Life Cycle Environmental Impact Study
For Europe, Middle East and Africa (EMEA)

HP LaserJet Toner Cartridges
vs.
New Build Compatible & Clone 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 Original HP LaserJet toner cartridges with New Build Compatible (NBC) and clone cartridges sold as substitutes (collectively referred to as NBCs). The 2017 study on the Europe, Middle East and Africa (EMEA) region, mirroring an externally peer-reviewed 2017 LCA of the same subject covering North America (NA), adheres to the International Standards Organization (ISO) 14040 series 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 Original HP toner cartridges and NBC alternatives in EMEA. The study found that, as in previous HP LCA studies, paper consumption during printing is the largest contributor to the environmental impact across all phases of the life cycle for both the Original HP toner cartridge and the NBC alternative.

The study also shows that in all assessed categories, the Original HP cartridge showed lower environmental impact than the NBC alternative. Optimized print quality performance minimized the environmental impact for the Original HP cartridge because fewer pages were reprinted. For customers who print documents for both internal and external purposes, and who are concerned about the environmental impact of their cartridge choice, Original HP cartridges are a wise choice compared to NBC alternatives. The study also found that for users whose print quality requirements are not high, the environmental impact of Original HP cartridges is still lower than NBCs, thanks to advanced cartridge recycling processes within HP's Planet Partners program and the lack of recycling infrastructure for, or reusability of, NBC cartridges.

SUMMARY REPORT

INTRODUCTION

For over a decade, HP has been evaluating life cycle environmental impacts of its LaserJet toner cartridges; the most recent set of studies were in 2016, where HP commissioned Four Elements Consulting, LLC, to perform life cycle comparisons of Original HP toner cartridges and remanufactured cartridges sold in the NA, EMEA, Asia, and Latin America markets. This LCA carried over the same methodology and goals, this time comparing Original HP toner cartridges to NBC cartridges sold as substitutes. The study utilized the most current research and data for production practices, disposition, and product quality for Original HP toner cartridges and NBCs sold in the EMEA markets. The external peer review for the NA study consisted of three experts, ensuring a sound methodology, high credibility and objectivity of the data and results, and conformance with the ISO standards for an LCA. The results are summarized below.

METHODOLOGY

Products Studied

HP selected the CF280A (80A) and CF283A (83A) toner cartridges for this study. These models are popular top-sellers in EMEA that have a wide selection of aftermarket cartridges available, including NBCs. They also cover different customer bases, reaching a broad range of users. The 80A model is a top-selling mono print cartridge model. The 83A has replaced the CE278A, which has been a top-selling mono print cartridge model, and the 83A has proven to be a top seller for its target markets. For the LCA, the two cartridges were averaged into one hypothetical cartridge model. The life cycle data weighting for these two cartridges is based on the number of cartridges shipped in fiscal year 2015, multiplied by their ISO page yield.[i] A separate analysis was run during the production of the NA study that evaluated each cartridge model separately; since the results did not vary significantly from one model to the next and did not change any outcomes of the study, the hypothetical model was used.

Table 1 Summary of Cartridges Studied

Cartridge SKU	HP Original Printer	Page Yield	Wt.Avg Split	Relevance to this study
CF280A (80A)	LaserJet Pro 400 M401	2,700	76%	Significant contributor to its target markets: SMB and Enterprise
CF283A (83A)	LaserJet Pro MFP M127fn	1,500	24%	Significant contributor to its target markets: home office and small business

The HP 80A and 83A cartridges were compared to NBC cartridge substitutes. This study defines an NBC, or New Build Compatible, as a new replacement cartridge made with a shell, 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, or a Non-OEM New Build. An NBC can sometimes be a clone,

or an NBC that violates the OEM's intellectual property.[ii] This analysis does not intend to mirror one specific brand of NBC cartridge; it is acknowledged that there is broad variability in the NBC industry.

The cartridges are modeled as single use. At the end of useful life, Original HP toner cartridges are assumed to be recycled through HP's Planet Partners recycling program, utilizing existing packaging and free shipping. NBC cartridges are likely not remanufactured or recycled. According to printing industry analyst InfoTrends Research (InfoTrends), remanufacturers reject NBC cartridges[iii] due to quality issues of the incoming cartridges. Furthermore, remanufacturing clones becomes an IP violation that remanufacturers need to avoid. State of the art recycling facilities throw away laserjet and inkjet cartridges collected with other recycling due to lack of infrastructure to disassemble cartridges and separate materials.[iv]

Adherence to the ISO Standards

This LCA adheres to the principles, framework and guidelines in ISO 14040 and 14044.[v] LCA is a tool for the systematic evaluation of the environmental impacts of a product through all stages of its life cycle, which include production, distribution to the customer, use of the cartridge, and end of life.

System Boundaries

Figure 1 presents the study's system boundaries. Life cycle phases include production, distribution to the customer, use of the cartridge, and end of life (EOL).

