESSES, WITH PAPER SUBSTRATE EXCLUDED FROM ANALYSIS

Contribution analysis

A second objective of this study was to identify the environmental hot spots in the A4 Catalogue printing life cycle, in order to better understand what drives the comparative results and to identify potential environmental improvement opportunities for each printing technology. The life cycle models for each printing press were developed in the GaBi LCA software program and were broken down into three primary life cycle stages, including:

1) Consumables: This life cycle stage refers to the upstream manufacturing and downstream waste associated with materials and equipment that are used during the printing process. This includes consumables that are more unique to each press type, such as the PIP, BID roller, BID base, and image transfer blanket for HP Indigo Series 5 digital press, and the offset printing plates and blankets used as consumables in the offset presses. The manufacturing and use of ink and paper substrate are captured in the following life cycle stages.

2) Print setup: The print setup stage accounts for the material and energy inputs and waste produced before steady-state printing, including inks and paper substrates. This is the make-ready phase of the printing life cycle where steps are taken to ensure that imaging systems and substrates are properly setup and aligned to ensure high print quality during steady-state printing.

3) Steady-state printing phase: The steady-state printing stage includes the material and energy inputs and waste produced during the commercial print job to produce the specified number of A4 color Catalogues ordered by the client. This includes the inks and paper substrate used.

In the following sections, the results of the LCA are explored further by showing and discussing the contribution of each of these life cycle stages to the overall study results for both the HP Indigo Digital Press and offset presses. Contribution analysis results are shown individually for each impact category (Figures 15 - 22). The figures indicate overall that consumables of offset prints are the key environmental impact hot spot. The offset printing plates are the main mass properties among consumables and they carry a high indirect environmental footprint. Print setup creates material waste and machine time loss, which can be translated into indirect material loss as well as energy loss. These elements were found to be the other key environmental impact hotspots rather than instances of environmental impact, such as waste during the steady-state printing phase.

1) The Global Warming Potential (unit: kg CO_2 eq.)

GHG EMISSION

Greenhouse gas (GHG) emissions trap the Sun's heat and lead to climate change. The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impact of different GHGs. Specifically, it is a measure of how much energy the emissions of one ton of a gas will absorb over a given period, relative to the emissions of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period.[*6]

Figure 15 shows that the primary source of GHG emissions was the manufacturing of consumables (including aluminum, synthetic polymer, and electricity) for both the B1 and B2 offset presses. The raw material extraction, material processing, and electricity use associated with production of the offset printing plates is the primary hot spot, followed by production of the paper substrate. Print setup is also a notable contributor for the offset presses, and such emissions are associated with inherent creation of non-sellable prints during print setup—a situation that can occur multiple times per job. Conversely, since minimal print setup is required for the HP Indigo Digital Press, GWP contribution of this part of the life cycle is negligible, as are the contributions from consumables. Nevertheless, Figure 15 points out that the primary contributor to global warming potential for the HP Indigo press is the steady-state printing stage, which accounts for over 75%-80% of life cycle GHG emissions caused by longer printing time due to lower machine throughputs compared to either offset printing presses.

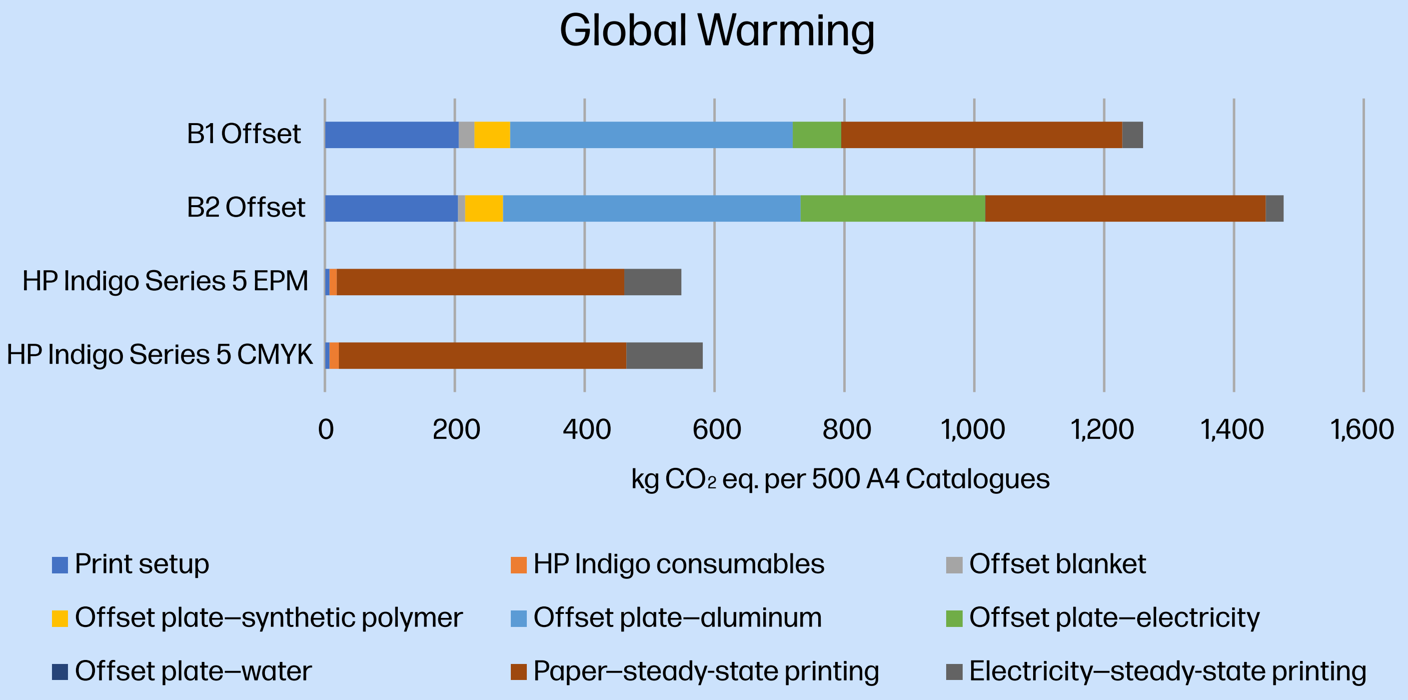


FIGURE 15: GLOBAL WARMING POTENTIAL

2) Ozone depletion (unit: kg CFC-11 eq.)

OZON LAYER OF THE EARTH

Ozone depletion and climate change are indirectly linked, but Ozone depletion is not a major cause of climate change. The stratospheric ozone (O3) layer protects us from hazardous ultraviolet radiation (UV-B). Ozone depletion increases skin cancer cases in humans as well as damage to plants. The potential impact of all relevant substances for ozone depletion are converted to their equivalent in kilograms of trichlorofluoromethane (also called Freon 11 or R-11), hence the unit of measurement is in kilogram of CFC-11 equivalent (kg CFC-11 eq). *7

For the offset presses, the primary source of ozone depletion impact was the consumption of paper during the steady-state printing stage followed by print setup. However, ozone depletion impact from print setup is also largely due to paper consumption during the more extensive print setup process for offset presses. The other hot spot for ozone depletion is the production of offset plates (including the aluminum, synthetic polymer, and electricity). The highest ozone depletion potential in the HP Indigo press stems from the steady-state printing stage, which accounts for over 90% of ozone depleting emissions. Electricity consumption during steady-state printing is the second hot spot, while consumables of the HP Indigo press made negligible contributions to impact.

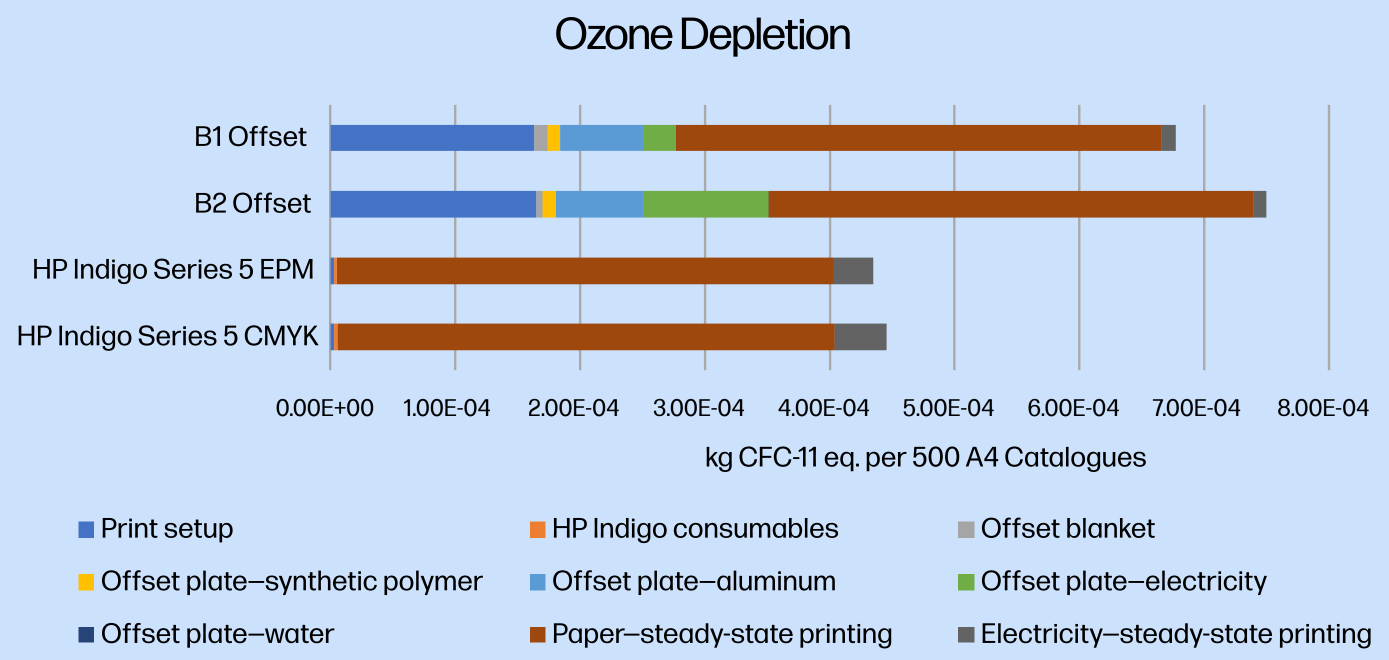


FIGURE 16: OZONE DEPLETION

3) Resource scarcity (unit: kg oil eq.)

