



Life Cycle Environmental Impact Study on LaserJet Toner Cartridges

HP Reused Cartridges vs. Remanufactured Cartridges

SUMMARY REPORT

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EXECUTIVE SUMMARY

HP Inc. commissioned Four Elements Consulting, LLC, to perform an environmental Life Cycle Assessment (LCA) comparing reused Original HP LaserJet toner cartridges used in France, called HP EvoCycles, with remanufactured (reman) cartridges sold as substitutes for purchase and use in France. In 2016 and again in 2019, a similar set of studies were performed, in which Original HP LaserJet toner cartridges were compared with remans. The 2016 studies underwent external peer-review for conformance with the International Standards Organization (ISO) 14040 and 14044 standards. This study uses the same methodologies and models as the 2016 studies – also adhering to the 14040 and 14044 ISO standards – and evaluates all phases of the life of the cartridges, from material sourcing, manufacturing, use, and end-of-life disposition. This Summary Report presents the results of the LCA.

The goal of this study was to provide a comparative environmental assessment utilizing the most current research and data on production practices, disposition trends, product quality, and usage trends of HP EvoCycle toner cartridges and reman alternatives sold and used in France. The study found that, as in previous HP studies that include the use stage, paper consumption related to printing is the largest contributor to the environmental footprint across all phases of the life cycle for both the HP EvoCycle and the reman alternative.

The study also shows that in all assessed categories, the HP EvoCycle cartridge showed lower or comparable environmental impacts than the reman alternative. Optimized print quality performance minimizes the environmental impact for the HP EvoCycle cartridge because fewer pages need reprinting. For customers who print documents for both internal and external purposes and who are concerned about the environmental impact of their cartridge choice, HP EvoCycle cartridges are a wise choice compared to reman alternatives. The study also found that for users whose print quality requirements are not high, the environmental impact of the HP EvoCycle still nets slightly lower than the reman, thanks to the advanced cartridge recycling processes within HP's Planet Partners program.

SUMMARY REPORT

INTRODUCTION

For almost two decades, HP has been evaluating life cycle environmental impacts of its LaserJet toner cartridges. The most recent set of studies were completed in 2019, where HP commissioned Four Elements Consulting, LLC, to perform life cycle comparisons of Original HP toner cartridges vs. remanufactured cartridges and New Build Compatible (NBC) cartridges, sold in the North America, Europe, Middle East & Africa (EMEA), Asia, and Latin America markets.ⁱ The 2016 version of the Original HP vs. reman study was externally peer reviewed for conformance with the ISO 14040 and 14044 standards for environmental LCA by a three-person panel of experts, ensuring a sound methodology and high credibility and objectivity of the data and results. This LCA carries over the same methodology and goals as these prior studies. It utilizes the most current available research and data for production practices, disposition, and product quality for HP toner cartridges and remans sold in France.

METHODOLOGY

PRODUCTS STUDIED

The CF226X (26X) toner cartridge, HP EvoCycle's predecessor, was used for this study. The 26X is a popular mono print cartridge in France and has a wide selection of aftermarket cartridges available, including remans. The 26X is a top-selling model for its target markets of home offices and small businesses. The 26X is summarized below.

Table 1 Summary of Cartridges Studied

Cartridge SKU	HP Original Printer	Page Yield	Relevance to this study
26X	HP LaserJet 400 M402n printer	9,000 ⁱⁱ	Significant contributor to its target markets: home office and small business

The HP EvoCycle 26X cartridge was compared to the 26X reman cartridge substitute. The HP EvoCycle is produced from an Original HP 26X empty cartridge that has been sent for recycling at an HP Planet Partner recycling facility in France. There, it is disassembled, inspected, cleaned, and then assembled with Original HP 26X parts that can be reused, new Original HP 26X parts, and HP toner. This study defines a reman cartridge as a used HP empty that has been disassembled, inspected, cleaned, repaired, and has some parts replaced. The cartridge is then refilled with non-HP toner and reassembled. The reman cartridge is most often made from a "virgin" OEM empty – one that has never undergone remanufacturing. This is supported by printing industry analyst InfoTrends Research

(InfoTrends), which found that 82% of remanufactured toner cartridges in the EMEA market are single “cycle”.ⁱⁱⁱ This analysis does not intend to mirror one specific brand of reman cartridge; it is acknowledged that there is broad variability in the reman industry and one specific brand would be unrepresentative. The HP EvoCycle and the reman cartridges are modeled as single use.

ADHERENCE TO THE ISO STANDARDS

This LCA adheres to the principles, framework and guidelines in ISO 14040 and 14044.^{iv}

SYSTEM BOUNDARIES

LCA is a tool for the systematic evaluation of the environmental impacts of a product through all stages of its life cycle. The defined life cycle phases include production, distribution to the customer, use of the cartridge, and end of life (EOL). Figure 1 presents the study’s system boundaries.

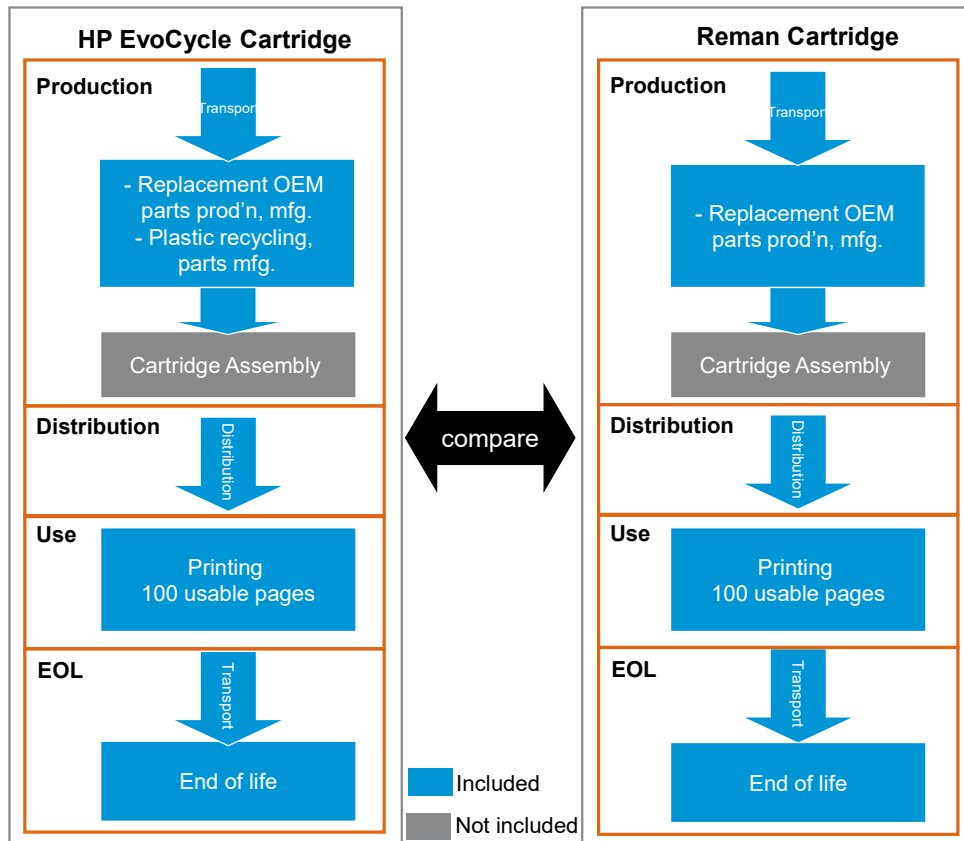


Figure 1 System boundaries

DATA SOURCES

HP provided data on the HP EvoCycle cartridge including the total bill of materials, parts reused, replaced, and recycled; place of manufacture; packaging specifications; printing specifications; and cartridge recycling practices. In 2019, HP commissioned *SpencerLab*, an internationally recognized leader in independent research and comparative analysis of print system performance, to test the print quality and reliability performance of Original HP 26A cartridges and compare them to top selling reman brands in EMEA.^v In 2021, *SpencerLab* performed the same testing methodology to assess the print quality and reliability performance for the EvoCycle cartridge so that it could be compared to its substitutes on the market.^{vi} In 2021, HP commissioned Escalent to conduct a Customer Experience study which provided intended page use data for customers who use HP LaserJet printers.^{vii} The studies by *SpencerLab* and Escalent were used to establish the number of pages printed to attain 100 usable printed pages, the basis upon which the comparison is made (next section). Key assumptions were checked for sensitivity.

Secondary data sources were evaluated for temporal, geographical, and technological coverage. Data available from LCA software databases were evaluated, and the most current and/or best quality data available at the time of the study were used. SimaPro, a commercial LCA software product, was used to model and calculate the LCA.^{viii} The study included data from the latest available

version of the Ecoinvent database.^{ix} Utilizing the most current and available data, especially from a widely-known and respected database, enhances the quality of the study and increases its transparency, reliability, and confidence level.