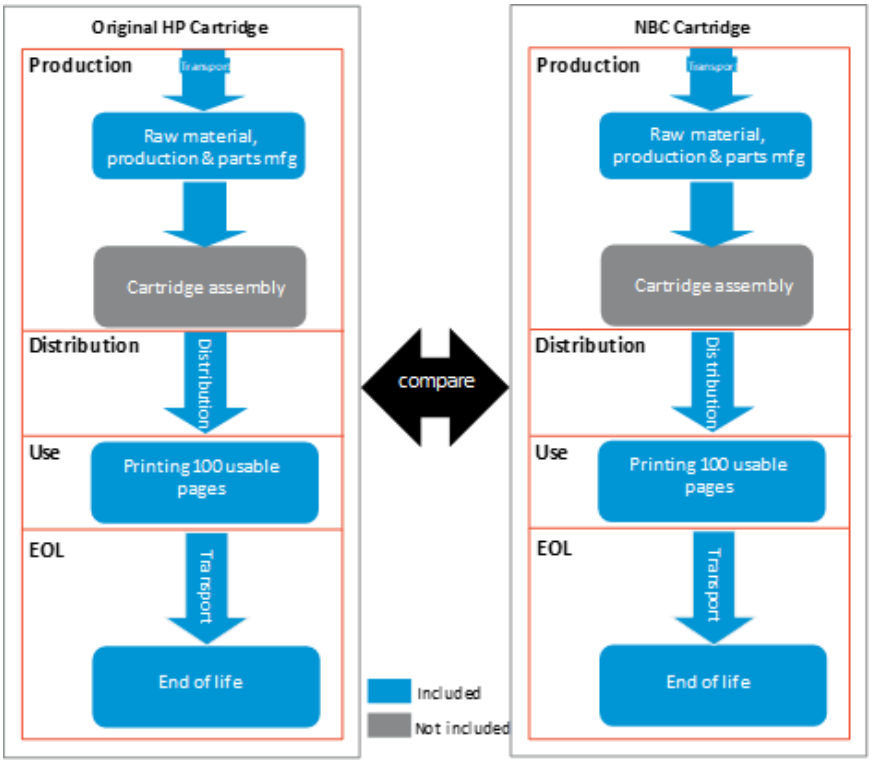


Figure 1 System boundaries

Data Sources

HP provided data on the HP cartridges including the bill of materials, place of manufacture, packaging specifications, printing specifications, and cartridge recycling practices. 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 the Original HP 80A and 83A cartridges and compare them to top selling NBC brands in EMEA.[vi] In 2017, HP commissioned Photizo Group 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 Photizo Group were used to establish the number of printed pages required 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 available data, especially from a well-known and accepted 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 is defined as "the printing of 100 usable monochrome one-sided pages," which includes 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. Including the Photizo Group page use distribution as part of the definition of the functional unit is an important study assumption. The relationship between how one uses a printed page and the required print quality determines the amount of reprints one might experience.

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 cartridge Production Phase includes the production of over 99.5% by mass of the materials in 80A and 83A cartridges, including parts forming (e.g., injection molding of plastic into cartridge parts, parts forming of aluminum and steel parts, etc.). Since an NBC cartridge is intended to be a duplicate of an OEM cartridge, it is modeled using the same parts and materials as the HP cartridge due to lack of specific data on the materials in the NBC and the high variability across NBC manufacturers. Nonetheless, it is acknowledged that NBC cartridges may be made using very different materials. Overall differences are probably minimal, however, as identical sets of parts – regardless of material – still need to be manufactured and formed.

Production also includes intermediate and final assembly but no data were available for this aspect of production. The HP OEM assembly process is automated while NBCs are largely manufactured with manual labor (i.e., with drills and other pneumatic tools). A more automated and precise OEM assembly plant may be relatively more energy intensive than a plant using mostly manual labor. But more manual labor increases the human-related impacts, such as transportation of workers to the factory, plus lighting and human labor-related aspects. 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 Original HP and the NBC cartridges from final assembly to the end user.

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 10. 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. 10). Page quality performance was assessed in the *SpencerLab* study where a sample of Original HP and NBC 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.[vi]

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
HP Cartridges Tested	95.1%	4.3%	0.6%	0.0%

Average NBC Cartridges Tested	46.8%	46.7%	6.1%	0.4%

From the *SpencerLab* study, 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 level for the intended use is not met, the page may be reprinted. From the acceptability categories, it could be deduced when a customer might reprint a page that is not suitable for the use it was intended. 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.

The Photizo Group study 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: "External Use", "Internal Use", and "Individual Use".[vii] These categories corresponded to the page use categories from the *SpencerLab* study shown in Table 2. The Photizo page use distribution was used for the 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	Photizo Group	35.6%	44.0%	20.3%
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. To account for uncertainty associated with the use and quality results, Monte Carlo simulation was used to calculate the average number of prints needed to obtain 100 usable printed pages:

Table 4 Pages printed to obtain 100 Usable Pages

		Total pages printed to obtain a functional unit		% More NBC Pages Printed	% Less HP Pages Printed
		HP	NBC		
Baseline	Photizo Group	102	128	25%	20%
Sensitivity	100% External Use	105	215	105%	51%
	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. The NBC cartridge is assumed to be thrown away into the municipal solid waste (MSW) stream, which includes landfilling (41%) and incineration with energy recovery (waste-to-energy (WTE)) (59%)[xi], since it is not able to be recycled. Sensitivity analyses looked at results where the HP cartridge was thrown away into the MSW stream and the NBC cartridge goes to a recycling facility should infrastructure be available.

RESULTS

Baseline results

Table 5 and Figure 2 present results for the baseline comparison. The second to last column in the table shows that the environmental impacts for the NBC cartridge are 26% or higher in all categories. Conversely, in the last column, the impacts of the HP cartridge range from 21% to 31% lower than the NBC cartridge. 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). As a result, one cannot

definitively conclude that one alternative is better than another without accounting for some margin of error, and a +/- 10% margin of error has been applied to these results. Since none of the baseline results fall within this range, it can be said that the NBC cartridge impacts are higher than HP in the impact categories measured.