EXTRACTION OF FINITE RESOURCES

The earth contains a finite amount of non-renewable resources, such as fossil fuels like coal, oil and gas. The basic idea behind this impact category is that extracting resources today will force future generations to extract less or different resources. *7

For the offset presses, the primary contributor to resource scarcity was the consumption of paper during steady-state printing (as well as in print setup). The second hot spot for offset resource scarcity was extraction of aluminum and use of electricity for offset plate production. Figure 17 indicates that that the steady-state printing stage of the life cycle results in higher resource depletion for the HP Indigo press relative to offset presses. This stems from the higher electricity consumption due to longer net printing time required for the HP Indigo press during commercial printing.

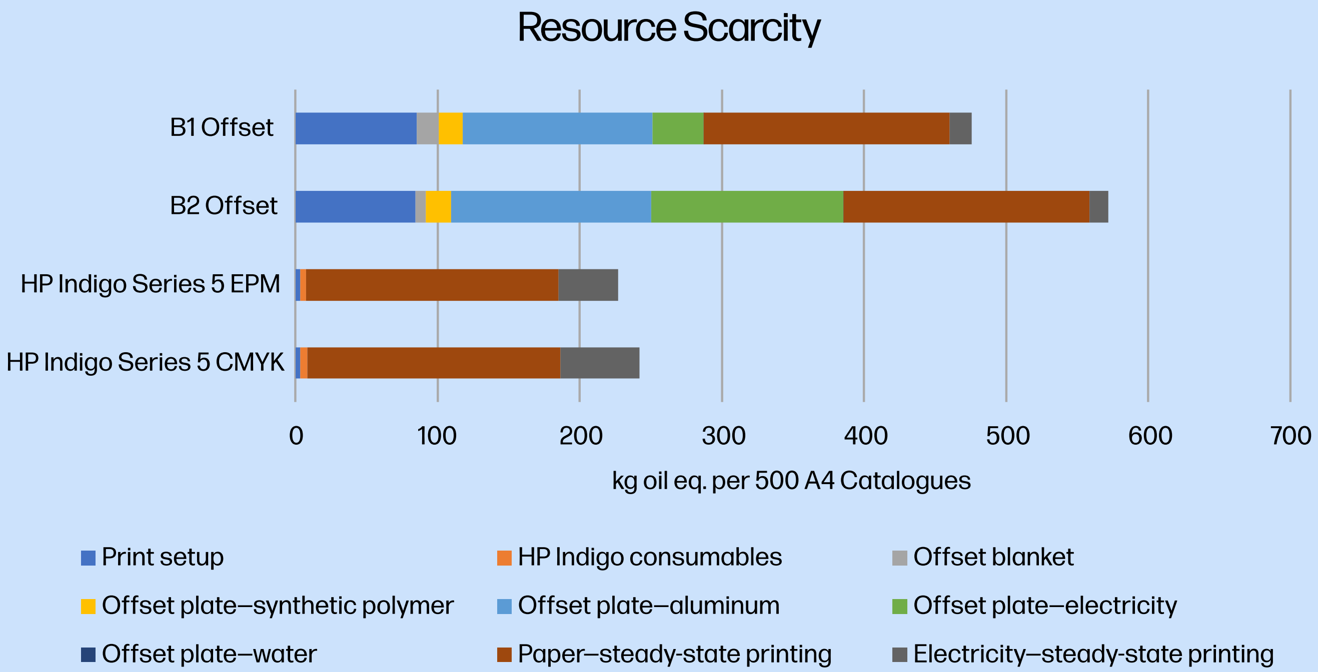


FIGURE 17: RESOURCE SCARCITY

4) Water use (unit: M3)

WATER

The withdrawal of water from lakes, rivers or groundwater can contribute to the ‘depletion’ of available fresh water. This impact category considers the availability or scarcity of water in the regions where the activity takes place if this information is known. The potential impact is expressed in cubic meters (m3) of water used relative to the local scarcity of water. *7

For the offset presses, the hot spot for water use was paper consumption during the steady-state printing stage, as well as paper consumption during print setup. The production of offset plates was the other hot spot for the offset presses. The primary contributor to water use for the HP Indigo press is the steady-state printing stage, which accounts for over 90% of life cycle water use. The other hot spot is electricity consumption during steady-state printing, with HP Indigo press consumables making a negligible contribution.

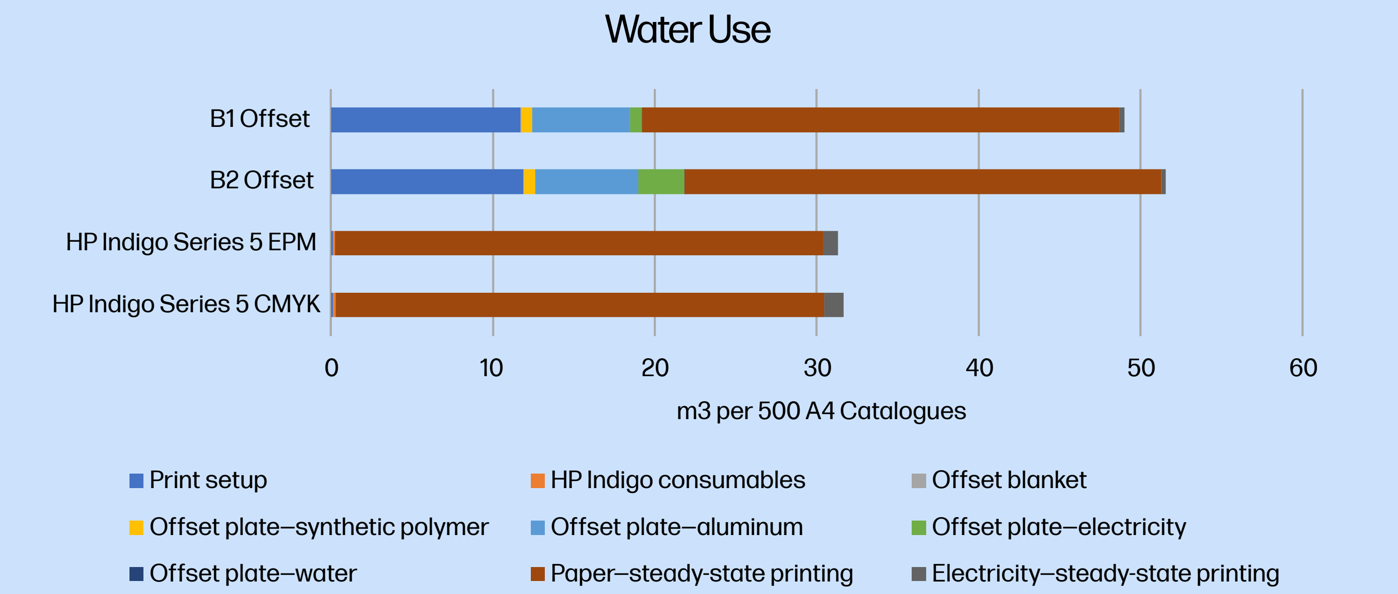


FIGURE 18: WATER USE

5) Fine particulate matter (Unit: kg PM2.5 eq.)

TOXIC SMOG

This indicator measures the adverse impact on human health caused by emissions of Particulate Matter (PM) and its precursors (e.g. NOx , SO2). Usually, the smaller the particles, the more dangerous they are, as they can go deeper into the lungs. The potential impact is measured as the change in mortality due to PM emissions, expressed as disease incidence per kg of PM2.5 emitted. *7

For offset presses, the primary contributor to fine particular matter was the production of offset plates (including the aluminum, synthetic polymer) followed by paper and energy use during print setup.

The primary contributor to fine particulate matter emissions for the HP Indigo press is the consumption of paper during steady-state printing stage, which accounts for over 90% of life cycle particulate emissions.

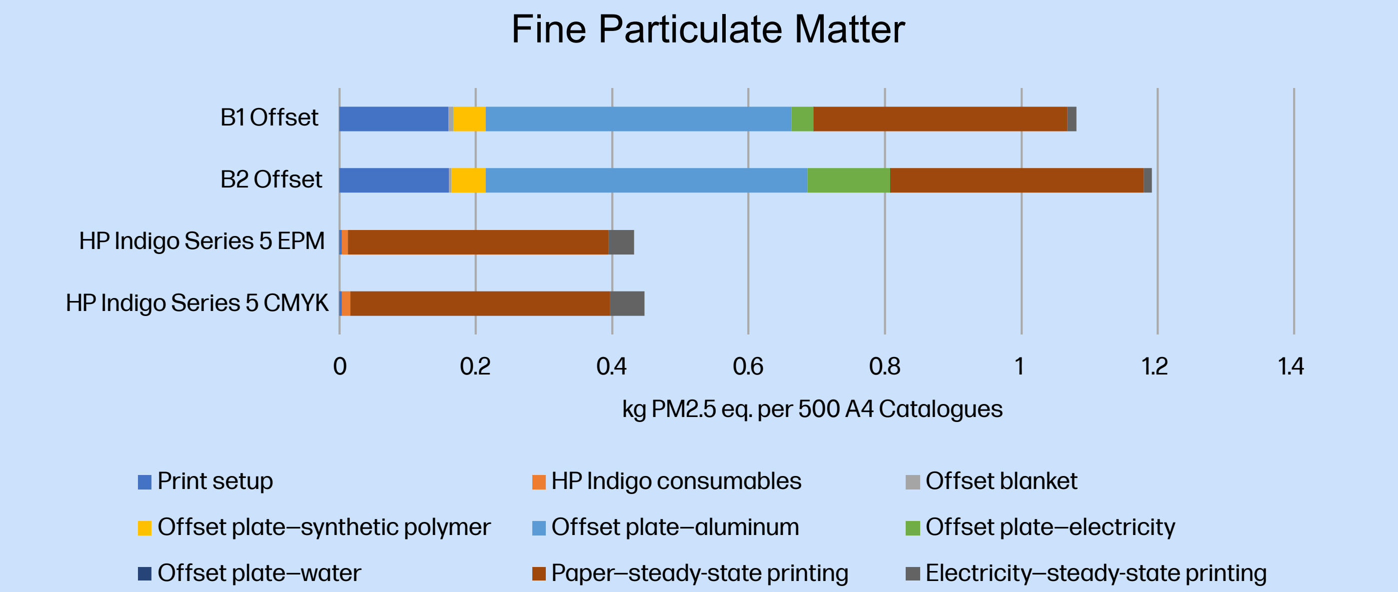


FIGURE 19: FINE PARTICULATE MATTER

6) Land use (unit: annual crop eq.)