FUNCTION AND FUNCTIONAL UNIT

In order to conduct an ISO-compliant LCA, all flows within the system boundaries must be normalized to a unit summarizing the *function* of the system, enabling the comparison of products or systems on an equivalent basis. The function of a cartridge is to print pages. Because cartridge print quality performance has been evaluated, the function incorporates the print quality differences. Thus, the function of the system has been defined as printing to obtain usable pages for their intended use. With the function defined, a “functional unit”, or reference flow, is chosen in order to calculate the systems on that quantitative basis. For this study, the functional unit was defined as “the printing of 100 usable monochrome one-sided pages,” which accounts for printing 100 pages plus any reprinting needed to satisfy the intended use. The *SpencerLab* study defined print quality in terms of the acceptability of the printed pages. The Escalent page use distribution is an important study parameter; the relationship between how one uses a printed page and the required print quality determines the number of pages one might have to reprint.

MODELING AND ASSUMPTIONS

The sections below summarize each life cycle stage’s modeling and assumptions. Appendix 2 provides the data and assumptions.

PRODUCTION

The HP EvoCycle is produced when a used Original HP 26X is sent for recycling at HP’s Planet Partners facility in France. There, it is disassembled, inspected, and cleaned. Using proprietary HP processes, the HP EvoCycle is assembled with Original HP 26X parts that can be reused, new Original HP 26X parts, and new HP toner. The HP EvoCycle’s body is made from closed loop recycled polystyrene, sourced from Original HP cartridges recycled at the Planet Partner facility. The HP EvoCycle cartridge undergoes stringent quality testing before being sold to customers in France. The replaced parts undergo Planet Partners’ patented cartridge recycling processes. New HP parts are modeled as the mass of the materials in the parts plus parts forming (e.g., injection molding of plastic into cartridge parts, forming of aluminum and steel parts, etc.).

The reman cartridge model includes transport of the used cartridge to the remanufacturer, disassembly, inspection, and cleaning. The cartridge is reassembled with some reused parts, some replaced parts, and new toner, before it is packaged and prepared for the market. The reman production phase also includes managing the original cartridge parts that have been replaced and cartridges not suitable for remanufacturing, which are determined at the “sort and discard” step prior to remanufacturing. Management of these parts includes recycling, incineration with energy recovery (waste-to-energy, WTE), and going to municipal waste. The remanufacturer is modeled as located in the EMEA region for a lower, or more conservative, transportation distance. The sensitivity analysis section looks at the reman facility located farther away, in Asia.

While both cartridge alternatives include intermediate and final assembly, no data were available for this aspect of production. The HP EvoCycle’s assembly process is automated using HP technology. While energy is consumed during this process, energy use is likely small relative to parts manufacturing. Remanufacturing may be done using manual labor (i.e., with drills and other pneumatic tools), it may be a more automated process, or a combination thereof. A more automated and precise OEM assembly process may be relatively more energy intensive than a plant using manual labor. But more manual labor potentially increases the human-related impacts, such as transportation of workers to the factory, plus lighting and human labor-related aspects. Similar to the HP EvoCycle, replaced parts production and forming has been included, but energy usage and other process aids used in the activities at the reman facility is also a data gap. The implications and limitations of the energy and processing data gaps are addressed in the Limitations section.

DISTRIBUTION

The Distribution Phase refers to the delivery of the packaged HP EvoCycle cartridges and the reman cartridges from final assembly to the end user in France.

USE

Use Phase modeling accounts for the amount of paper and printer energy needed to print 100 usable pages. Information on pages printed and printer energy are found in Table 12. The paper production model, based on a comprehensive North American paper and printing LCA completed in 2010^x is described in the Data Quality section (p. 11). Page quality performance was assessed in the *SpencerLab* study where a sample of Original HP and reman cartridges were evaluated and 64 pages were taken at periodic intervals over the life of each cartridge tested. The sampled pages were graded on overall print quality using a scale created from a psychometric research study of business laser printing users. The psychometric research provided a scale in which print quality could

be sorted into four acceptability levels or categories, described as follows and summarized with the *SpencerLab* test results in Table 2.^v

1. All uses, including External Use: Acceptable for all uses, including distribution outside a company to customers, vendors, suppliers, etc. Examples: marketing materials to promote the company or products, official company correspondence, invoices.
2. Internal Use: Acceptable for distribution inside a company, but not acceptable for distribution outside a company. Examples: documents to distribute to colleagues, immediate superiors or subordinates as business communication.
3. Individual Use: Individual use only; usable as a copy to read, file or mark-up but not acceptable for distribution, either within or outside a company.
4. Unusable: Not acceptable for any business purpose.

Table 2 Print Quality Distribution

	External Use	Internal Use	Individual Use	Unusable
EvoCycle Cartridges Tested ^{vi}	94.7%	5.3%	0.0%	0.0%
Reman Cartridges Tested (Average) ^v	71.9%	28.1%	0.0%	0.0%

From *SpencerLab* methodology, HP learned that print quality acceptability depends on the intended use for the pages being printed. The psychometric study demonstrated that in business settings, some minimum level of print quality is necessary for External, Internal or Individual use. If the minimum required print quality is not met, the page may be reprinted. The acceptability categories help distinguish when a customer might reprint a page that is not suitable for their intended use. For example,

1. External use pages would not need to be reprinted for any purpose as they are of the highest quality.
2. Internal use pages would need to be reprinted if the intended use was for external distribution.
3. Individual use pages would need to be reprinted if the intended use was for internal or external distribution.
4. Unusable pages would need to be reprinted for any intended use.

As part of its test protocol, *SpencerLab* also checked and documented any cartridges that were deemed “Dead on Arrival” (“DOA”). A cartridge was considered DOA when it was found to be defective in printing or structural integrity such that it is unusable.^{xi} Of the cartridges tested, 10% of the remans were DOA. While these unusable cartridges do not contribute to impacts related to printing at Use Phase, other aspects of the life cycle of the cartridge would need to be accounted for, since the DOA cartridge is still produced, manufactured, distributed, and disposed of, regardless of its ultimate efficacy. DOA was included in the baseline analysis and a sensitivity analysis assesses its significance in the overall results. No Original HP cartridges arrived as DOA.

Escalent surveyed HP LaserJet users in Germany, France, Italy, Poland, Russia, Turkey, and U.K. on their printing behavior in the work environment, and the resulting page use was distributed across three categories that the users identified: 1) documents to be shared with others outside my organization such as for customers, marketing materials, official company correspondence, invoices etc.; 2) documents to be shared with others inside the organization, such as to colleagues, superiors or subordinates as business communication; and 3) documents for personal use only, such as for use to read, file or make mark-ups.^{vii} These categories corresponded to the page use categories from *SpencerLab* (Table 2). The Escalent page use distribution was used for the LCA’s Use Phase baseline analysis. Sensitivity analyses were performed to examine the case in which a user requires all output to be used for external communication, with reprinting required for all pages not of the highest quality, and another case in which a user prints for individual use only, where lower quality prints are acceptable. Table 3 summarizes the distributions for each scenario.

Table 3 Page Use Distribution

		External Use Acceptable for all uses	Internal Use Limited use: Not for external distribution	Individual Use Limited use: Not for distribution
Baseline	Escalent Survey	31%	41%	28%
Sensitivity	100% External Use	100%	0%	0%
	100% Individual Use	0%	0%	100%

Page use was combined with print quality performance to calculate the number of pages where reprinting is required to meet the intended use and, hence, total number of pages printed in order to obtain the functional unit of 100 usable pages. Understanding the potential for broad variability with the user and quality results, Monte Carlo simulation was used to calculate the average number of prints needed to obtain 100 usable printed pages in order to accommodate this uncertainty.