Table 5 Baseline Results

Impact category	Unit	HP Cartridge	NBC Cartridge	NBC % Higher than HP	HP % Lower than NBC
Global warming	kg CO2 eq	8.4 E-01	1.2 E+00	+ 45%	- 31%
Terrestrial acidification	kg SO2 eq	6.0 E-03	8.0 E-03	+ 34%	- 26%
Freshwater eutrophication	kg P eq	1.5 E-04	2.1 E-04	+ 37%	- 27%
Human carcinogenic toxicity	kg 1,4-DCB e	5.0 E-02	7.2 E-02	+ 42%	- 30%
Ozone formation, Human health	kg NOx eq	2.8 E-03	3.8 E-03	+ 39%	- 28%
Terrestrial ecotoxicity	kg 1,4-DCB e	2.8 E-04	3.8 E-04	+ 37%	- 27%
Water consumption	m3	1.0 E-01	1.3 E-01	+ 26%	- 21%
Fossil resource scarcity	kg oil eq	2.5 E-01	3.5 E-01	+ 43%	- 30%
Total energy (CED)	MJ	2.9 E+01	3.8 E+01	+ 32%	- 24%

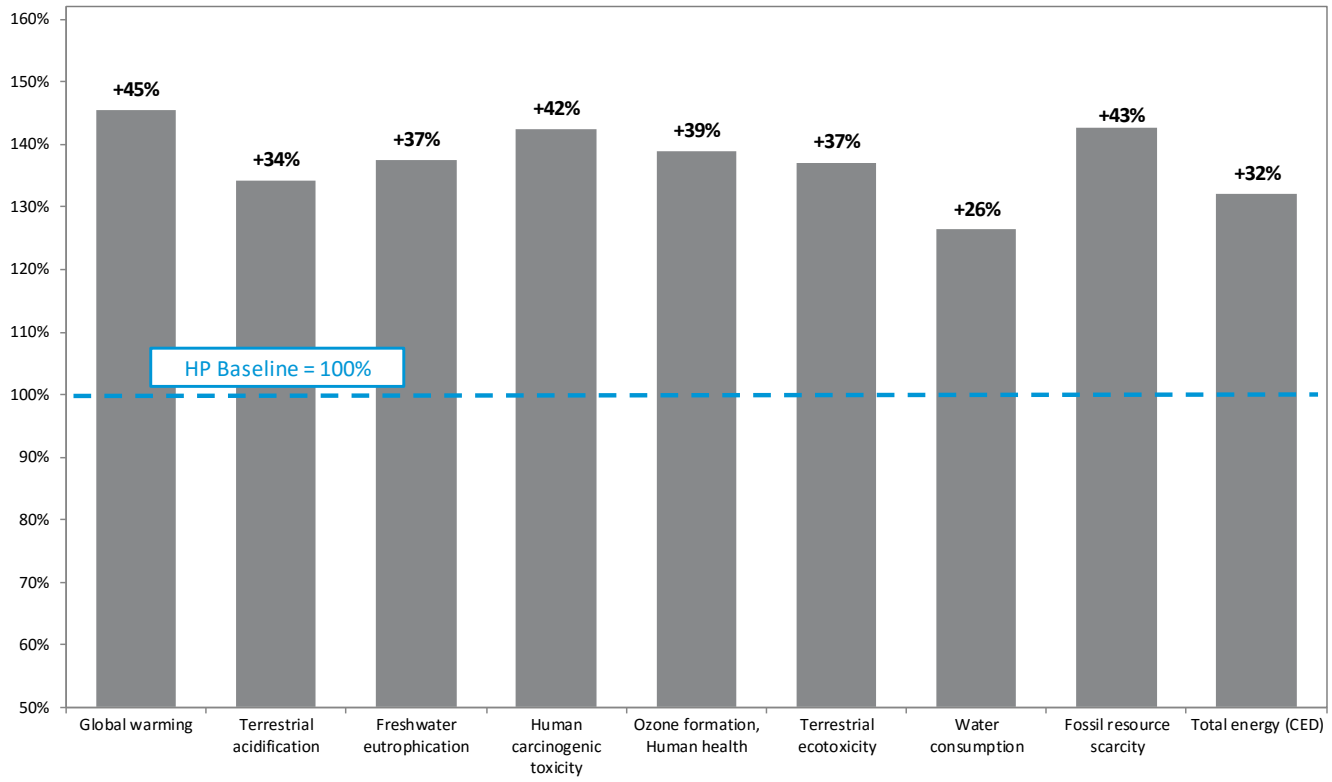


Figure 2 NBC Results Compared to HP Results

Life Cycle Stage Contribution Analysis

Table 6 and Table 7 present a breakdown of impact category results across the four defined life cycle stages of the cartridges. Figure 3 depicts the Global Warming metric. 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 Original HP and NBC cartridges. 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 10).

Table 6 Contribution Analysis - Life Cycle of HP Cartridge

Impact category	Unit	HP TOTAL	HP Production	HP Distribution to User	HP Use Phase	HP EOL - Recycling program

Global warming	kg CO2 eq	8.4 E-01	25%	4.5%	84%	-13.2%
Terrestrial acidification	kg SO2 eq	6.0 E-03	14%	3.0%	90%	-6.7%
Freshwater eutrophication	kg P eq	1.5 E-04	35%	0.2%	79%	-13.6%
Human carcinogenic toxicity	kg 1,4-DCB e	5.0 E-02	94%	0.2%	20%	-14.2%
Ozone formation, Human health	kg NOx eq	2.8 E-03	15%	7.8%	85%	-7.7%
Terrestrial ecotoxicity	kg 1,4-DCB e	2.8 E-04	25%	4.1%	75%	-4.1%
Water consumption	m3	1.0 E-01	13.7%	0.2%	87%	-0.6%
Fossil resource scarcity	kg oil eq	2.5 E-01	26%	5.2%	82%	-12.5%
Total energy (CED)	MJ	2.9 E+01	12%	2.0%	91%	-4.9%