CHANGES IN LAND USE

Use and transformation of land for agriculture, roads, housing, mining or other purposes: the impact can vary. *7

For the offset presses, the primary contributor to land use was the production of offset plates (including the aluminum, synthetic polymer, and electricity). Electricity consumption during steady-state printing was a relatively small contributor for offset presses, indicating the reduced energy consumption during printing, relative to the HP Indigo press. The primary contributor to land use for the HP Indigo press is use of electricity during the steady-state printing stage, which accounts for over 90% of land use impact. This is a result of the higher electricity consumption due to lower machine throughputs of the HP Indigo press during commercial printing. Paper use and HP consumables made negligible contributions to impact.

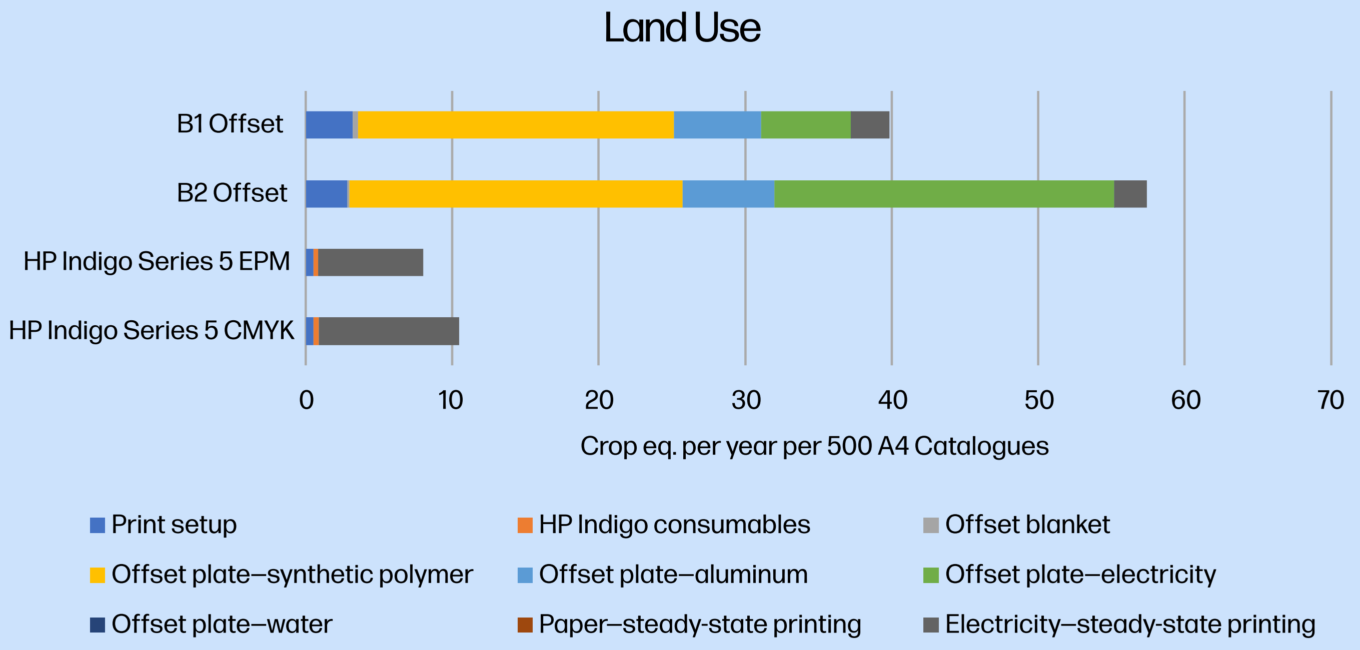


FIGURE 20: LAND USE

7) Ecotoxicity (unit: kg 1,4-DB eq.)

WASTEWATER

This indicator refers to potential toxic impact on an ecosystem, which may damage individual species as well as the functioning of the ecosystem as some substances have a tendency to accumulate in living organisms. *7

Toxicity impact scores were grouped under more general headings. The “Ecotoxicity” category reported is a summation of freshwater ecotoxicity, marine ecotoxicity, and terrestrial ecotoxicity.

Figure 21 indicates that the primary contributor to ecotoxicity for all of the HP Indigo press and offset presses is paper consumption during steady-state printing. For the offset presses, the second hot spot is paper consumption during print set-up. All other life cycle stages for all printing presses make negligible contributions.

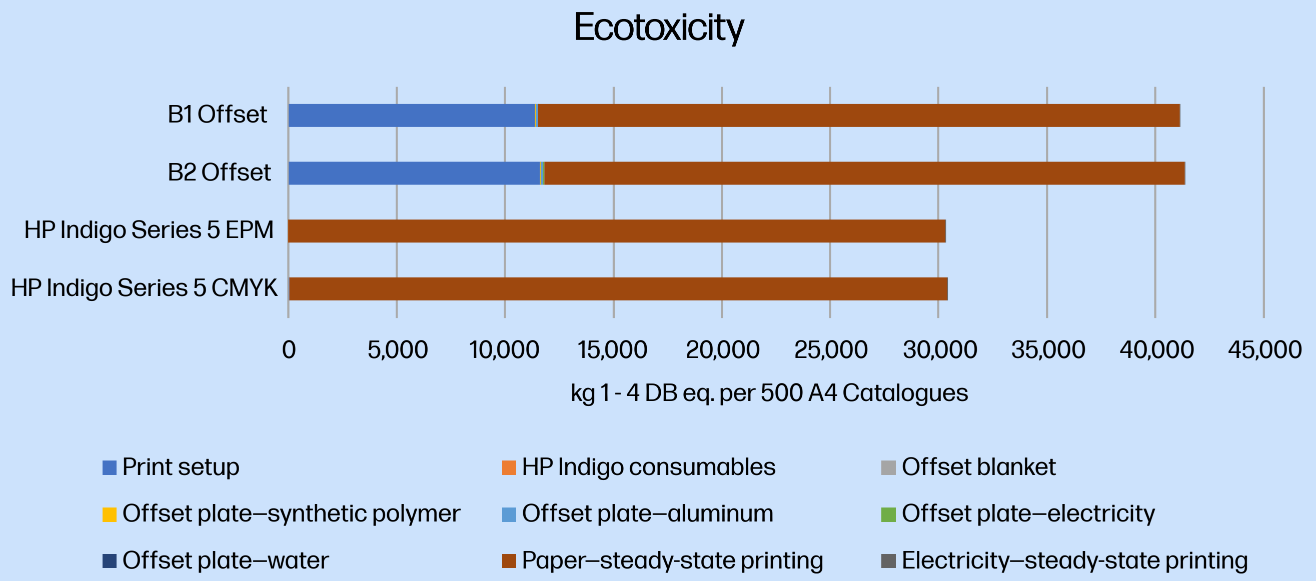


FIGURE 21: ECOTOXICITY

8) Human toxicity (Unit: kg 1,4-DB eq.)

HUMAN BODY

This indicator refers to potential impact on human health caused by absorbing substances through the air, water, and soil. *[7] Toxicity impact scores were grouped under more general headings. The “Human Toxicity” category reported is a summation of human toxicity: cancerous, and human toxicity: non-cancerous.

Figure 22 indicates that the primary contributor to human toxicity for all of the HP Indigo press and offset presses is paper consumption during steady-state printing. For the offset presses, the second hot spot is paper consumption during print setup. All other life cycle stages for all printing presses make negligible contributions.