Table 4 Pages printed to obtain 100 Usable Pages

		Total pages printed to obtain a functional unit		% More Reman Pages Printed	% Less EvoCycle Pages Printed
		EvoCycle	Reman		
Baseline	Escalent Survey	102	110	8%	7%
Sensitivity	100% External Use	106	139	31%	24%
	100% Individual Use	100	100	0%	0%

END OF LIFE

End of life Phase refers to the fate of the cartridge after toner depletion. The used HP cartridge is assumed to be returned for recycling through HP Planet Partners Return and Recycling Program, utilizing existing packaging and free shipping. The reman cartridge is assumed to be thrown away into the municipal solid waste (MSW) stream, which includes landfilling (43%) and WTE (57%).^{xii} A sensitivity analysis of remans being returned to a remanufacturer has been made; since remanufacturers generally do not accept reman cartridges due to quality issues, the sensitivity analysis looks at the spent cartridge managed with other unusable parts.ⁱⁱⁱ Toner cartridges are generally not accepted for recycling at municipal recycling facilities due to lack of infrastructure to disassemble cartridges and separate materials.^{xiii}

RESULTS

BASELINE RESULTS

Table 5 and Figure 2 present results for the baseline comparison. The second to last column in the table presents how much higher the environmental impacts are for the reman cartridge relative to the HP EvoCycle cartridge. In all categories, the reman is 3% or higher. The last column shows how much lower the EvoCycle is compared to the reman, and this ranges from 3% to 12%. As mathematical models of complex systems, all LCAs have inherent limitations that result in some level of uncertainty (see the limitations section for more details). LCA results are therefore assessed using some margin of error, and a +/- 10% margin of error has been used. Several impact categories show differences within +/- 10%: ozone depletion potential, terrestrial ecotoxicity, water use, and total primary energy. For these, the two cartridge types can be considered to be comparable. For the remaining impact categories, the reman results are higher than the EvoCycle.

Table 5 Baseline Results

Impact category	Unit	HP EvoCycle Cartridge	Reman Cartridge	Reman % Higher than EvoCycle	EvoCycle % Lower than Reman
Global warming	kg CO2 eq	7.2 E-1	8.1 E-1	+ 12 %	- 11 %
Ozone depletion	kg CFC11 eq	6.7 E-7	7.3 E-7	+ 8.4 %	- 7.8 %
Ozone formation (smog)	kg NOx eq	2.8 E-3	3.1 E-3	+ 10 %	- 9.2 %
Terrestrial acidification	kg SO2 eq	4.8 E-3	5.4 E-3	+ 11 %	- 10 %
Freshwater eutrophication	kg P eq	2.3 E-4	2.7 E-4	+ 12 %	- 11 %
Human toxicity	kg 1,4-DCB	3.3 E-2	2.6 E-2	+ 13 %	- 12 %
Terrestrial ecotoxicity	kg 1,4-DCB	9.5 E-1	1.3 E+0	+ 3.2 %	- 3.1%
Water consumption	m3	9.4 E-1	1.0 E+0	+ 7.9 %	- 7.3%
Total primary energy	MJ	2.9 E+1	3.2 E+1	+ 9.1 %	- 8.3%

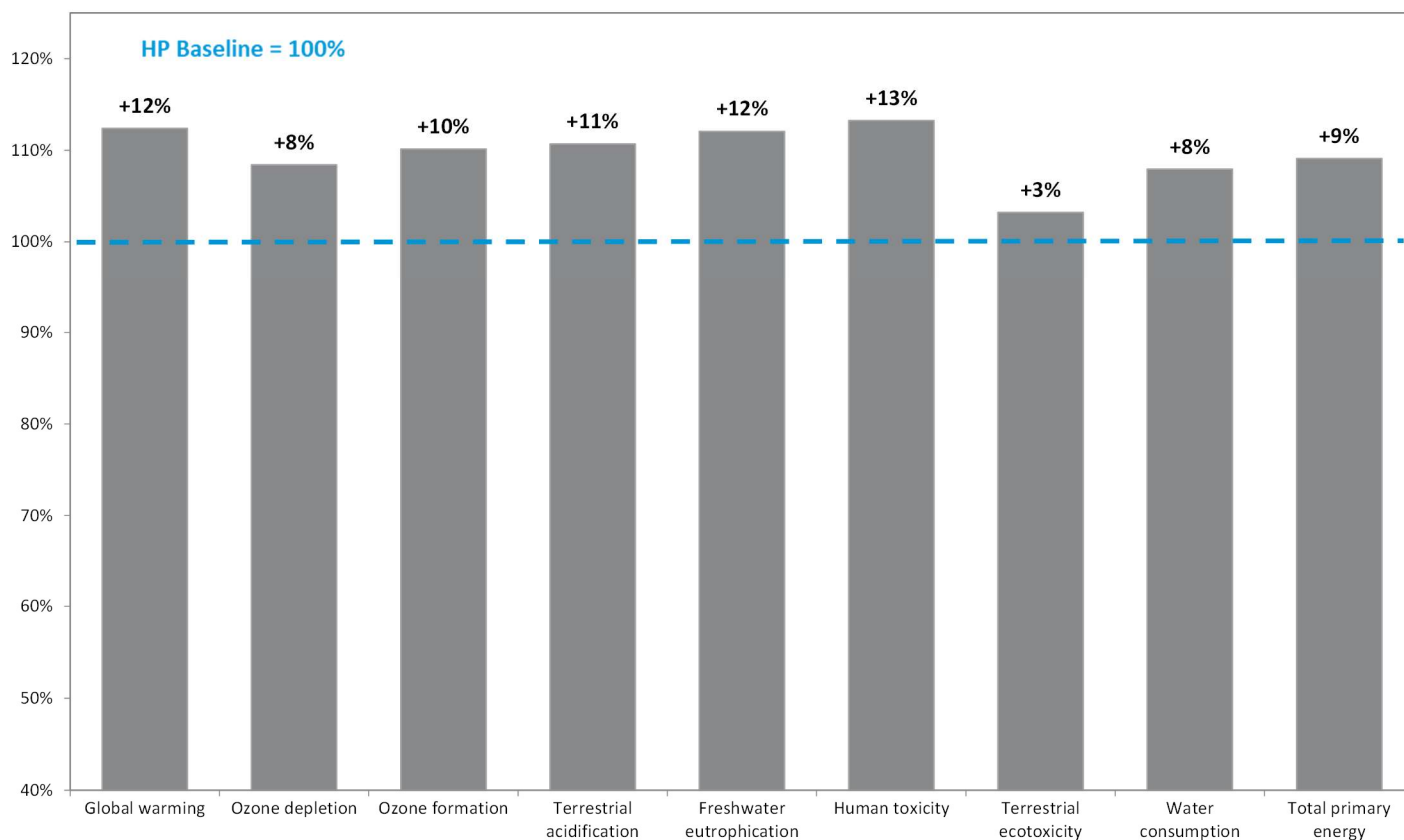


Figure 2 Reman Results Compared to HP EvoCycle Results

Life Cycle Stage Contribution Analysis

Table 6 and Table 7 present a breakdown of impact category results across the four defined life cycle stages. Global warming is presented in life cycle stages in percentages (Figure 3) and absolute values (Figure 4). These results illustrate that the “Use Phase,” and specifically paper use, is the largest contributor to the environmental impact of a toner cartridge. This is the case for both the HP EvoCycle cartridge and the reman cartridge. Note that the negative values for end-of-life represent the offset of materials at recycling and the energy offset from WTE (see EOL assumptions in Table 12).

Table 6 Contribution Analysis - Life Cycle of HP EvoCycle

Impact category	Unit	HP EVOCYCLE TOTAL	EvoCycle Production	EvoCycle Distribution to User	EvoCycle Use Phase	EvoCycle EOL Recycling program
Global warming	kg CO2 eq	7.2 E-1	6.2%	0.1%	97%	-3.3%
Ozone depletion	kg CFC11 eq	6.7 E-7	5.6%	0.1%	94%	-0.2%
Ozone formation	kg NOx eq	2.8 E-3	4.1%	0.1%	98%	-2.0%
Terrestrial acidification	kg SO2 eq	4.8 E-3	2.3%	0.0%	100%	-2.3%
Freshwater eutrophication	kg P eq	2.3 E-4	4.1%	0%	99%	-3.5%
Human toxicity	kg 1,4-DCB	3.3 E-2	15%	0.2%	93%	-8.4%
Terrestrial ecotoxicity	kg 1,4-DCB	9.5 E-1	11%	0.2%	90%	-1.3%
Water consumption	m3	9.4 E-1	0.5%	0%	99.5%	0%
Total primary energy	MJ	2.9 E+1	2.9%	0.1%	98%	-1.1%

Notes: 0% implies value less than 0.1%. Numbers may not add to 100% due to rounding.

Table 7 Contribution Analysis - Life Cycle of Reman Cartridge

Impact category	Unit	Reman TOTAL	Reman Production	Reman Distribution to User	Reman Use Phase	Reman EOL - Waste Manage
Global warming	kg CO2 eq	8.1 E-1	6.1%	0.4%	93%	0.3%
Ozone depletion	kg CFC11 eq	7.3 E-7	2.8%	0.3%	97%	0%
Ozone formation	kg NOx eq	3.1 E-3	4.2%	0.3%	96%	-0.2%
Terrestrial acidification	kg SO2 eq	5.4 E-3	3.2%	0.2%	97%	-0.3%
Freshwater eutrophication	kg P eq	2.7 E-4	6.0%	0.1%	95%	-0.7%
Human toxicity	kg 1,4-DCB	2.6 E-2	11%	0.3%	90%	-1.5%
Terrestrial ecotoxicity	kg 1,4-DCB	1.3 E+0	6.0%	0.6%	94%	-0.1%
Water consumption	m3	1.0 E+0	0.6%	0%	99.4%	0%
Total primary energy	MJ	3.2 E+1	3.0%	0.2%	97%	-0.2%

Notes: 0% implies value less than 0.1%. Numbers may not add to 100% due to rounding.