Note: 0% implies value less than 0.1%

Table 7 Contribution Analysis - Life Cycle of NBC Cartridge

Impact category	Unit	NBC TOTAL	NBC Production	NBC Distribution to User	NBC Use Phase	NBC EOL - Waste Manage
Global warming	kg CO2 eq	1.2 E+00	22%	6.2%	72%	-0.1%
Terrestrial acidification	kg SO2 eq	8.0 E-03	12.9%	4.4%	84%	-1.4%
Freshwater eutrophication	kg P eq	2.1 E-04	32%	0.3%	72%	-3.9%
Human carcinogenic toxicity	kg 1,4-DCB e	7.2 E-02	83%	0.3%	17%	-0.8%
Ozone formation, Human health	kg NOx eq	3.8 E-03	14%	11.2%	76%	-1.5%
Terrestrial ecotoxicity	kg 1,4-DCB e	3.8 E-04	23%	8.6%	69%	-0.2%
Water consumption	m3	1.3 E-01	13.6%	0.2%	86%	-0.1%
Fossil resource scarcity	kg oil eq	3.5 E-01	23%	7.2%	72%	-1.7%
Total energy (CED)	MJ	3.8 E+01	11.2%	3.1%	87%	-0.9%

Note: 0% implies value less than 0.1%

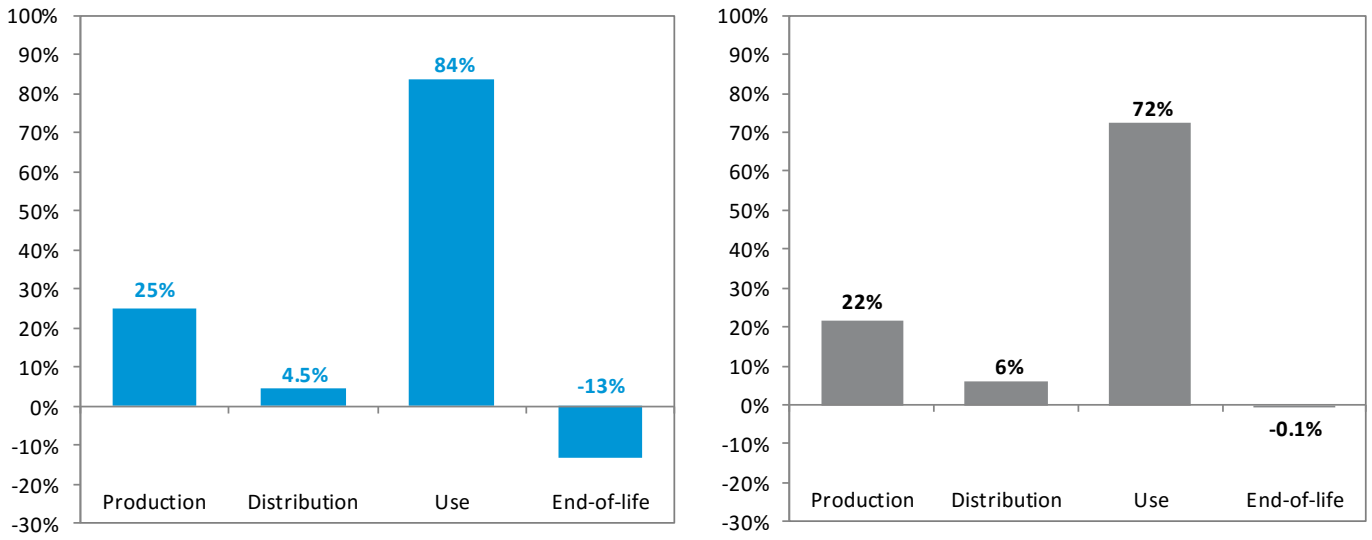


Figure 3 Contribution Analysis by Life Cycle Stage – Global Warming

While it appears as though HP has higher overall impacts using percentages, viewing the cartridges' results in absolute numbers in Figure 4 tells the story differently; here, the NBC's production and distribution impacts are greater than the HP cartridge. Due to the higher number of NBC reprints exhausting toner supply (Table 4), approximately 1.3 NBC cartridges are needed to obtain the same output quality as an HP OEM, necessitating more frequent replacement. The need to reprint causes not only more paper to be produced but also higher production and other life cycle stage impacts.