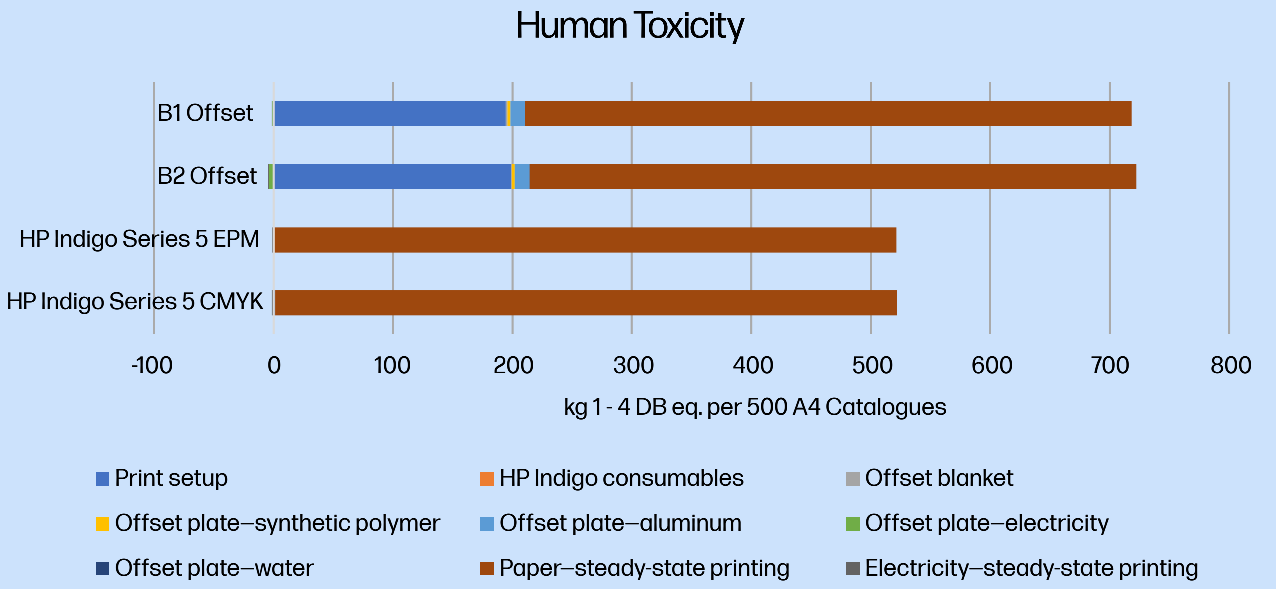


FIGURE 22: HUMAN TOXICITY

A key environmental impact hot spot

Aluminum in offset printing plates

BAUXITE OPEN-PIT MINING

Contribution analysis reveals that offset printing plates can become a significant environmental impact hot spot in key impact categories such as global warming potential. The result was a higher overall environmental footprint of offset prints compared with HP Indigo Series 5 prints. The following paragraph explains the lengthy production process of offset printing plates and the product's life cycle from cradle-to-grave. Offset printing plates consist of a base and a synthetic polymer that is a very thin, light or thermal-sensitive coating which retains the offset printing ink. Most of the material mass of an offset printing plate comes from its base, which is mostly made of aluminum. and every aluminum-based offset plate begins its product life from bauxite mining.

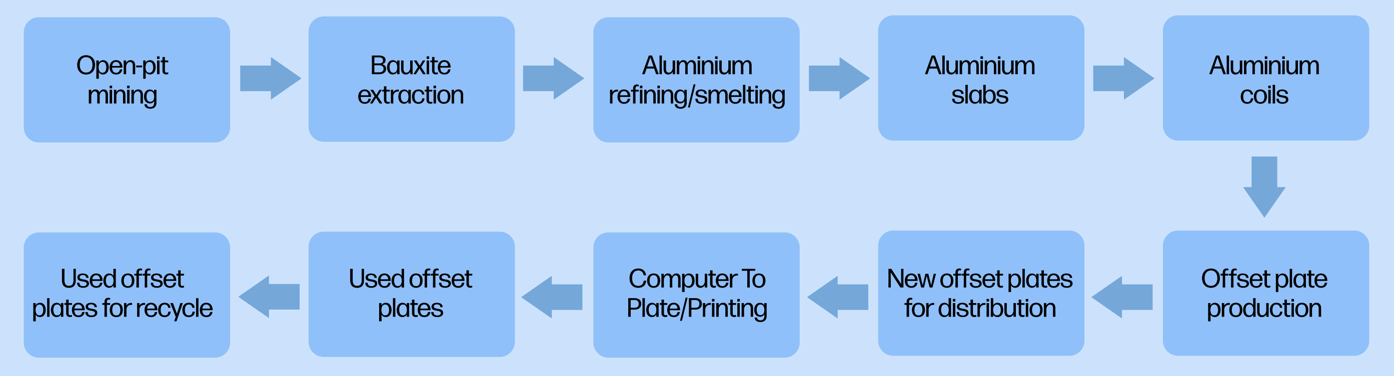


FIGURE 23: LIFE CYCLE OF ALUMINUM IN OFFSET PRINTING PLATE

1. Extraction of bauxite ore: Aluminum is mostly produced by extraction from bauxite ore, which is a mixture of different minerals, primarily comprised of aluminum oxide compounds (Alumina), but also containing varying amounts of impurities such as iron oxides, titanium dioxide, and silica. Aluminum is the most abundant metal in the earth's crust, but extraction of bauxite ore comes with a significant environmental footprint due to explosives required to break up the rocks, requiring heavy machinery to plow through a huge piece of land. The large-scale open-pit mining operations destroy the surrounding biosphere. Bauxite ore is transported to processing plants by heavy trucks, rails, and conveyers, then the ore is washed, ground and prepared for the ensuing two-step refining process.

2. Alumina production: The bulk of the world's bauxite production is used to feed the manufacture of alumina via a wet chemical caustic leach method commonly known as the Bayer process.[*8] The Bayer process

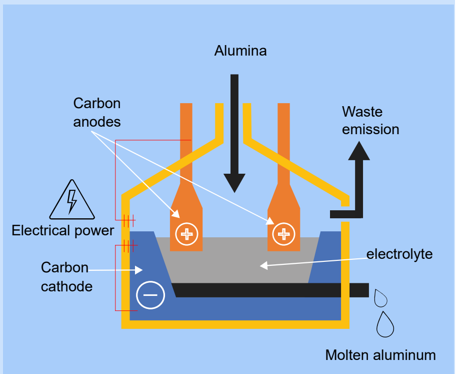


FIGURE 24: THE HALL-HÉROULT ELECTROLYTIC PROCESS

produces a variety of toxic waste during alumina production. High alkalinity and high caustic content in bauxite residue risks contaminating fertile soil and ground water and can be harmful to the biosphere. The caustic content in bauxite residue leads to human health risks as well.

3. Aluminum smelting (electrolysis): Approximately 70% of the world's bauxite production is refined through the Bayer chemical process into alumina, then refined into pure aluminum metal through the Hall-Héroult electrolytic process.[*9] Aluminum is a highly reactive metal, which means that it reacts very easily with other substances. Therefore, it cannot be extracted economically using chemical processes, but only extracted by electrolysis in the Hall-Héroult process. The downside of the Hall-Héroult electrolytic process is that it consumes a significant amount of electric power.

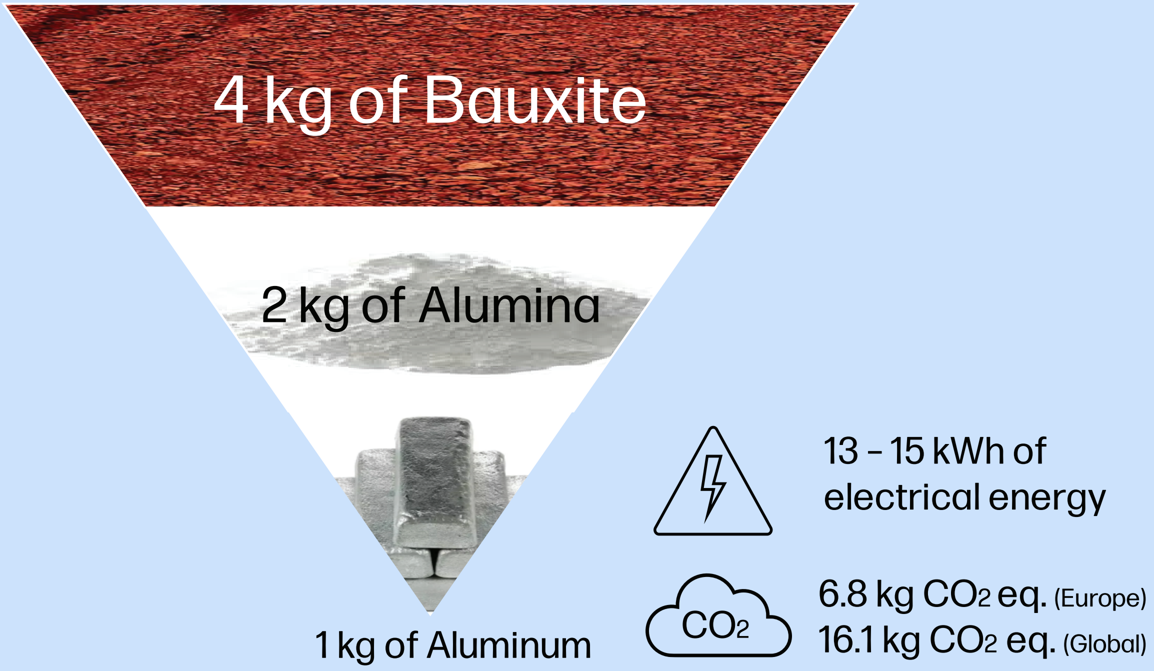


FIGURE 25 : RAW MATERIALS AND ENERGY TO PRODUCE 1KG OF ALUMINUM

Finally, the pure molten aluminum is cast into blocks, called ingots, slabs, or other shapes, and ready for shipment. Producing 1 kg of aluminum requires approximately 13-15 kWh of electric power. [*10] Figure 26 shows how the global average GHG emission is determined as CO_2 eq. per ton of primary aluminum in each process. High electric-power consumption of aluminum smelting resulted in significant indirect CO_2 emission. Aluminum smelting also adds direct CO_2 emissions. According to the statistical data compiled by the International Aluminum Institute (IAI)[*11], GHG emissions from electrolysis (smelting) are the most energy and carbon intense processes, accounting for 73% of primary aluminum's carbon footprint at the global level in 2021. There are significant variations in GHG emission intensity between smelters depending on the source of electricity. For instance, renewable energy production and consumption have increased rapidly across Europe in recent years, which helps reduce GHG emissions and other pollutants across industries. According to an association of European Aluminum, the carbon footprint of Europe's primary aluminum production process is much lower than the global average, with only 6.8 kg of CO_2 emissions compared to the global average of 16.1 kg CO_2 per kg of aluminum produced.[*12] CO_2 emissions caused by mining are a fraction of those caused by aluminum smelting. Smelting defines product carbon footprint of primary aluminum. The majority of aluminum smelters are situated where cheap electricity is available rather than at availability of renewable energy. The IAI's statistical data[*11] (Figure 27) shows that China is by far the largest producer of primary aluminum, accounting for nearly 60% of global primary aluminum production in 2022. The majority of China's electricity comes from coal, which is the cheapest fuel to burn. Coal burning is the major cause of overall GHG emissions in China.