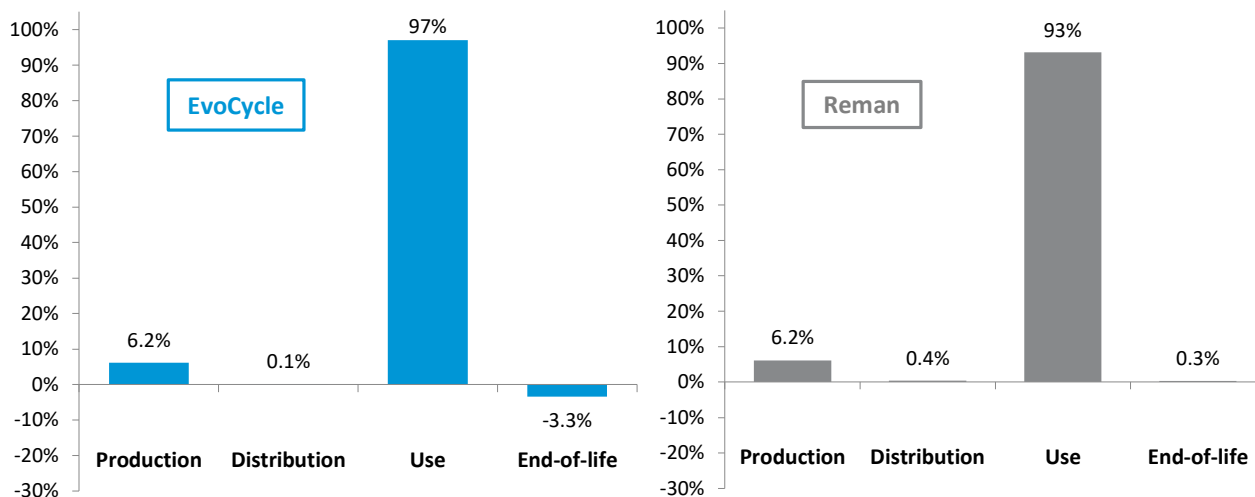


Figure 3 Contribution Analysis by Life Cycle Stage – Global Warming in Percentages

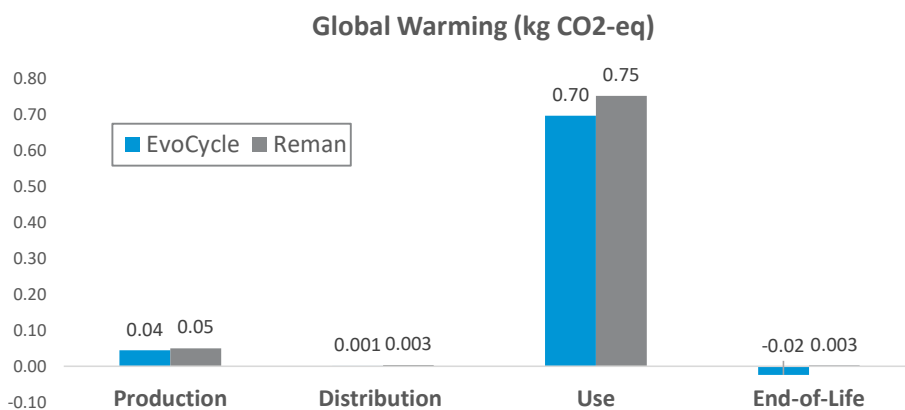


Figure 4 Contribution Analysis by Life Cycle Stage – Global Warming in Absolute Values

Production Phase

Table 8 presents the Production Phase for the EvoCycle and reman cartridges in terms of 100 usable pages printed. The first two columns of numbers present the Production numbers for each impact category. The third and fourth columns present how much higher the reman production impacts are, and how much lower the EvoCycle impacts are, relative to the other. Figure 5 depicts global warming and total energy.

Table 8 Production Phase Results

Impact category	Unit	HP EvoCycle Production	Reman Production	Reman % Higher than EvoCycle	EvoCycle % Lower than Reman
Global warming	kg CO2 eq	4.4 E-2	5.0 E-2	+ 13 %	- 12 %
Ozone depletion	kg CFC11 eq	3.7 E-8	4.1 E-8	+ 11 %	- 10 %
Ozone formation	kg NOx eq	1.1 E-4	1.3 E-4	+ 13 %	- 11 %
Terrestrial acidification	kg SO2 eq	1.1 E-4	1.5 E-4	+ 38 %	- 27 %
Freshwater eutrophication	kg P eq	9.5 E-6	1.4 E-5	+ 45 %	- 31 %
Water consumption	m3	4.7 E-3	5.7 E-3	+ 21 %	- 17 %
Total primary energy	MJ	8.4 E-1	9.5 E-1	+ 13 %	- 12 %

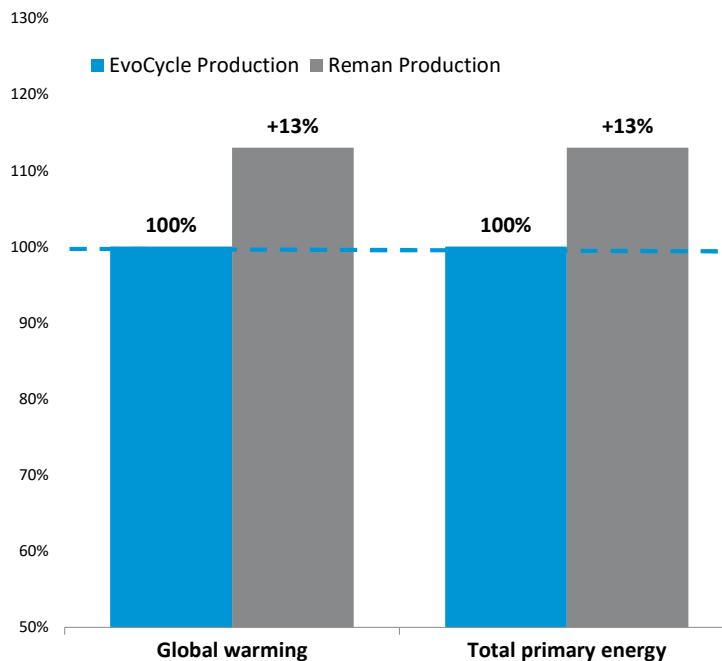


Figure 5 EvoCycle Production Compared to Reman Production

SENSITIVITY ANALYSES

Sensitivity of Page Use Distribution

As has been demonstrated, cartridge performance and page use have a critical influence on the cartridge's environmental life cycle metrics. The baseline analysis incorporated print quality and customer usage data which were used to model use phase performance differences, necessitating 8 more pages reprinted from the remanufactured cartridge to fulfill the functional unit of 100 usable printed pages (Table 4). In order to examine the degree of influence that page use has on the results, a sensitivity analysis was performed where all prints were for individual use (usable as a copy to read, file or mark-up) – i.e., necessitating no reprints. As Table 9 shows, when both cartridge types are modeled as printing exactly 100 pages, all results categories are within the +/- 10% error threshold, or considered to be on par.

Table 9 Sensitivity Analysis – All Individual Use; No Reprints

Impact category	Unit	HP EvoCycle Cartridge	Reman Cartridge	Reman % Higher than HP	EvoCycle % Lower than Reman
Global warming	kg CO2 eq	7.05 E-1	7.34 E-1	+ 4.2 %	- 4.0 %
Ozone depletion	kg CFC11 eq	6.55 E-7	6.57 E-7	+ 0.4 %	- 0.4 %
Ozone formation	kg NOx eq	2.75 E-3	2.80 E-3	+ 2.1 %	- 2.0 %
Terrestrial acidification	kg SO2 eq	4.70 E-3	4.83 E-3	+ 2.6 %	- 2.6 %
Freshwater eutrophication	kg P eq	2.30 E-4	2.39 E-4	+ 3.9 %	- 3.8 %
Human toxicity	kg 1,4-DCB	3.26 E-2	3.42 E-2	+ 4.9 %	- 4.6 %
Terrestrial ecotoxicity	kg 1,4-DCB	9.38 E-1	8.96 E-1	- 4.5 %	+ 4.7 %
Water consumption	m3	9.26 E-1	9.27 E-1	+ 0.1 %	- 0.1 %
Total primary energy	MJ	2.88 E+1	2.92 E+1	+ 1.1 %	- 1.1 %

Another sensitivity analysis looked at results in which all prints were used for external purposes only. When the page use is for external purposes only, the need for higher quality (customer-ready) pages requires the user to reprint more pages if using the reman cartridge – 31% more pages than when using the EvoCycle cartridge (Table 4).