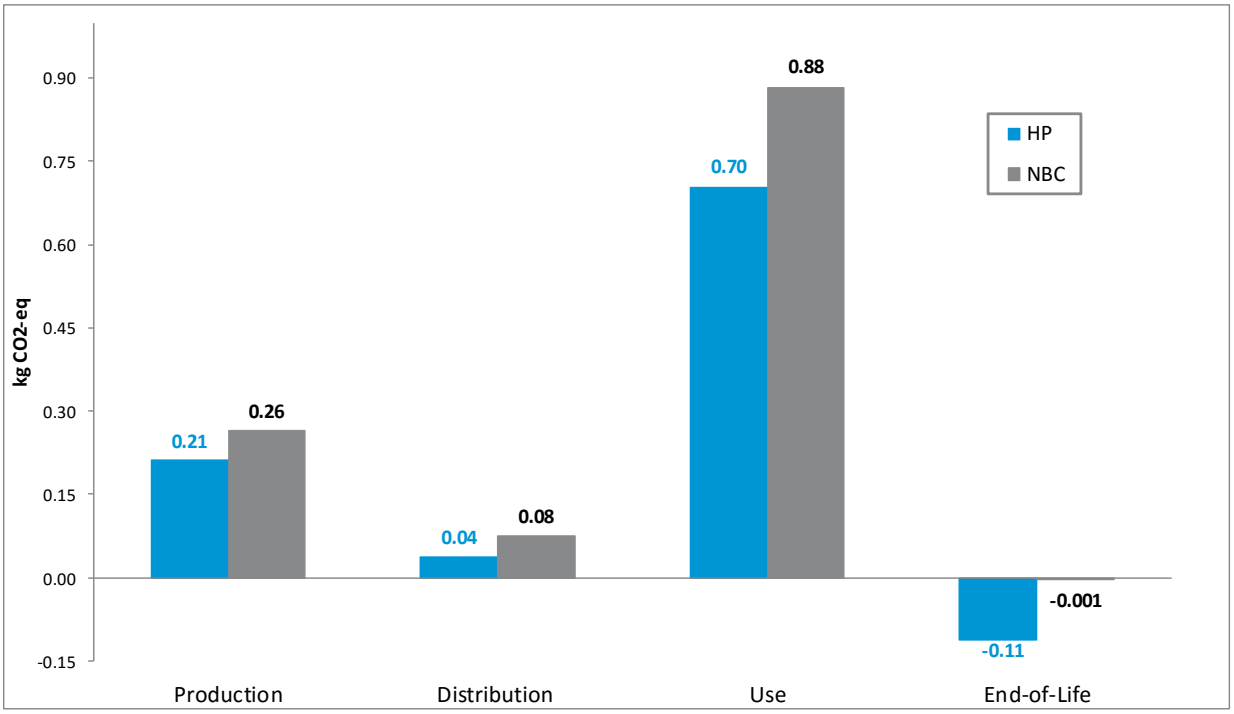


Figure 4 Contribution Analysis by Life Cycle Stage – Global Warming in Absolute Values

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. In order to examine the degree of influence that page use has on the results, two sensitivity analyses were performed: one in which all prints were used for external purposes (distribution outside of the company or marketing material) and one in which all prints were for individual use (usable as a copy to read, file or mark-up).

The Global Warming metric is used to present the sensitivity results in Figure 5. When the page use is for external purposes only, the need for higher quality (customer ready prints) pages require the user to reprint more pages if using an NBC cartridge – 105% more pages than when using an Original HP cartridge (see Table 4). As a result, the NBC cartridge Global Warming life cycle impact jumps to 137% higher (or nearly 1.4 times higher) than HP. When prints are used for individual use only, which are of much lower quality, both cartridge types print the same number of pages. However, the NBC cartridge is still higher than the HP cartridge owing to HP's recycling at end of life giving benefit to the HP cartridge. 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 Original HP cartridge also increases. When low quality prints are acceptable, the HP cartridge still has the environmental advantage since it benefits from recycling through HP Planet Partners program.

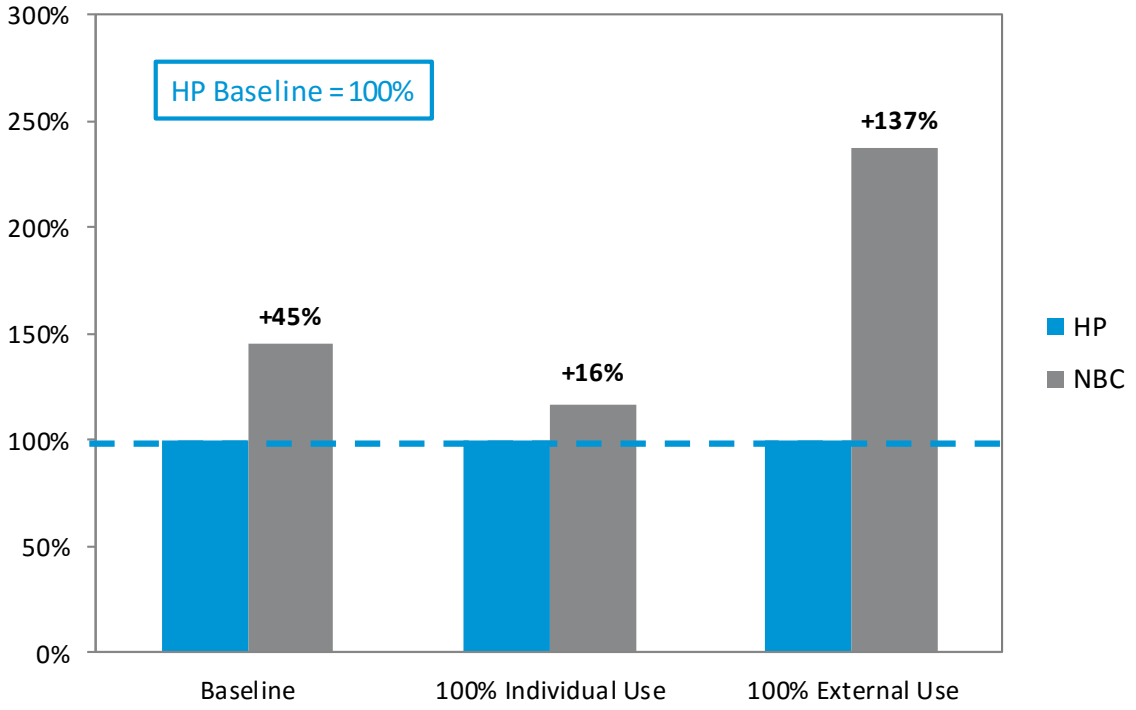


Figure 5 Sensitivity Analysis on Page Use – Global Warming

Sensitivity of End of Life

Different end of life scenarios were assessed for sensitivity, summarized in Table 8. The Global Warming category was used to present the results in Figure 6.

Table 8 Sensitivity Analysis on End of Life – Fates for the HP and NBC Cartridges

Model Affected	Baseline assumption	Sensitivity assumptions
HP	Cartridge is recycled through HP's Planet Partners recycling program at end of life.	Cartridge is disposed of in the MSW stream at end of life. Benefits of recycling are no longer applied.
NBC	Cartridge is disposed of in the MSW stream at end of life.	Cartridge is recycled at end of life, assuming technology is in place to disassemble and recycle cartridge parts.