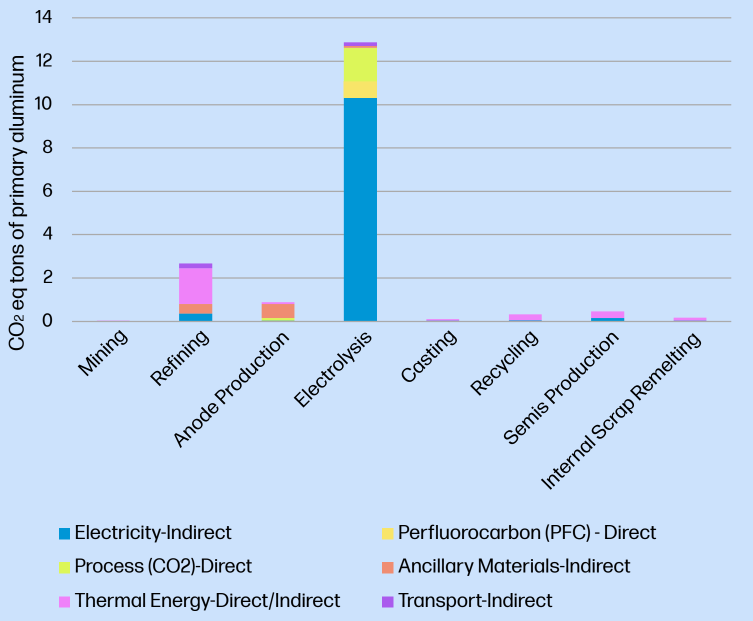


FIGURE 26: GHG EMISSION BY UNIT PROCESS AND PROCESS TYPE IN GLOBAL PRIMARY ALUMINUM PRODUCTION IN 2021

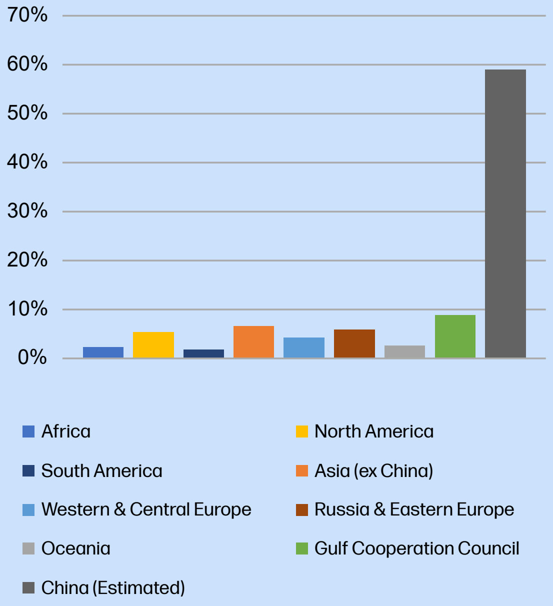


FIGURE 27: GLOBAL PRIMARY ALUMINUM PRODUCTION IN 2022

Aluminum slabs becoming coils of aluminum

Aluminum slabs continue their long journey with the following rolling process which turns slabs into high grade aluminum coils.

1. Scalping: slabs are scalped to create a smooth surface.

2. Preheating and hot rolling: slabs are annealed gradually up to the temperature of 800°C; then go through hot rolling at approximately 500°C, then the strip is rolled to a coil.

3. Cold rolling: step by step cold rolling reduces thickness of the aluminum coil to the range between 0.15 mm and 0.40 mm

4. Rewind coil: the aluminum coil is strengthened and conditioned to the final product sizes. Finally, aluminum coils are ready for inter-regional shipment to offset plate manufacturers around the world.

Offset printing plate manufacturers receive a special grade of aluminum coil, which already carry heavy cumulative environmental footprints even before converting them into offset printing plates, regardless of the geographical origin of primary aluminum.

ALUMINIUM COILS

Aluminum-based offset plate production

Aluminum coils continue their inter-regional journey to become offset printing plates. The aluminum coil normally undergoes a one-pass special treatment process to meet demanding quality requirements and eventually become printing plates. The surface of the aluminum is physically and chemically treated to create fine pores and micropores. The smoother, micro-porous surface is a prerequisite for aluminum to become a high quality printing plate.

1. Etching: aluminum oxidizes with air; therefore, the surface of the aluminum coil must be treated by an etching process. Chemical etching is a non-traditional machining process in which material is removed using a strong chemical solution called an "etchant". This is simply the "accelerated and controlled corrosion" process. *13
2. Graining: grain refinement of aluminum provides better surface properties, which define the lithographic behavior of the plate. Graining is done by roughening the surface mechanically or treating it chemically or electrolytically.
3. Anodizing: anodization improves the durability of the printing plate, making the surface corrosion-resistant, with an anodic oxide finish. Anodizing is accomplished by immersing the aluminum into an acid electrolyte bath and passing an electric current through the medium (AAC).*14
4. Coating: the aluminum is coated with a light or thermal-sensitive emulsion at a constant thickness, then dried in an inline process.
5. Inspection and finishing: after the inspection, the web is leveled and trimmed according to the final product size and then packed for product shipment to PSPs around the world.

A plate cylinder with a large diameter typically accommodates thicker plates to reduce risk of stretching and cracking of the plate. Hence, it is common practice to use thicker offset plates for B1 offset presses. The commonly used 0.3 mm thickness offset printing plate for a B1 offset press contains more than 600 grams of high-quality primary aluminum per plate.

The LCA study compiles all life cycle inventory (LCI) data arising from material and their processes. Aluminum is the most significant environmental impact contributor due to its energy-intensive, lengthy interregional manufacturing operations' accumulating large environmental footprints for the creation of new offset printing plates.

Aluminum recycling

Aluminum is regarded as an "energy bank" in that nearly all of the original energy stored in the metal can be recovered again and again every time the product is recycled.*15 According to the International Aluminum Institute. (IAI, 2020*16) The global Recycling Efficiency Rate (RER) of aluminum is currently 76%. Recycling aluminum is done by heating it in a molten salt flux of sodium and potassium chlorides, which absorbs the impurities in the scrap. A pool of molten aluminum then sinks to the bottom of the furnace and can be tapped off. Aluminum recycling requires as little as 5% of the energy needed for primary aluminum production.*17 Hence, aluminum recycling is highly desirable from both the economic and the environmental sustainability standpoints. The only downside of the recycled aluminum is its impurities, originating from the scrap treatment process, generally not present in primary alloys. Therefore, a mixed source of recycled aluminum is not the ideal material for products which require purity of aluminum to ensure strict product performance. Unfortunately, offset printing plates used among quality conscious PSPs fall under such a product category. The typical alloy used in an offset printing plate is a litho-grade aluminum, such as 1050 aluminum alloy, with a purity of no less than 99.5%.

Circular economy of offset printing plates

USED OFFSET PRINTING PLATES

1. Reused plates – some printers keep offset printing plates for reuse to reprint repeat job orders from the same clients. For instance, offset packaging printers are more familiar with inventory levels and ordering cycles of their clients. Hence, they have more reuse plate opportunities than commercial offset printers. Although reusing an offset plate can help a PSP reduce initial tooling costs, there are significant downsides as well. Print quality issues can occur by plate wear and tear, resulting in plate scumming (the non-image areas of a plate becomes receptive to ink). These issues are typically only found after the plates are mounted on the press and prints are made. From an overall business standpoint, reprints created by reuse of offset plates do not really pay off vs. the risk of print failure. Hence, most PSPs who guarantee high quality print with a small margin of color tolerance prefer using new offset plates.

2. Recycled plates – collection rates of used offset printing plates are well over 90% because most PSPs try to recoup plate costs by selling used plates as scrap aluminum. Most recyclers will purchase aluminum printing plates for recycling and pay PSPs based on net weight and the aluminum scrap market price. From a sustainability point of view, recycled, repurposed aluminum printing plates create a legitimate ecosystem which contributes to circular economy, preserving natural resources and reducing landfill waste. Purity of aluminum is a critical parameter defining product performance of offset printing plates, but there are many other industrial applications which do not require such a high purity. Aluminum scrap collected at the end of a product's life might be mixed with other materials that spoil its purity. Figure 28 shows the possible input source and end of life output options for aluminum printing plates.

3. Regenerated plates – the leading offset printing plate suppliers were trying to create closed loop recycling of aluminum in the offset printing plates market. (Figure 28, Product life cycle flow 2-4-3), They claimed up to 60% CO_2 reduction by closed loop recycling of aluminum printing plates (CTP, PS) comparing with CO_2 emission from plate production using primary aluminum. However, availability of such a service is limited in practice due to the economic viability of its business model collecting used offset plates from remotely located user sites to a central location for specific recycling. Furthermore, sales of offset printing plates have been declining due to the transition to digital media, and the diversification of printed output driven by digital printing. The shrinking business environment makes it harder to scale up environmentally-driven programs such as closed loop recycling of plates.