Figure 6 demonstrates the span of Global Warming results for the all-internal and all-external purpose scenarios. The result for all internal purposes is discussed above. When the printing is for only external purposes, the reman cartridge Global Warming impact jumps to 37% higher than the EvoCycle. While these two page-use extremes are not common scenarios, the results illustrate that as user print quality requirements increase, the environmental advantage offered by the EvoCycle cartridge also increases. When low quality prints are acceptable, the benefit of recycling the EvoCycle cartridge at end of life, through HP Planet Partners program, helps to offset some of its production impacts.

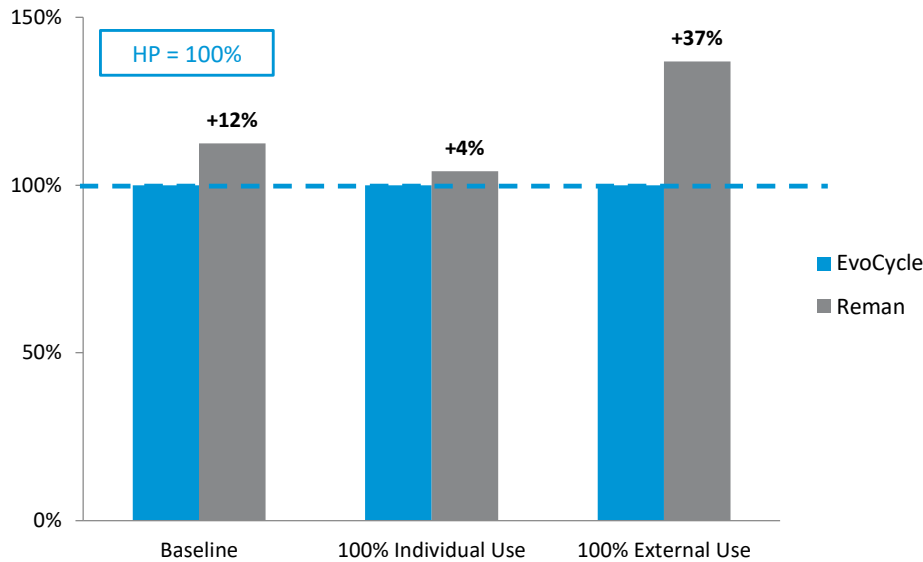


Figure 6 Sensitivity Analysis on Page Use – Global Warming

Sensitivity of Various Model Assumptions

Some of the models’ assumptions were tested for sensitivity, and these are summarized in the table below. The Global Warming category was used to present the results in Figure 7.

Table 10 Summary of Sensitivity Analyses

Model Affected	Baseline assumption	Sensitivity assumptions
HP EvoCycle	Cartridge is recycled through HP's Planet Partners recycling program at end of life.	HP cartridge is disposed of in the MSW stream at end of life.
Reman	Parts replaced: OPC drum, cleaning blade, developer blade, chip, toner and toner dam seal.	1) Additional parts replaced: primary charge roller and developer roller sleeve. 2) only toner replaced. ^{xiv}
Reman	The end user is in EMEA and remanufacturing facilities are located in western Europe, eastern Europe and Asia. ⁱⁱⁱ The spent cartridge is transported from EMEA users to these locations, and returned to the user locations.	The end user is in EMEA and the remanufacturing facility is in Asia. The spent cartridge is transported from the EMEA region to China, and returned to EMEA (see Table 12).
Reman	Sort & discard (unusable cartridges) rate is 19% ⁱⁱⁱ	Sort & discard rate is 5%. (Less transportation impacts to the remanufacturing facility, less waste to manage.)
Reman	Cartridge is disposed of in the MSW stream at end of life.	1) The cartridge is sent back to remanufacturer with intent to recycle. In this situation, unusable cartridge is managed by the facility (mix of recycling, landfilling, WTE) ⁱⁱⁱ 2) Cartridge is recycled at end of life.
Reman	DOA rate is 10%. ^v	DOA rate is 0%.

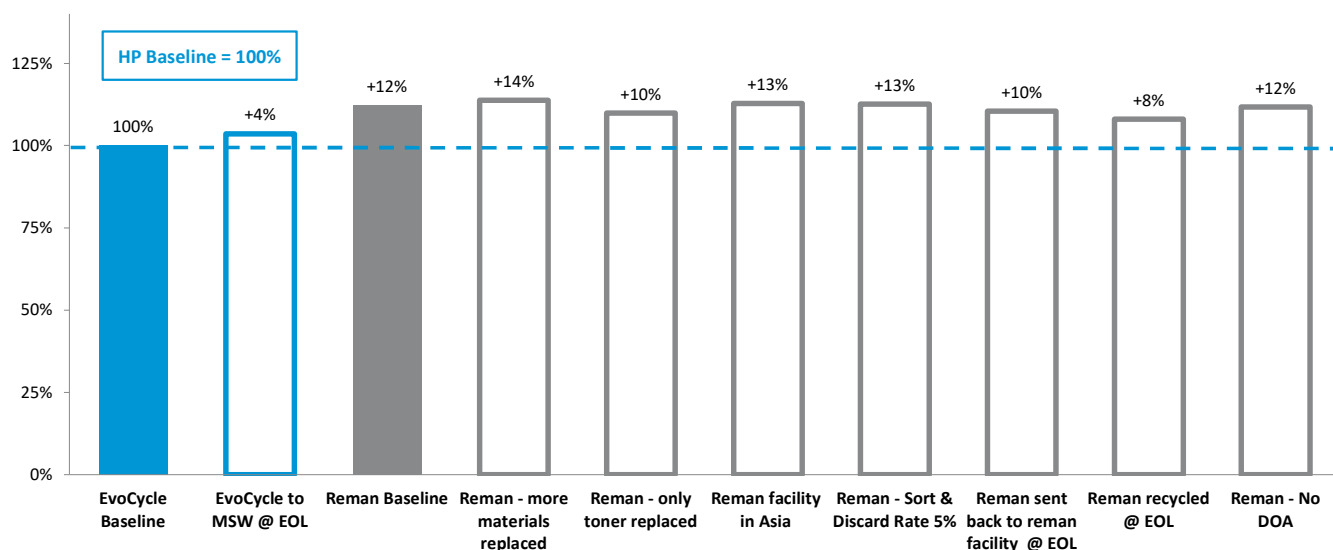


Figure 7 Sensitivity Analysis on Other Study Parameters - Global Warming

The EvoCycle baseline (solid blue) is on the far left, followed by its corresponding sensitivity analysis. The reman baseline has a dark grey fill with its corresponding scenarios to the right. Results are normalized to the HP baseline, and the percentages shown are the net differences. When the HP EvoCycle cartridge is thrown away instead of recycled at the end of life, its overall Global Warming impact for increases by 4%. When more reman parts are replaced, the environmental impact increases by 2%. When only toner is replaced, the baseline reman results decrease by 2% - but it should be noted that no adjustment in the Use Phase has been made for the potential lower print quality resulting when no key parts have been replaced. There is a 1% increase when the remanufacturing facility is located farther away. When the sort & discard rate decreases from 19% to 5%, the results increase slightly because there is less recycling offset (which is counterintuitive). When the reman is sent back to a remanufacturer with intent to have it remanufactured, most of the time it is not usable. The management of the unusable cartridges decreases the baseline reman results by 2%, again, due to recycling practices at some reman facilities. When the reman is recycled through a proper cartridge recycling facility at end of life, the impact decreases by 4%. When the DOA rate decreases from 10% to 0%, there is negligible results difference.

As is evident from the figure above, even though results increase and decrease to some degree, modifications to the baseline model assumptions do not significantly affect the outcome of the study, giving testament to the main driver of the results: paper production. Many other aspects of the life of the cartridges are secondary to that.