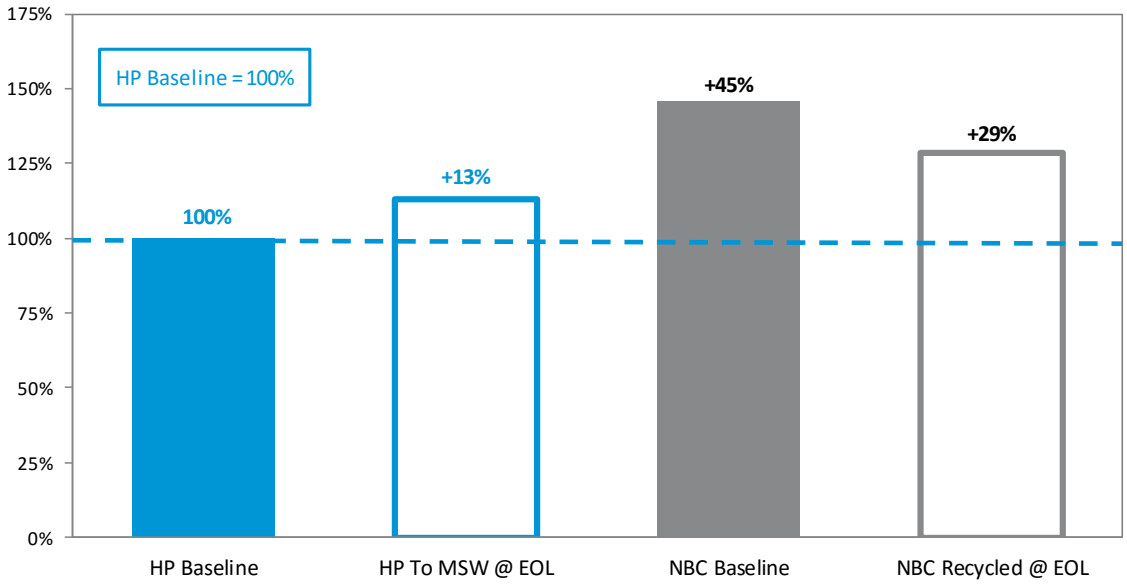


Figure 6 Sensitivity Analysis on End of Life - Global Warming

The HP baseline (solid blue) is on the far left, with its corresponding sensitivity analysis to its right. The NBC baseline has a dark grey fill with its corresponding end of life scenario to its right. Results are normalized to the HP baseline, and the percentages shown are the net difference.

When the HP cartridge is thrown away instead of recycled at the end of life, the overall Global Warming impact increases by 13% because there is no benefit from material recovery. When the NBC cartridge is recycled at the end of life, its Global Warming impact decreases by 16% due to material recovery from recycling and energy offsets from WTE. Still, since the lower performing NBC cartridge drives the number of reprints higher, the use phase still dominates the life cycle impacts.

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 these specific office printer models. An overall weighted average of 11.4% of pages saved was used.[xii]

Table 9 Sensitivity Analysis – Duplex

		Duplex Results			Baseline
Impact category	Unit	HP Cartridge	NBC Cartridge	% Difference (NBC vs. HP)	% Difference (NBC vs. HP)
Global warming	**kg CO2 eq**	7.6 E-01	1.1 E+00	**47%**	45%
Terrestrial acidification	**kg SO2 eq**	5.4 E-03	7.3 E-03	**35%**	34%
Freshwater eutrophication	**kg P eq**	1.4 E-04	1.9 E-04	**39%**	37%
Human carcinogenic toxicity	**kg 1,4-DCB e**	4.9 E-02	7.0 E-02	**43%**	42%
Ozone formation, Human health	**kg NOx eq**	2.5 E-03	3.5 E-03	**40%**	39%
Terrestrial ecotoxicity	**kg 1,4-DCB e**	2.5 E-04	3.5 E-04	**38%**	37%
Water consumption	**m3**	9.3 E-02	1.2 E-01	**26%**	26%
Fossil resource scarcity	**kg oil eq**	2.2 E-01	3.2 E-01	**44%**	43%
Total energy (CED)	**MJ**	2.6 E+01	3.4 E+01	**33%**	32%

When pages are saved using duplex, the overall environmental profile decreases for both options. However, comparative results are slightly worse for the NBC cartridges than in the baseline (presented in the rightmost column in Table 9); the same percentage of paper has decreased for each option, but the NBC cartridge's higher production and distribution 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 80A and 83A and their NBC substitutes 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, it 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, typical.

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 NBC 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 a 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 on par.

Missing Production Data

Similar to previous studies, a data gap has been encountered for cartridge manufacturing and assembly for both alternatives, due to lack of available data. The production stage of the cartridges included over 99.5% of the materials from the PMLs plus generic parts forming. While this is considered robust inclusion of the embodied materials in the cartridges, no specific cartridge manufacturing or assembly data was available. Differences between the HP and NBC cartridges in assembly practices were highlighted but unfortunately the lack of available data for both creates a data gap. Nonetheless, it is believed that this data gap does not affect the outcome of the study, and that uncertainty around this data gap is not so high, for the following reasons:

- Because LCA normalizes products to a functional unit, the relative, not absolute, differences in impacts for products being compared are measured. Both cartridge options are manufactured with all new materials (albeit possibly different

materials), with parts forming consisting of similar and different processing. Only the net difference of these production data is an unknown, not the full production category itself, mitigating the data gap;
- Often the bill of materials collectively embody higher environmental impacts than assembly, which represents only one portion of the production stage. So excluding the assembly data due to the lack of available data for HP OEMs and NBCs probably has little effect on the overall models.
- Since the NBCs need to be replaced faster due to more reprinting, the NBC's production results are larger relative to the HP cartridge. Filling in some of the data gaps will not change the production impact results in such a way that the overall outcome will be affected.
- 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.

CONCLUSION

The most current, available research and data on production, product quality, and disposition trends were used to model the life cycles of the Original HP cartridges and popular NBC cartridge substitutes. Reliability testing of these cartridges showed that Original HP exhibited more reliable output quality than the NBC alternatives. Based on these data, pages where quality was unacceptable for their intended use were assumed to require 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 Original HP and NBC 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.