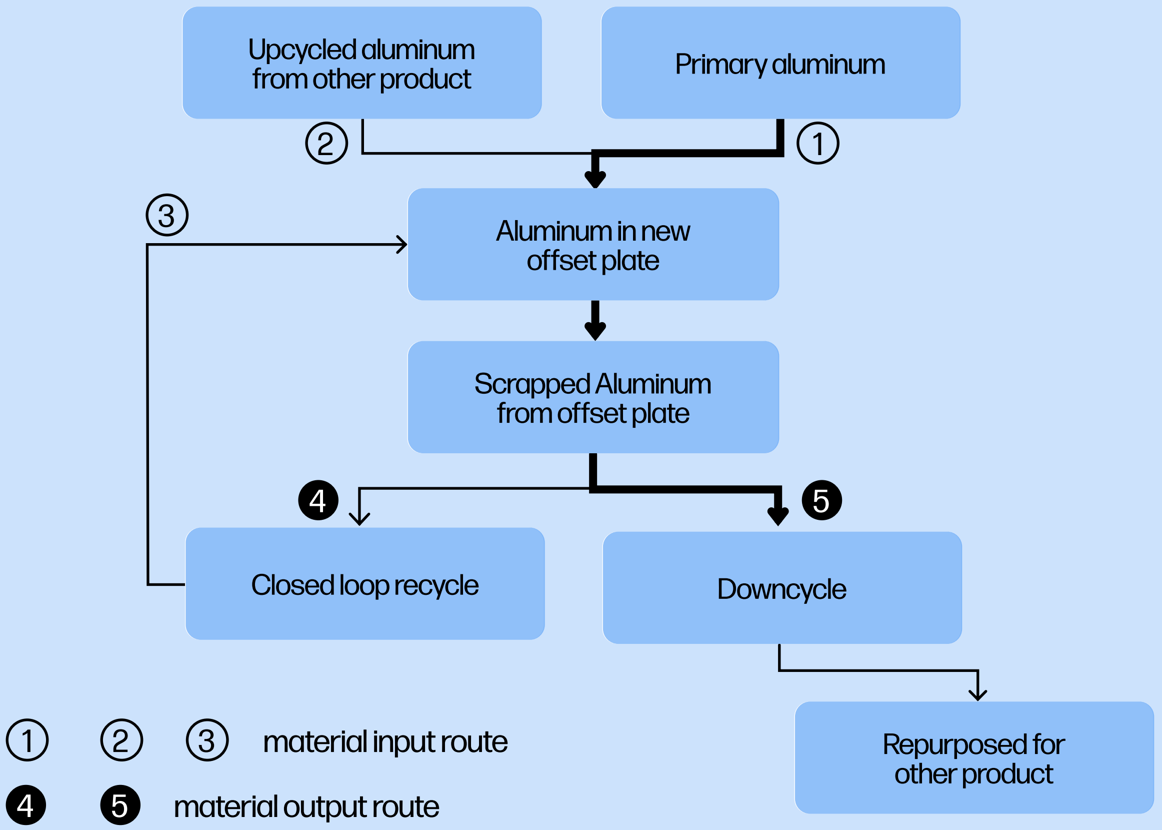


FIGURE 28: DIAGRAM OF PLATE RECYCLING

In practice, most aluminum printing plates are down-cycled and repurposed, (Figure 28, Product life cycle flow 1-5) therefore this LCA study used down cycle scenario for offset printing plate. The choice of technologies for printing according to jobs, which define needs for the number of printing plates, make a significant difference operating low environmental impact production printing. Use of litho-grade quality aluminum alloy among the main consumables for manufacturing equipment can become a potential hot spot of environmental impact. Furthermore, low reuse rate of offset printing plates in commercial print applications significantly affects LCA results.

Sensitivity analysis

Sensitivity analysis was conducted to test the sensitivity of the study results to changes in key parameters and assumptions in the life cycle models

1) Sensitivity analysis: number of required offset printing plates per job

This LCA revealed the manufacturing and processing of offset plates was a hot spot for several of the impact categories considered in this LCA study.

A sensitivity analysis was conducted to determine the potential change in the study results as the number of offset plates required to print 500 A4 Catalogues varies. Some of these scenarios are likely unrealistic but were included to explore the best and worst case scenarios.

Results of the sensitivity analysis (Figure 29) indicate that even at unrealistic levels of reduced plate usage, the global warming potential of the offset printing presses declines substantially but still does not crossover with the HP Indigo press. This indicates that even producing small numbers of plates has a high impact relative to consumables of an HP Indigo press, and that the impact from the material and energy use required for print setup of offset presses remains a major contributor overall.

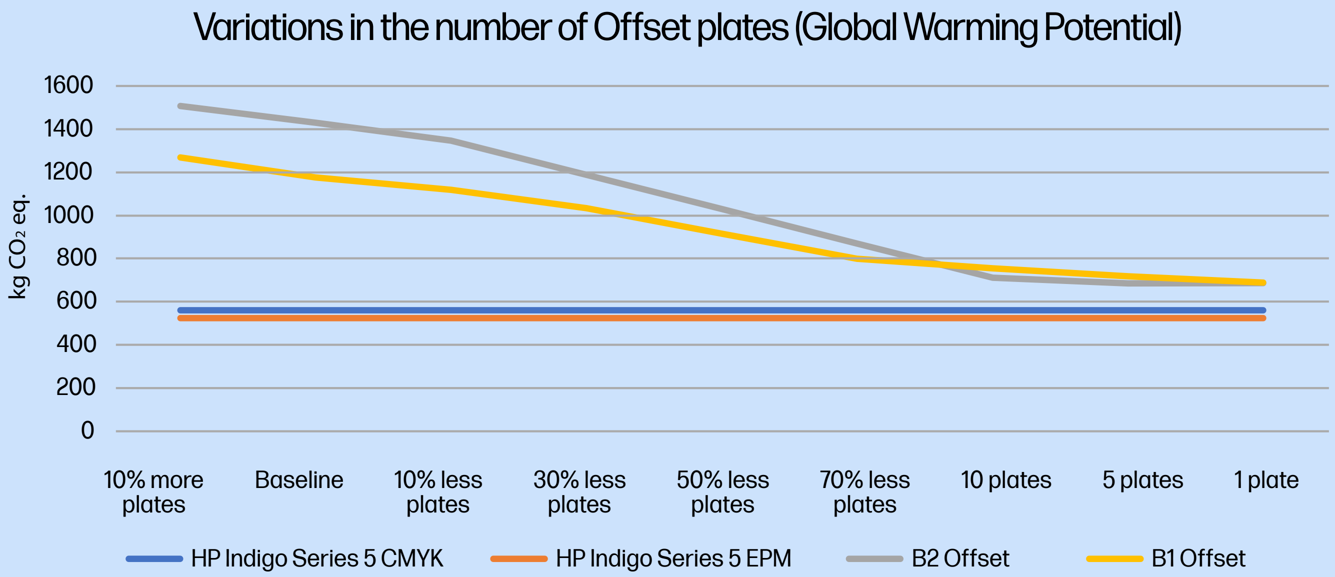


FIGURE 29: SENSITIVITY ANALYSIS - VARIATIONS IN NUMBER OF OFFSET PRINTING PLATES

2) Sensitivity analysis: lower impact aluminum used in offset printing plate

Sensitivity analysis was also conducted to determine the change in study results when lower impact aluminum sources are used to produce offset plates. These scenarios may not be completely realistic but are included to account for maximum uncertainty in the inventory data quality for offset plates. Results of this analysis (Figure 30) show that although the global warming potential of the offset presses starts to converge with HP Indigo press as the impact of aluminum is decreased, they do not crossover, even at 100% reduced impact aluminum. This further highlights the impact from the higher material and energy use required for print setup of offset presses, as well as the electricity use for plate production, which remain major contributors overall despite reduction in plate impact.

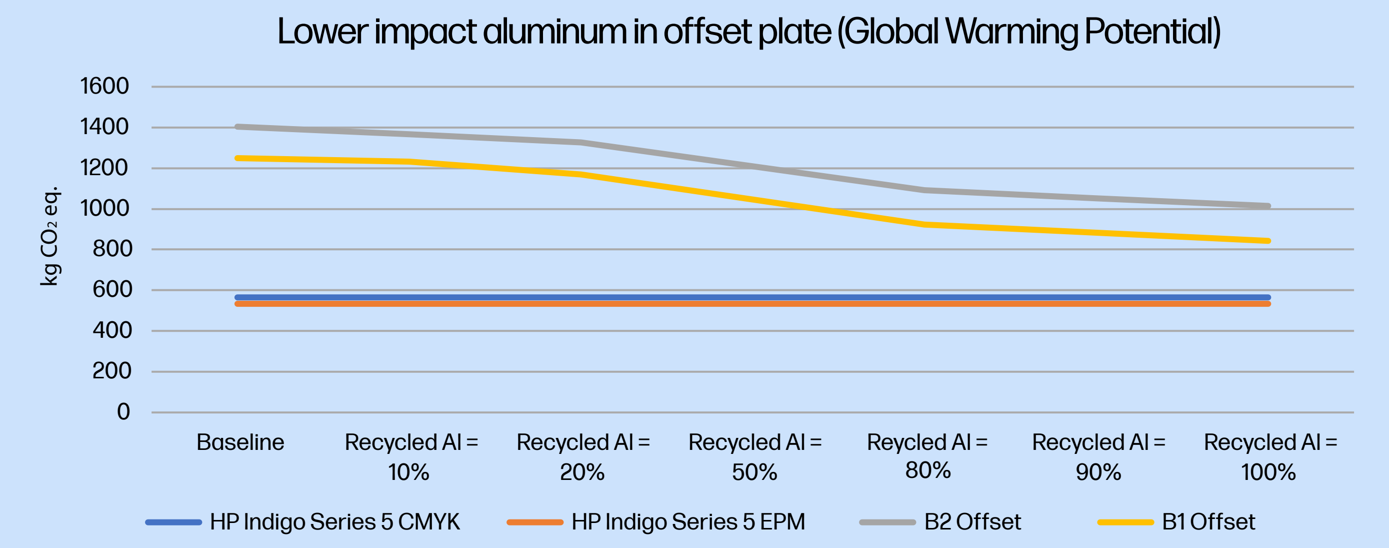


FIGURE 30: SENSITIVITY ANALYSIS - LOWER IMPACT ALUMINIUM IN OFFSET PLATES

3) Sensitivity analysis: number of pages in A4 Catalogue

In Figure 9, it was shown that the economic crossover point for HP Indigo Series 5 press and offset presses occurs somewhere around 500 to 700 A4 Catalogueues printed (160 pages each) depending on which press is used. Sensitivity analysis was also conducted to determine if similar crossover points could be identified for environmental performance. In the first sensitivity test, global warming potential results are shown for all printing presses when the number of pages in each of the 500 Catalogueues. As the number of pages decreases below the baseline analysis of 160 pages per Catalogueue, the number of offset plates required per print job declines for the offset presses, which could potentially have a substantial influence on the comparative results due to the high contributions to impact from offset plate production.

Results of this sensitivity test (Figure 30) indicate that when the number of pages is decreased, the global warming potential for offset presses is closer to that of HP Indigo press due to the decreased number of plates required. However, even at four pages per Catalogueue, the global warming results do not crossover with HP Indigo press. At higher page numbers, more plates are needed, and the global warming potential for offset presses show a wider spread. Note that these results are shown per Catalogueue printed.