Sensitivity of Duplex

The effect of duplex was evaluated on the baseline results, using HP internal data on monthly print volume and duplex use rates on HP printer customers in this target market. An overall weighted average of 20% of pages saved was used.^{xv}

Table 11 Sensitivity Analysis – Duplex

Impact category	Unit	Duplex Results			Baseline
		HP EvoCycle Cartridge	Reman Cartridge	Reman % Higher than EvoCycle	Reman % Higher than EvoCycle
Global warming	kg CO2 eq	5.8 E-01	6.6 E-01	+ 13 %	+ 12 %
Ozone depletion	kg CFC11 eq	5.4 E-07	5.9 E-07	+ 8.5 %	+ 8.4 %
Ozone formation	kg NOx eq	2.3 E-03	2.5 E-03	+ 11 %	+ 10 %
Terrestrial acidification	kg SO2 eq	3.8 E-03	4.3 E-03	+ 11 %	+ 11 %
Freshwater eutrophication	kg P eq	1.9 E-04	2.2 E-04	+ 13 %	+ 12 %
Human toxicity	kg 1,4-DCB	2.7 E-02	2.1 E-02	+ 14 %	+ 13 %
Terrestrial ecotoxicity	kg 1,4-DCB	7.8 E-01	1.1 E+00	+ 2.2 %	+ 3.2 %
Water consumption	m3	7.6 E-01	8.2 E-01	+ 7.9 %	+ 7.9 %
Total primary energy	MJ	2.4 E+01	2.6 E+01	+ 9.4 %	+ 9.1 %

When pages are saved using duplex, the overall environmental profile, bolded above, decreases for both options. For a couple impact categories, comparative results are slightly worse for the reman cartridges than in the baseline (presented in the rightmost column in Table 11); the same percentage of paper has decreased for each option, but the reman’s higher distribution and end of life impacts remain the same.

DATA QUALITY REQUIREMENTS AND EVALUATION

This LCA adheres to the ISO standards on data quality to help ensure consistency, reliability, and clear-cut evaluation of the results.

Temporal, Geographical, and Technological Representativeness

Temporal representativeness describes the age of data and the minimum length of time (e.g., one year) over which data are collected. The data applied to this study represent current products and practices. The HP EvoCycle and its reman substitute are used in popular printer models. The parts and materials lists (PMLs) provided by HP are current and representative. Waste management practices for the cartridges are based on the best available current data, as is the MSW management disposition percentages to landfill and WTE. The cartridge performance data came from a recently published study. Other cartridge specifications (electricity usage, etc.) are current. Energy and transportation data are mid-2010’s, and production data for materials are largely based on data sets ranging from the mid- to late-2010’s and beyond. The paper production data are based on primary data collected for production years 2006 and 2007; after rigorous checking during the 2017 external peer review process, including testing other paper production data sets, this one was determined to be the best data available in terms of representativeness and completeness, despite the age of the data.

Geographical representativeness describes the geographical area from which data for unit processes are collected to satisfy the goal of the study. Data for energy, materials, processes, and transportation are based on European sources. Paper production comes from U.S. and Canadian paper producers and represents average North American production. This data source is considered to be high quality, representing current technologies and primary data.

Technological coverage, corresponding to the time period of the data sets, is current. Technological data for most materials and processes are generally industry average, and in some instances, based on one typical technology.

Consistency

Consistency is a qualitative understanding of how uniformly the methodology is applied to the various components of the study. Consistency was maintained in the handling of the products as well as the approach to previous toner cartridge LCA studies.

Reproducibility

The level of detail and transparency provided in this report allow the results to be reproduced by another LCA practitioner as long as the production datasets are similar.

Precision and Completeness

Precision represents the degree of variability of the data values for each data category. Precision cannot be quantified for this study since only one set of data for each HP cartridge was provided. For the reman cartridges, there is so much variability amongst practices that precision could not be explicitly quantified; however, sensitivity analyses were performed to address variation. Completeness is the percentage of flows that have been measured or estimated. The PMLs contain well-measured, accurate data. However, no other primary data was collected so an evaluation on completeness is not possible.

LIMITATIONS AND UNCERTAINTY

General Limitations and Uncertainty

It should be borne in mind that the LCA, like any other scientific or quantitative study, has limitations. While it provides an indication of the environmental impacts and attributes associated with product systems, it is not a perfect tool for assessing actual impacts and attributes. This is true for all LCA studies. As is normal for an LCA, much of the data used for modeling the materials is secondary. Because the quality of secondary data is not as good as primary data, the use of secondary data creates some level of uncertainty since it may cover a broad range of technologies, time periods, and geographical locations. Furthermore, since hundreds of data sets are linked together and it is often unknown how much the secondary data used will deviate from the specific system being studied, quantifying data uncertainty for the complete system becomes very challenging. As a result, it is not possible to provide a reliable quantified assessment of overall data uncertainty for the study, but it is understood that each product compared possesses this similar type of uncertainty. Because of the uncertainty in the study, results within +/- 10% are characterized as inconclusive as to which option has a lower environmental impact.

Missing Production Data

Similar to previous studies, a data gap is encountered for cartridge processing and assembly for both alternatives, due to lack of available data.^{xvi} While the cartridges' production stages included over 99.5% of the materials from the PML plus generic parts forming, no specific precise dis-assembly/reassembly, cleaning, testing, or other process data were available. Potential differences between the HP EvoCycle and reman have been cited but unfortunately the lack of available data for both creates a data gap. Furthermore, in light of broadly varying remanufacturing practices over the multitude of remanufacturers, this lack of manufacturing/assembly data may result in greater uncertainty. However, updated information from InfoTrends provided information on parts replacement, and the model captured production of new parts and waste management of replaced parts, two important aspects of remanufacturing processes.

For both cartridges, process impacts are missing. Yet, this in itself may give way to slightly less uncertainty for the following reasons:

1. The LCA normalizes products to a functional unit, so the relative, not absolute, differences in impacts for products being compared are measured. Therefore, when both products lack similar information, the data gap may be mitigated.
2. The results and sensitivity analyses have shown that the overwhelming contributor to the life cycle of the cartridges is paper consumption at the Use Phase, so the exclusion of assembly and other process impacts may not make a difference, although quantifying the magnitude of this uncertainty is not possible.
3. Often the bill of materials collectively embodies higher environmental impacts than assembly, which represents only one portion of the production stage. Thus, excluding the assembly data may have little effect on the overall models.

CONCLUSION

The most current, available research and data on production, product quality, and disposition trends were used to model the life cycles of the HP EvoCycle cartridge and its reman substitute. Reliability testing showed that the HP EvoCycle cartridge had a higher print quality performance than the reman. Based on the data, pages where quality was unacceptable for their intended use were assumed to require more reprinting, leading to greater consumption of paper and printer energy. In the Use Phase, paper consumption during printing was found to be the largest contributor to environmental impacts for both the HP EvoCycle and reman cartridges. Factors that influence the consumption of paper – in this case, quality of the printed pages – were found to have a controlling effect on life cycle environmental impacts.

The baseline analysis demonstrated that the reman's poor print quality performance resulted in higher environmental impacts relative to the HP EvoCycle in most of the categories measured. Only a few categories showed inconclusive results. For users who require the highest quality, customer-ready prints, the HP EvoCycle cartridge offers a clear environmental advantage. For users whose print quality requirements are low, where the quality is only good enough for individual use, the environmental impact of the HP EvoCycle was still found to be comparable to the reman, especially since the HP EvoCycle makes use of HP's Planet Partners cartridge recycling program. None of the other sensitivity and scenario analyses that were performed affected the overall outcome of the results, further substantiating the dominating Use Phase and the environmental impact that a less quality print cartridge can have.

To conclude:

- Environmentally based decision-making for cartridges should undoubtedly consider the cartridge's reliability and performance during its Use Phase, given that:
 - Paper use during printing is the overwhelming contributor to the life cycle environmental impacts of a print cartridge; and
 - Factors that influence the use of paper – in this case, output quality – can have a controlling effect on life cycle environmental impacts.
- The use of the higher quality HP EvoCycle cartridge results in fewer reprints and less paper consumed, which lowers environmental impact and makes them a wise overall choice.
- For the end of life phase of a toner cartridge, recycling and recovery of materials can be especially important in reducing its environmental impact.
- The reman cartridge can improve its environmental profile with improved printing performance and the ability to recycle at end of life.

APPENDIX 1 SPENCERLAB PAGE CATEGORY EXAMPLES

External Use	External/Internal Boundary Lower PQ - Internal	Internal/Individual Boundary Lower PQ - Individual	Individual/Unusable Boundary
<p>External Use</p> <p><i>Lorem Ipsum Ltd.</i></p> <p>January 12, 2012</p> <p>Mr. Black,</p> <p>External/Internal Boundary Lower PQ - Internal</p>	<p>External/Internal Boundary Lower PQ - Internal</p> <p><i>Lorem Ipsum Ltd.</i></p> <p>January 12, 2012</p> <p>Mr. Black,</p> <p>Internal/Individual Boundary Lower PQ - Individual</p>	<p>Internal/Individual Boundary Lower PQ - Individual</p> <p><i>Lorem Ipsum Ltd.</i></p> <p>January 12, 2012</p> <p>Mr. Black,</p> <p>Individual/Unusable Boundary</p>	<p>Individual/Unusable Boundary</p> <p><i>Lorem Ipsum Ltd.</i></p> <p>January 12, 2012</p> <p>Mr. Black,</p> <p>Individual/Unusable Boundary</p>

Figure 8 Print Quality Categories ^v

*Note: Page scans may not be accurately reproduced when printed from this report.