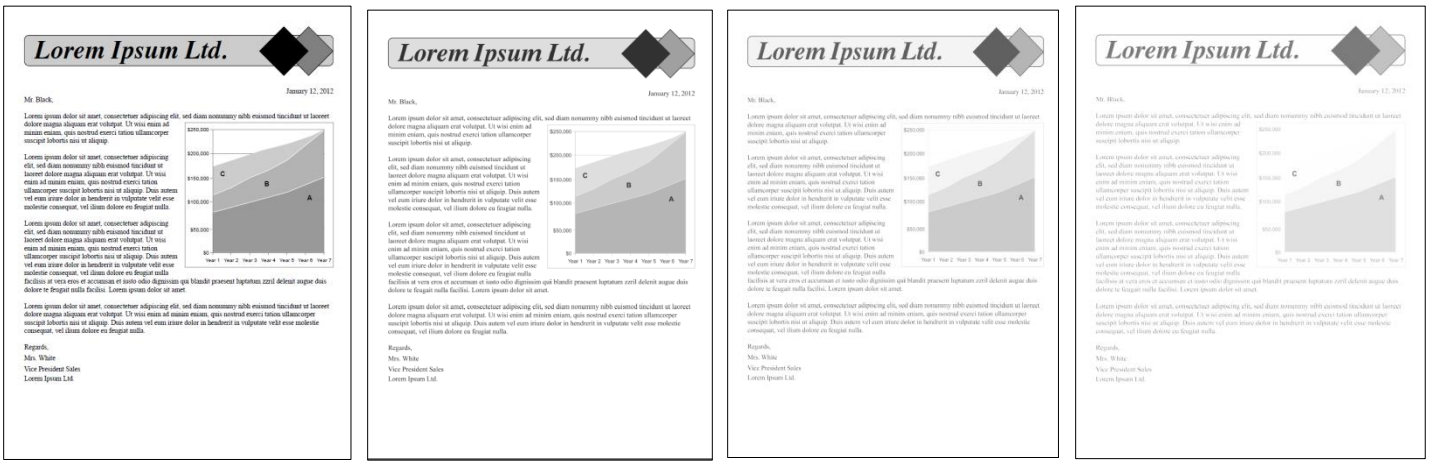
The baseline analysis demonstrated that the NBC's poor print quality performance resulted in higher environmental impacts relative to the Original HP cartridge in all of the categories measured. For users who require the highest quality, customer-ready prints, the Original HP cartridge offers a clear environmental advantage. For users whose print quality requirements are much lower, where the quality is only good enough for individual use, the environmental impact of the Original HP cartridge was still found to be lower than the NBC cartridge, especially since the HP cartridge 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.

The results have shown that the lower quality NBC is disadvantageous from an environmental standpoint, both for wasted paper and toner and also the cartridge itself: the lower quality performance of the NBC cartridge necessitates replacement more frequently than the HP cartridge. The higher level of reprinting leads to increased cartridge and paper purchases, so the initial low cost of the NBC may not necessarily guarantee savings in the long run.

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 higher quality Original HP cartridges 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 NBC 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

Figure 7 Print Quality Categories[vi]

*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 10 Summary of the Cartridge Data used in the Study

	HP Cartridge	NBC 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.	The bill of materials was assumed to be identical to HP's parts and materials for these cartridges. Thus, over 99.5% of materials in the cartridge were included in the modeling. It is acknowledged that NBC cartridges' parts may be made up of different materials than HP's.
Transportation to Manufacturing	• HP80A and 83A are manufactured in Japan and Virginia, USA. • Transportation of materials and components to final manufacturing is represented by global averages for materials by truck and other modes of transport.	• NBC cartridges are manufactured in China. • Transportation of materials and components to final manufacturing is represented by global averages for materials by truck and other modes of transport.
Manufacturing & Assembly	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.	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.
Packaging	Packaging is included:[xiii] – Box / carton: corrugated paper (from recycled sources) – Composite plastic bag, composite air-filled bag – Pulp end caps: molded pulp / paper, assumed to be from recycled sources - Polyethylene bag Online shipping exterior packaging: corrugated box with protective air bubble wrap	Packaging is included, and is modeled the same as the HP cartridges.
DISTRIBUTION		
Distribution to End-User	• HP80A and 83A are manufactured in Japan and Virginia. • Consumers purchase HP cartridges at a retail store or online (assumed 50%/50%) • Retail: weighted averages are taken for the cartridges to be distributed: 393 mi (632 km) by truck and 7,232 mi (11,636 km) by ship to end-user locations in Frankfurt, London, Rome, and Paris. • Online: weighted averages are taken for distribution of cartridges: 7,232 mi by ship to EMEA. From there, they are transported through the postal service by truck and freight plane to the end-user locations.	• NBC cartridges are manufactured in China. • Consumers purchase NBC cartridges at a retail store or online (assumed 50%/50%) • Retail: NBCs are transported from China 10,002 mi (16,093 km) by ship (calculated from Shanghai) to port of Marseille, France. Then transported 625 mi (1,005 km) by truck to the end-user locations in Frankfurt, London, Rome, and Paris. • Online: NBCs are transported from China 10,000 mi by ship to EMEA. From there, they are transported through the postal service by truck and freight plane to the end-user locations.
USE PHASE		
Printing	• **Paper Type**: Standard 8.5 x11, 20lb (75gsm), copy paper. • **The electricity** use by cartridge for printing was modeled using HP's specifications on power consumption:[xiv] - LaserJet Pro 400 M401 (80A): 570 Watts in print mode, 35 ppm output. - LaserJet Pro MFP M127fn (83A): 480 Watts in print mode, 21 ppm output	• **Paper Type**: Standard 8.5 x11, 20lb (75gsm), copy paper. • **The electricity** used by the cartridge for printing was modeled using the HP printer specifications