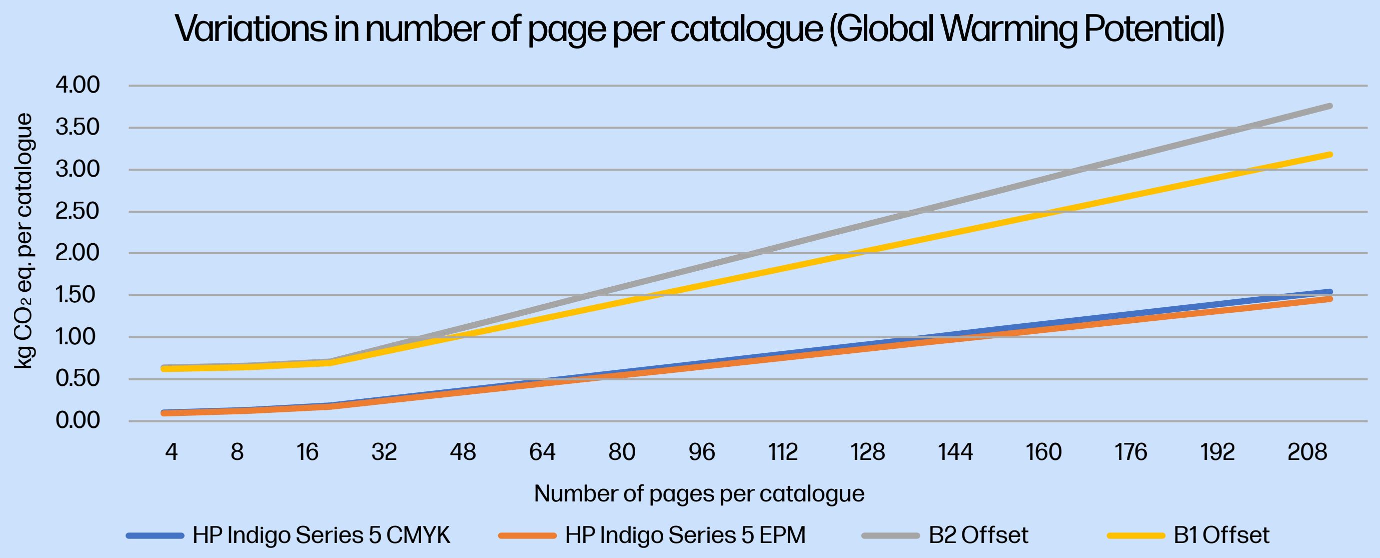


FIGURE 31: SENSITIVITY ANALYSIS - VARIATIONS IN NUMBER OF PAGES IN CATALOGUES

4) Sensitivity analysis: number of A4 Catalogues

In another sensitivity test, global warming potential results are shown for all printing technologies when the number of Catalogues printed (160 pages per Catalogue) is varied. Results of this sensitivity test (Figure 31) indicate that as the number of Catalogues printed increases, the results expressed on a per Catalogue basis start to converge, and a crossover point is reached at 5,000 Catalogues (equivalent to 100,000 B2 sheets). The finding of this crossover point reinforces the general trend that conventional offset printers perform more efficiently at higher production levels, however it is a much higher crossover point than what was shown for the economic analysis in Figure 9.

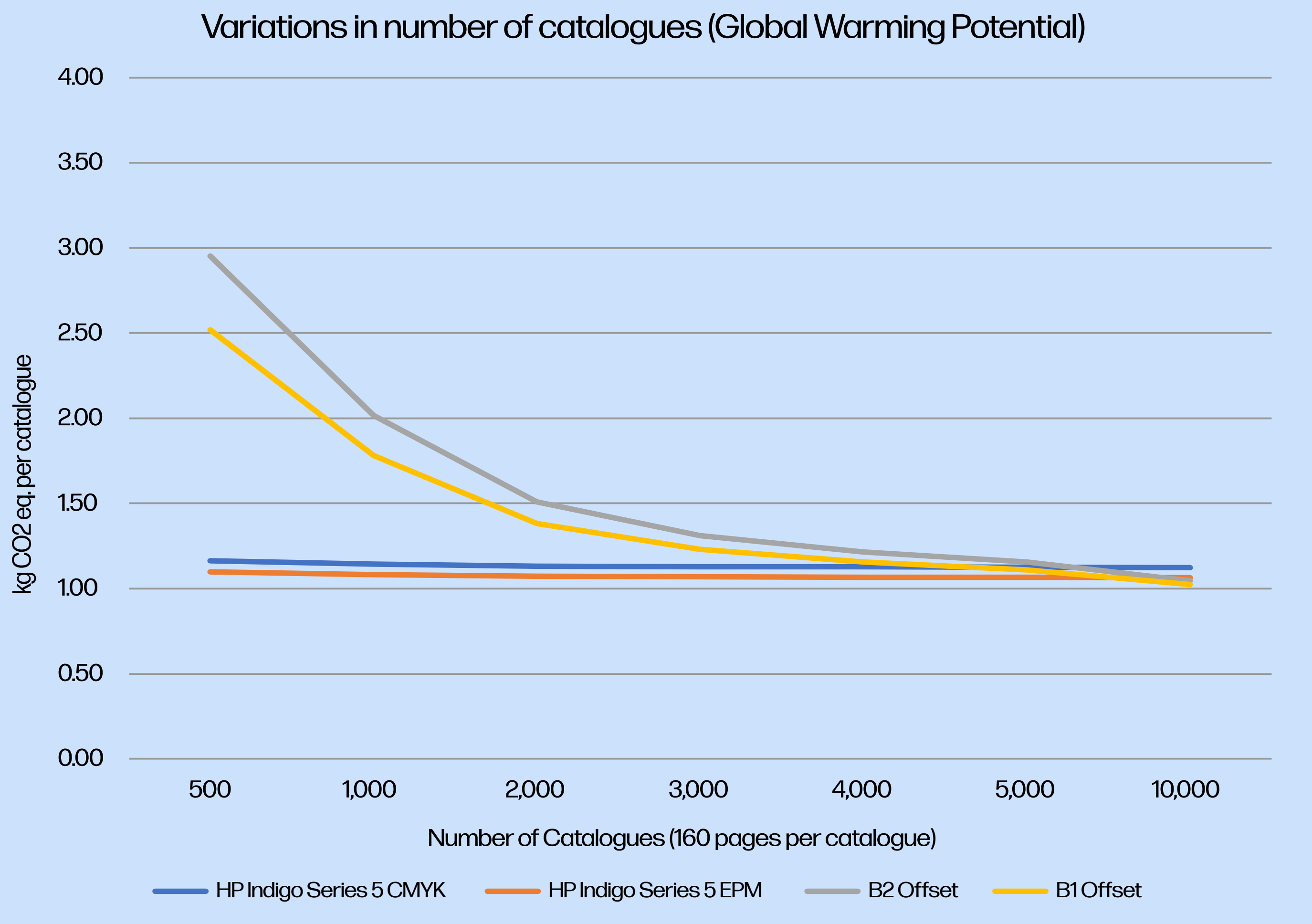


FIGURE 32: SENSITIVITY ANALYSIS - VARIATIONS IN NUMBER OF CATALOGUES

5) Sensitivity analysis: offset press with perfecting device

Energy efficiency of offset printing press can be impacted by various parameters such as choice of ink type, fountain solution, type of print images which defines ink coverage, substrate, use of over print varnish, and quantity of print outputs per job etc. Furthermore, system configuration such as perfecting device can improve energy efficiency when printing duplex printing job. The baseline comparative analysis was based on non-perfector offset printing press that requires an additional step, such as pile-turner (flipping the pile of printed sheets and feeding them back into the printer) for duplex printing. Figure 33 shows transition of press mode from Off to ON – STAND – IDLE/Print Ready – RUN and which correlates between make ready (incl. Calibration) and production printing. While Indigo press prints duplex in one pass, 6C offset press requires offline pile turner for duplex print. In essence, HP Indigo digital press does not need setup procedure, press can start production run immediately from Stand – Print ready mode. Digital press does not need to stop for plate changes; hence, all the necessary images (pages) are imposed according to finishing and complete print of all the pages needed for a finished product.

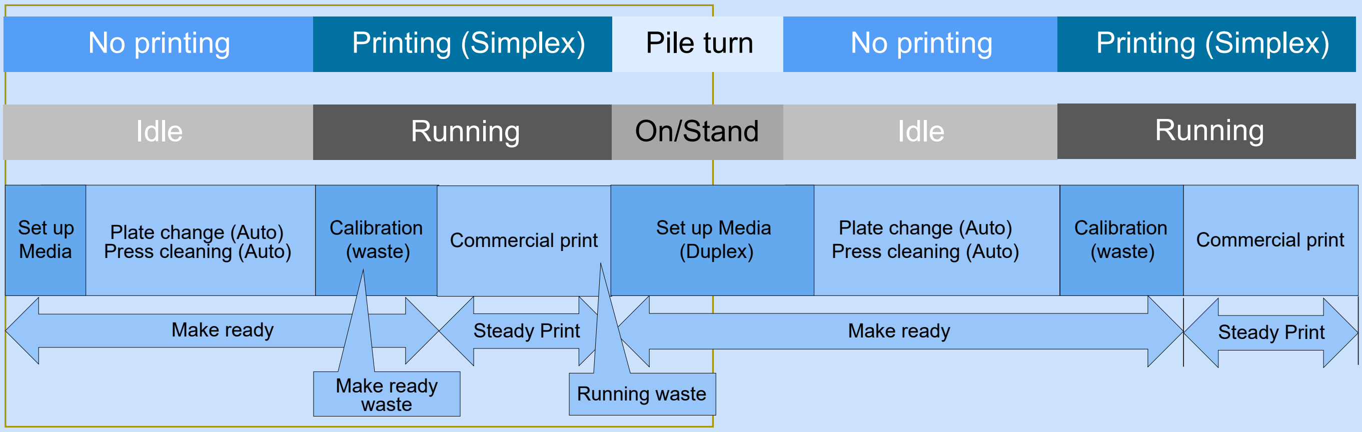


FIGURE 33: LCA BASELINE SCENARIO OF NON-PERFECTING OFFSET PRINTING PRESS (6C+L), SIMPLEX PRINT JOB (CMYK) X 20 SETS

Figure 33 demonstrates complexity and inefficiency with printing a small quantity GCP job (duplex) with 6C offset press. Although the latest model of offset press is equipped with highly automated make-ready features such as auto plating, auto cleaning and fast color calibration, and which enables press-to-start run of new job in less than five minutes. That said, unlike Digital press, offset press has inherent operational constraints of plate change per image. (i.e., page). The offset presses can provide the best energy efficiency at peak throughput. Although, the latest model of offset press can run speed up to 18,000 B1 sheets per hour and does not take minutes to speed up to maximum speed. However, if print volume to changing of printing plates is as few as a few thousand sheets, more time can be spent for make-ready production runs and it also cause make ready waste per job.