**Scanned pages are for demonstration purposes only, and not specific to any single printer platform or brand in the study.

APPENDIX 2 SUMMARY OF DATA

Table 12 Summary of the Cartridge Data used in the Study

	Baseline		Sensitivity Analyses	
			Lower Limit	Upper Limit
	HP EvoCycle	Reman Cartridge	Reman Cartridge	Reman Cartridge
PRODUCTION				
Upstream Materials Production	The bill of materials was provided by HP in current Parts Materials List (PMLs). Over 99.5% of materials in the cartridge were included in the modeling. HP provided the itemization of the 1) parts reused; 2) polystyrene (PS) parts recycled and re-manufactured into new 26X cartridge parts; and 3) parts replaced with new Original HP 26X parts.	<ul style="list-style-type: none"> The Organic Photoconductor (OPC) drum, wiper (cleaning) blade, toner and the toner dam are replaced.ⁱⁱⁱ Fate of replaced parts at facilities in EMEA:ⁱⁱⁱ <ul style="list-style-type: none"> - Landfill: 10% - Incineration with energy recovery (waste-to-energy (WTE)): 46% - Recycle: 44% 	<ul style="list-style-type: none"> Sensitivity: No materials are replaced except for the toner. Sensitivity of fate of replaced parts at facilities in EMEA: <ul style="list-style-type: none"> - 100% recycled 	Selected additional components are replaced: primary charge roller (PCR) & developer roller sleeve. ⁱⁱⁱ
Transportation to Manufacturing	The empty HP 26X cartridge is transported from users in EMEA to the HP recycling center in Bretagne, France, the Planet Partners regional recycling facility. Transportation of new OEM replacement parts to cartridge manufacturing at the Planet Partners facility is represented by global averages for materials by truck and other modes of transport.	<ul style="list-style-type: none"> Remanufacturing locations are in western Europe (15%), eastern Europe (38%), and Asia / Middle East (47%).ⁱⁱⁱ Spent HP cartridge is sourced from users in EMEA and new remans are sold in France. Cartridge transported a weighted average of 645 mi (1,038 km) by ship and 662 mi (1,066 km) by truck. 		<ul style="list-style-type: none"> Remanufacturing is in Asia; spent HP cartridges are sourced from EMEA and new remans are sold in France. Cartridge is transported a weighted average of 10,002 mi (16,093 km) by ship then 625 mi (1,005 km) by truck.
Manufacturing & Assembly	Recycling of original 26X PS parts and new recycled content PS parts manufacturing included. There were no data available on final steps of manufacturing including assembly, yet injection molding and other plastic parts forming data and steel and aluminum parts forming processes were included as data proxies to cartridge parts manufacturing. See Limitations section.	<ul style="list-style-type: none"> Very limited manufacturing data on remanufacturing processes. No assembly modeled. Replaced parts were given the same modeling (injection molding, parts forming, etc.). <p>See Limitations section</p>		
Discarded Empty Cartridges	Unusable empties (sort & discard) rate: N/A	Unusable empties (sort & discard) rate: <ul style="list-style-type: none"> 19% of collected cartridges are unsuitable for remanufacturing.ⁱⁱⁱ Management of unusable empties at facilities in EMEA:ⁱⁱⁱ <ul style="list-style-type: none"> - Landfill: 10% - WTE: 46% - Recycle: 44% 	Unusable empties (sort & discard) rate: <ul style="list-style-type: none"> Sensitivity: 5% discard rate is assessed. Sensitivity: Management of unusable empties: <ul style="list-style-type: none"> - Recycled 	
Packaging	Packaging includes: ^{xvii} <ul style="list-style-type: none"> Box / carton: corrugated paper (from recycled sources) Composite plastic bag, air-filled bag (cushioning) Pulp end caps and cushioning: molded pulp / paper, assumed to be from recycled sources Low density polyethylene bag <p>Online shipping exterior packaging adds corrugated box with protective air bubble wrap</p>	Packaging is included, and is modeled the same as the HP cartridges.		
DISTRIBUTION				

Distribution to End-User	<ul style="list-style-type: none"> • HP EvoCycle 26X is manufactured in France. • Consumers purchase HP EvoCycles using a purchase order. • Cartridges are transported to locations in France an average of 450 mi by truck. 	<ul style="list-style-type: none"> • Remanufacturing locations are in western Europe (15%), eastern Europe (38%), and Asia / Middle East (47%).ⁱⁱⁱ • Consumers purchase remans at a retail store or online (assumed 50%/50%) • Retail: Cartridge transported an average of 645 mi by ship and 450 mi by truck. • Online: reman are transported 645 mi by ship. From there, they are transported through the postal service by truck to the end-user. 		<ul style="list-style-type: none"> • Remans transported from China 10,002 mi (16,093 km) by ship (calculated from Shanghai) to port of Marseille, France. Then transported 450 mi by truck to the end-user in France. • Online: Remans transported from China 10,002 mi by ship to EMEA. From there, they are transported through the postal service by truck to the end-user. • Online and retail 50%/50%.
USE PHASE				
Printing	<ul style="list-style-type: none"> • Paper Type: A4, 20lb (75gsm), copy paper. • The electricity use by cartridge for printing was modeled using HP's specifications on power consumption:^{xviii} <ul style="list-style-type: none"> - LaserJet Pro 400 M402n (26X): 591 Watts in print mode, 40 ppm output. 	<ul style="list-style-type: none"> • Paper Type: A4, 20lb (75gsm), copy paper. • The electricity used by the cartridge for printing was modeled using the HP printer specifications 		
Print Quality Data	Print quality distribution (2021 SpencerLab)^{vi} <ul style="list-style-type: none"> - 94.7% External use - 5.3% Internal use - 0.0% Individual use - 0.0% Unusable 	Print quality distribution (2019 SpencerLab)^v <ul style="list-style-type: none"> - 71.9% External use - 28.1% Internal use - 0.0% Individual use - 0.0% Unusable 		
Pages printed per 100 usable pages	Customer Use data (2021 Escalent)^{vii} <ul style="list-style-type: none"> - 31% External use - 41% Internal use - 28% Individual use <p>Total pages printed to obtain the functional unit: 102</p>	Customer Use data (2021 Escalent)^{viii} <ul style="list-style-type: none"> - 31% External use - 41% Internal use - 28% Individual use <p>Total pages printed to obtain the functional unit: 110</p>	Sensitivity: <ul style="list-style-type: none"> • Page use: 100% for individual use. • Total pages printed to obtain the functional unit: <ul style="list-style-type: none"> - HP cartridge: 100 - Reman cartridge: 100 <p>Sensitivity on use of duplex (double-sided printing): Weighted average of 20% of pages saved using duplex on the LJ Pro 400 M402n.^{xv}</p>	Sensitivity: <ul style="list-style-type: none"> • Page use: 100% for external use. • Total pages printed to obtain the functional unit: <ul style="list-style-type: none"> - HP cartridge: 106 - Reman cartridge: 139
Re-use Scenario	Used 1 time, i.e., An Original HP cartridge is used one time in the printer.	Used 1 time, i.e., a depleted Original HP cartridge is remanufactured and then used one time in the printer. (82% of toner cartridges are remanufactured 1 time). ⁱⁱⁱ		
END-OF-LIFE				
	Baseline: <ul style="list-style-type: none"> • HP cartridge is sent to the HP regional recycling center in Bretagne, France, which includes crushing, disassembly/sorting, and recycling. • An average of 71% of the cartridge materials is recycled, and the balance goes to WTE.^{xix} No material goes to landfill.^{xx} • Includes transport of the used cartridge to Bretagne. Sensitivity: HP cartridge is disposed of per France average MSW disposition (see to right).	Baseline: Reman is discarded by the end- user per France average MSW disposition for landfill (43%) and WTE (57%), excluding recycling or material recovery ^{xii}		Sensitivity: The cartridge is sent back to remanufacturer (with intent to remanufacture). <ul style="list-style-type: none"> • 18% of the time it is made into reman (82% of toner cartridges are remanufactured 1 time).ⁱⁱⁱ • Remaining portion:ⁱⁱⁱ <ul style="list-style-type: none"> - Landfill: 10% - WTE: 46% - Recycle: 44% Sensitivity: Reman is recycled.

APPENDIX 3 INDICATOR DESCRIPTIONS

The life cycle impact assessment (LCIA) categories evaluated in this study are from the ReCiPe methodology^{xxi} (except where noted below), and reflect a comprehensive set of environmental issues that cover different environmental media (i.e., air emissions, water effluents, waste, etc.) and endpoints (affects to vegetation, human health, etc.). By presenting results for a comprehensive set of issues, the reader will be able to understand trade-offs in the systems. This reduces the subjectivity of choices made during category selection.