Print Quality Data	2016 *SpencerLab* Reliability Comparison study. **Print quality distribution**[vi] - 95.1% External use - 4.3% Internal use - 0.6% Individual use - 0.0% Unusable	2016 *SpencerLab* Reliability Comparison study. **Print quality distribution**[vi] - 46.8% External use - 46.7% Internal use - 6.1% Individual use - 0.4% Unusable
Pages printed per 100 usable pages	2016 Photizo Group Customer Experience study[vii] **Page use data** – 35.6% External use – 44.0% Internal use – 20.3% Individual use Total pages printed to obtain the functional unit: – Baseline analysis: 102 – Sensitivity: all for external use: 105 – Sensitivity: all for internal use: 100 Sensitivity on use of duplex (double-sided printing): A weighted average of 11.4% of pages was saved using duplex on the LJ Pro 400 M401 and LaserJet Pro MFP M127fn printers.[xii]	2016 Photizo Group Customer Experience study[vii] **Page use data** – 35.6% External use – 44.0% Internal use – 20.3% Individual use Total pages printed to obtain the functional unit: – Baseline analysis: 128 – Sensitivity: all for external use: 215 – Sensitivity: all for internal use: 100 Sensitivity on use of duplex (double-sided printing): A weighted average of 11.4% of pages was saved using duplex on the LJ Pro 400 M401 and LaserJet Pro MFP M127fn printers.[xii]
END OF LIFE		
End-of-Life	• The 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.[xv] No material goes to landfill.[xvi] • Includes transport of the used cartridge to Bretagne, France. **Sensitivity:** HP cartridge is disposed of per user location average MSW dispositions (see to right).	NBC cartridge is disposed of by the end-user, and the population-weighted average user location MSW disposition is used (41% and 59%, respectively, excluding recycling or material recovery)[xi] **Sensitivity:** NBC cartridge is recycled.

APPENDIX 3 INDICATOR DESCRIPTIONS

The life cycle impact assessment (LCIA) categories evaluated in this study are from the ReCiPe methodology[xvii] (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 measures 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.
- Human Carcinogenic Toxicity and Terrestrial Ecotoxicity: Human toxicity provides an indication of the risk of cancer 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.
- Ozone formation, human health 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.
- Fossil Resource Scarcity is the measure of the use – or depletion – of fossil fuels used in a system and is measured in oil-equivalents. Fossil fuel depletion tracks use of fossil fuels for energy as well as fossil fuels embedded in products made up of hydrocarbons, such as plastics.
- Total Energy, reported in Megajoules and based on the Cumulative Energy Demand methodology,[xviii] includes not only energy for the cartridge to print but also the energy required to produce paper during use, all cartridge parts and materials, and transportation throughout

the supply chain. Total energy 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.

- **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] 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.

[ii] NBC definitions supplied by: Supplies Sales Core Training presentation titled "Competition & Selling Against", by Matthew Barkley (Ink) & Betsy Porter (Toner), dated March 11, 2014.

[iii] John Shane, InfoTrends, 2016. U.S., E. Europe, LAR Cartridge Collections & Recycling Refresh 2016.

[iv] 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.

[v] 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.

[vi] A *SpencerLab* 2016 study commissioned by HP compared Original HP Mono LaserJet toner cartridges with three non-HP brands of cartridges sold in EMEA for the 80A and 83A cartridge models used in the HP LaserJet Pro 400 M401and HP LaserJet Pro M127fn, respectively. SpencerLab Digital Color Laboratory (2016), Monochrome Cartridge Reliability Comparison Study – 2016: HP LaserJet Toner Cartridges vs. Eastern European Non-HP New Build Cartridges. For details, see: http://www.spencerlab.com/reports/HPReliability-EE-NBC2016.pdf

[vii] A 2017 tracking survey for EMEA conducted by Photizo Group and commissioned by HP. The survey responders were micro, small, medium, large, and enterprise business customers. Results based on 1002 HP monochrome LaserJet users who had used both Original HP and non-HP toner cartridges. Studies were conducted on-line by customers in Germany, France, Italy, Poland, Russia, Turkey, and the U.K. For details, see: http://photizogroup.com/wp-content/uploads/2017/08/2017_HP_EMEA.pdf

[viii] PRe Consultants, SimaPro version 8 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.

[xi] MSW management data based on population-weighted average of U.K. (38% LF, 19% WTE, 43% recycling, https://www.gov.uk/government/statistical-data-sets/env18-local-authority-collected-waste-annual-results-tables); Germany (1% LF, 37% WTE, 62% recycling, http://www.eea.europa.eu/publications/managing-municipal-solid-waste/germany-municipal-waste-management), France (28% LF, 37% WTE, 35% recycling, www.eea.europa.eu/publications/managing-municipal-solid-waste/france-municipal-waste-management), Italy (50% LF, 14% WTE, 36% recycling, www.eea.europa.eu/publications/managing-municipal-solid-waste/italy-municipal-waste-management). Recycling is not included.

[xii] Internal HP research on monthly print volumes and duplex rates for the LJ Pro 400 M401 and the LaserJet Pro MFP M127fn.

[xiii] 2014 HP internal data.

[xiv] Specifications found at www.hp.com.

[xv] 2015 HP internal data.

[xvi] 2014 HP Global Citizenship Report: www8.hp.com/us/en/hp-information/global-citizenship/reporting.html

[xvii] 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: ttps://link.springer.com/article/10.1007/s11367-016-1246-y It was first made available in Fall 2009 and has been fully updated in 2016. The default version for the midpoint method, the "Hierarchist", was used. Please see www.pre.nl for more information.

[xviii] 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. Duebendorf, CH, www.ecoinvent.ch. See also www.pre.nl for more information.