Sensitivity analysis was conducted to determine the influence on the study results if perfecting press (8 ink towers) was used. Results of the sensitivity analysis (Figure 34) show that although global warming potential impact decreases slightly when a perfector is used, the reduced setup does not shift the impact, which becomes equivalent across all digital and offset presses in this scenario.

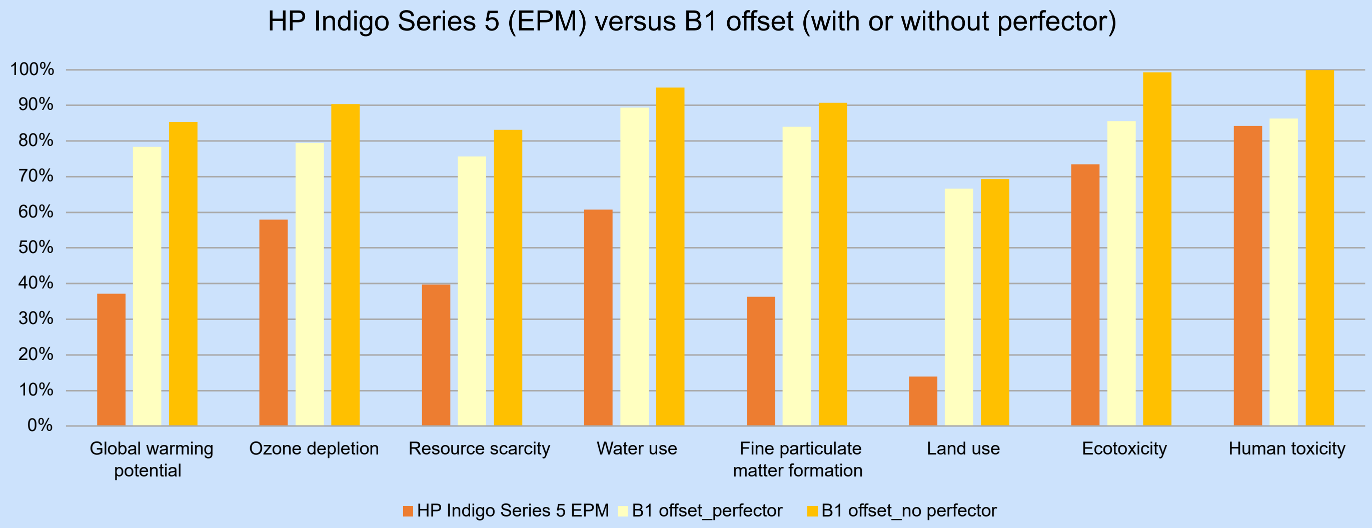


FIGURE 34: SENSITIVITY ANALYSIS - RELATIVE IMPACT FOR HP INDIGO SERIES 5 PRESS (EPM) AND B1 OFFSET PRESS (WITH OR WITHOUT PERFECTOR)

Critical review

The LCA model and report follows ISO 14040 (ISO, 2006a) and 14044 (ISO, 2006b) requirements for comparative LCA studies intended to be disclosed publicly. In compliance with ISO 14044 requirements for comparative assertions intended for public dissemination, a third-party critical review was carried out by a panel of experts and stakeholders, whose main purpose was to ensure ISO compliance and to decrease the likelihood that any processes or technologies were improperly represented. Critical review is a process that ensures consistency between a life cycle assessment and ISO requirements for carrying out an LCA.

Conclusion

This peer-reviewed LCA study revealed an environmental impact hot spot for both offset printing technology and HP Indigo LEP technology when used to produce small quantity or multi-SKU for commercial print jobs, which typically involve a number of offset plates and plate changeovers for offset presses. A number of sensitivity analyses and comprehensive evaluations were performed in compliance with ISO 14044. Those efforts led to the following summary, conclusion, and recommendations:

- In the baseline scenario, which ties to the economical crossover point, the HP Indigo Series 5 press outperformed offset print technology across all environmental impact categories considered.
- Contribution analysis revealed the offset printing plate as the unique hot spot for offset presses, which resulted in a larger overall environmental footprint than HP Indigo Series 5 press.
- Although paper substrate in the printing stage appeared as a primary contributor in many impact categories, it was not unique to offset presses and the same trends applied to the HP Indigo press. Therefore, paper substrate did not become a main cause of larger environmental footprint of offset presses in the comparative LCA study.
- In the baseline scenario, printing on the HP Indigo Series 5 press with EPM demonstrated the lowest environmental impact, while gaining economic benefits. It is therefore the most recommended printing technology for PSPs who have job baskets similar to the baseline scenario.
- Sensitivity analysis showed that the environmental impact of offset presses decreased as the number of plates was reduced however, even when using a minimum number of plates it did not meet the environmental footprint crossover point against the HP Indigo Series 5 press. This means that the lower environmental impact advantage of the HP Indigo press does not depend only on the environmental footprint of the offset printing plate.
- An increased number of Catalogues means more print volume. And offset presses gain not only economic benefits but also start closing the environmental impact gap by offsetting environmental footprint originating from the offset plate. However, sensitivity analyses showed that a crossover point can reach 5,000 Catalogues (equivalent to 100,000 B2 sheets), which is far beyond the economic crossover point.
- In essence, offset printing technology and HP Indigo Digital offset technology are complementary. Nevertheless, when seeking to reduce the environmental footprint of commercial print jobs, it is worth considering HP Indigo Series 5 press for even larger print volumes than the economical crossover point.

The optimized finishing process was not considered in this LCA study. It is worth noting that a digital press can simplify process flow with optimized finishing processes such as signature collation followed by binding the printed pages together. Implementing those optimized finishing solutions can reduce overall production waste, thus reducing environmental footprint. The environmental footprint of HP Indigo Digital presses in conjunction with optimized finishing solutions may further lower the environmental impact associated with manufacturing final products.

Citations & references

*1: UN,2022 : THE SUSTAINABLE DEVELOPMENT GOALS REPORT 2022
HTTPS://UNSTATS.UN.ORG/SDGS/REPORT/2022/THE-SUSTAINABLE-DEVELOPMENT-GOALS-REPORT-2022.PDF

*2: HP Indigo Sustainable Impact Overview 2020 and 2021 updates, page 29
HTTPS://H20195.WWW2.HP.COM/V2/GETDOCUMENT.ASPX?DOCNAME=4AA8-1407ENW

*3: HP Indigo FAQ, page 8 – 9
https://h20195.www2.hp.com/v2/getpdf.aspx/4AA7-8653ENW.pdf

*4: Iyyanki V. et al., (2017), Chapter Five - Life cycle Assessment, Editor(s): Iyyanki V. Muralikrishna, Valli Manickam, Environmental Management, Butterworth-Heinemann, 2017, Pages 57-75, ISBN 9780128119891,
https://doi.org/10.1016/B978-0-12-811989-1.00005-1.

*5: European Platform on LCA | EPLCA, Life cycle Assessment (LCA)
https://eplca.jrc.ec.europa.eu/life cycleassessment.html

*6: United States Environmental protection agency, Understanding Global Warming Potential
https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

*7: European Platform on LCA | EPLCA, The 16 impact categories of the Environmental Footprint
https://eplca.jrc.ec.europa.eu/uploads/EF_categories_description.pdf

*8: The U.S. Geological Survey, National Minerals Information, Center Bauxite and Alumina Statistics and Information
https://www.usgs.gov/centers/national-minerals-information-center/bauxite-and-alumina-statistics-and-information

*9: The Aluminum association, Bauxite 101
https://www.aluminum.org/bauxite-101

*10: Kvande, Halvor & drabløs, per arne. (2014), The Aluminum Smelting Process and Innovative Alternative Technologies. Journal of occupational and environmental medicine / American College of Occupational and Environmental Medicine. 56 Suppl 5S. S23-S32. 10.1097/JOM.0000000000000062.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4131935/

*11: International Aluminum Institute, Statistics, Greenhouse Gas Emissions – Aluminum Sector, Date of Issue: 25 January 2023
https://international-aluminium.org/statistics/greenhouse-gas-emissions-aluminium-sector/

*12: European Aluminum association
https://european-aluminium.eu/projets/a-low-carbon-footprint/#

*13: O. Çakır, (2008) Chemical etching of aluminum, Journal of Materials Processing Technology, Volume 199, Issues 1–3, 2008, Pages 337-340, ISSN 0924-0136, https://doi.org/10.1016/j.jmatprotec.2007.08.012.

*14: Aluminum apodizers council
https://www.anodizing.org/page/what-is-anodizing

*15: U.S. Energy Requirements for Aluminum production (February 2007)
https://www.energy.gov/eere/amo/articles/us-energy-requirements-aluminum-production

*16: International Aluminum Institute, ALUMINIUM RECYCLING
https://international-aluminium.org/wp-content/uploads/2021/01/wa_factsheet_final.pdf

*17: The aluminum association
https://www.aluminum.org/Recycling

Learn more at
hp.com/go/indigo

Share with colleagues

Rate this document

Product number TS5OO-00003

Trademark acknowledgments, if needed.

HP Indigo