- **Global warming** calculates the greenhouse gas emissions which have been generated by the systems and includes production of materials, production of paper, electricity during use, transportation and distribution, etc. The “greenhouse effect” refers to the ability of some atmospheric gases to absorb energy radiating from the earth, trapping the heat and resulting in an overall increase in temperature. Global Warming is also referred to as “Climate Change” or the “carbon footprint”. Global warming is reported in kilograms (kg) of carbon dioxide-equivalents.
- **Stratospheric ozone depletion** provides an indication of the decline in the ozone layer, which allows more harmful short wave radiation to reach the Earth’s surface, potentially causing damage to human health, plants, and changes to ecosystems. Ozone depletion is reported in kg of trichlorofluoromethane (CFC-11) equivalents.
- **Human Toxicity and Terrestrial Ecotoxicity:** Human toxicity provides an indication of the risk of disease to human health, while terrestrial ecotoxicity provides an indication of the risks of damage to ecosystems on land. These are reported in terms of 1,4 dichlorobenzene equivalents. These impact categories have higher uncertainty associated with them so these results should be understood to be directional only.
- **Ozone formation** quantifies the potential for smog-forming gases that may produce photochemical oxidants or ground-level ozone. This is reported in kg of NOx equivalents.
- **Terrestrial Acidification** quantifies acidifying gases that may dissolve in water (i.e., acid rain) or fix on solid particles and degrade or affect the health of vegetation, soil, building materials, animals, and humans. Acidification is measured in terms of kg of sulfur dioxide-equivalents.
- **Freshwater Eutrophication** quantifies nutrient-rich compounds released into water bodies, resulting in a shift of species in an ecosystem and a potential reduction of ecosystem diversity. A common result of eutrophication is the rapid increase of algae, which depletes oxygen in the water and causes fish to die. Eutrophication is measured in phosphorous equivalents.
- **Total Energy**, reported in Megajoules and based on the Cumulative Energy Demand methodology,^{xxii} encompasses fuel energy, including fossil- and non-fossil fuels such as nuclear power, hydropower, and biomass, and embodied energy, such as hydrocarbons embodied in plastics. It includes not only printing energy but also the energy required to produce paper during use, the production of cartridge parts and materials, and transportation throughout the supply chain.
- **Water Consumption**, reported in cubic meters, measures the use of water in the systems and encompasses cooling water, process water, and any water use associated with the systems.

Endnotes

- ⁱ A New Build Compatible is defined in this context as a new replacement cartridge made with a body, components and ink or toner that are produced by a company NOT affiliated with a printer hardware manufacturer. It is also known as a compatible non-OEM new build, or more colloquially an “imitation” or “knock-off” cartridge. An NBC can sometimes be a “clone”, which is an NBC that violates the OEM’s intellectual property.
- ⁱⁱ Page yield is based on 5% coverage, per the ISO standard method for the determination of toner cartridge yield for monochrome laser printers. See ISO/IEC 19752:2004 – Method for the determination of toner cartridge yield for monochromatic electrophotographic printers and multi-function devices that contain printer components. Actual use varies considerably. HP Page yield data found in product specifications published on www.hp.com.
- ⁱⁱⁱ Keypoint Intelligence / InfoTrends, 2020. Primary Research: WE (Western Europe) Cartridge Collection and Recycling Report. EMEA Supplies Recycling study, commissioned by HP and based on average results of interviews with 20 remanufacturers and NBC resellers in 12 countries. See www.hp.com/go/EMEA-2020InfoTrends.
- ^{iv} ISO 14040:2006, the International Standard of the International Standardization Organization, Environmental management. Life cycle assessment. Principles and framework. ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.
- ^v 2019 EMEA SpencerLab Monochrome Reliability study, commissioned by HP, compared Original HP cartridges with eight brands of remanufactured cartridges for HP Pro M402 and Pro M521 printers; HP 26A and 55A cartridges. For details, see <http://www.spencerlab.com/reports/HPReliability-EMEA-RM2019.pdf>.
- ^{vi} 2021 SpencerLab Monochrome Reliability study, commissioned by HP, compared the Original HP 26X mono cartridge with the HP EvoCycle cartridge sold in Europe, Middle East, and Africa for the HP Pro M402. For details, see <https://www.spencerlab.com/reports/HP-EvoCycle2021.pdf>.
- ^{vii} 2021 EMEA Escalent survey, commissioned by HP. Results based on 1,942 surveys from customers in UK, France, Germany, Italy, Poland, Turkey and Russia who print at least once a week using an HP LaserJet, that have used both Original HP and non-HP toner cartridges in the past 12 months. Non-HP cartridges include remanufactured, refilled and new-build imitation cartridges. See <http://escalent.co/hp/EMEA-Customer2021.pdf>.
- ^{viii} PRe Consultants, SimaPro version 9 LCA Software (Analyst). More information can be found at www.pre.nl.
- ^{ix} Ecoinvent Centre, *Ecoinvent data v3* (Dübendorf: Swiss Centre for Life Cycle Inventories, 2013), www.ecoinvent.org, retrieved within SimaPro.
- ^x June 2010, National Council for Air and Stream Improvement, Inc., Life Cycle Assessment of North American Printing and Writing Paper Products – Final Report, prepared for American Forest and Paper Association (AF&PA) and Forest Products Association of Canada (FPAC), found at [www.afandpa.org/docs/default-source/default-document-library/life-cycle-assessment-\(lca\)-final-report.pdf](http://www.afandpa.org/docs/default-source/default-document-library/life-cycle-assessment-(lca)-final-report.pdf).
- ^{xi} SpencerLab (2019) Appendix 4 defines DOA as a condition determined by one of four mechanisms: 1) cartridge has 50% or more handling surface covered in toner; 2) within the first ten pages printed, the cartridge prints an “unusable” or “individual use” page. Cartridge continues this level of print quality after two “recovery” operations are performed; 3) cartridge is broken or has missing parts; 4) cartridge fails to operate upon installation and does not recover upon removing the cartridge and re-installing. 2019 EMEA SpencerLab Monochrome Reliability study, commissioned by HP, compared Original HP cartridges with eight brands of remanufactured cartridges for HP Pro M402 and Pro M521 printers; HP 26A and 55A cartridges. For details, see <http://www.spencerlab.com/reports/HPReliability-EMEA-RM2019.pdf>.
- ^{xii} MSW management data based on France (26% LF, 35% WTE, 39% recycling), from European Environment Agency (EEA), Municipal Waste Management Country Fact Sheet, October 2016. Recycling has been removed.
- ^{xiii} Based on a June 2017 phone conversation between Four Elements, LLC and a representative at Recology Cleanscapes, a state of the art recycling facility located in Seattle, Washington.
- ^{xiv} When only toner is replaced, the cartridge is considered a refilled cartridge, not a reman cartridge. While refilled cartridges were not evaluated in this study, looking at the overall impact of a used HP cartridge with only the toner replaced was still worthwhile to understand the sensitivity of parts replaced.
- ^{xv} November 2018 internal HP research on monthly print volumes and duplex rates for the HP LaserJet 400 M402 and the HP LaserJet Pro MFP M521.
- ^{xvi} Note: One data point, 7.9 kWh electricity per remanufactured cartridge, was found in an Ecoinvent report (Hischier, R. et al., Life cycle inventories of Electric and Electronic Equipment: Production, Use & Disposal. ecoinvent report No.18. Empa / Technology & Society Lab, Swiss Centre for Life Cycle Inventories, Dübendorf, 2007). This was not used since the data were over 10 yrs old, and using this data point for the reman and not the HP cartridge would have created an unfair comparison for the reman system.
- ^{xvii} 2019 HP internal data.
- ^{xviii} Specifications found at www.hp.com.
- ^{xix} 2015 HP internal data.
- ^{xx} 2020 Sustainable Impact Report: <https://h20195.www2.hp.com/v2/GetDocument.aspx?docname=c07539064>.
- ^{xxi} Huijbregts M.A.J., Steinmann Z.J.N., Elshout P.M.F., Stam G., Verones F., Vieira M., Zijp M., Hollander A., van Zelm R. ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. *Int J Life Cycle Assess* (2017) 22: 138: <https://link.springer.com/article/10.1007/s11367-016-1246-y>. Latest adaptations made in 2018. The default version for the midpoint method, “Hierarchist”, was used. See www.pre.nl for more information.
- ^{xxii} CED is based on Ecoinvent version 2.0 and has been expanded to include elements from the SimaPro database. Frischknecht R., Jungbluth N., et al. (2003). Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent 2000, Swiss Centre for LCI. Dübendorf, CH, www.ecoinvent.ch. Recent adaptations to the method in 2018. See also www.pre.nl for more information.