Cartridge Remanufacturing and Energy Savings

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1 Summary

This case study focusses on evaluating the energy savings potential of remanufacturing printer toner cartridges. Better known as *Refilling*, remanufacturing printer cartridges is a well known industrial practice and can cumulatively influence the environment significantly. This influence can be both positive and negative, as will be observed with the results below.

In this report we use life cycle assessment as a tool to compare the total energy consumption upon choosing to use a refilled cartridge with that upon choosing to use a new cartridge. The results indicate the prominent influence of paper over the total life cycle energy inventory making the performance of the refilled cartridge during use phase to be a key factor. Thus, in order for cartridge remanufacturing to be a net energy savings strategy, relative to using a new cartridge, it is essential to improve its performance efficiency in producing "usable" printed-out pages.

2 Introduction

As computers have become ubiquitous in both professional and personal lives of people, the printers are not far behind. With increasing functionality (print rate, page yield, features etc) and decreasing prices, printing is replacing hand writing faster than ever. Printers, though bought once, require the replacement of its cartridge several times over its life, each time the ink / toner in the cartridge runs out. Because of this several remanufacturers have utilized this opportunity to procure used cartridges and resell them after filling them back with new fresh ink / toner. This process is more commonly know as Refilling of printer cartridges. In 2003, approximately 67 million cartridges were sold in the US of which approximately 27% were refurbished cartridges [3]. In fact Hauser and Lund [5] had estimated toner cartridge remanufacturing to be quite prevalent even around 1995 with 6,501 firms practicing it with $2.475 billion in sales. Hence, toner remanufacturing / refilling is a significant industry posing competition to the new replacement toners from the OEMs. This has lead to enormous strategic rivalry between the two including OEMs trying out "Prebate" schemes to revert the empty cartridge back to them and away from the hands of the refillers [8] as well as taking cartridge refillers to court for the infringement of the Digital Millennium Copyright Act [1]. This report however overlooks the business differences and concentrates on the life-cycle environmental impact difference between the replacement and refilled cartridge.

2.1 Printer Cartridge Refilling

Cartridge refilling is the process of refilling an empty, used printer cartridge with new ink (in the case of ink-jet cartridges) and toner (in the case of laser-jet cartridges) so as to bring back the cartridge into usable form. As a result, cartridge refilling restores part of the embodied energy inputted during initial manufactured and extends the life of a cartridge. In order to sustain another life, *refilling* entails more than mere refilling of the cartridge, with replacement of defective parts and refurbishment of parts being reused. Though this practice can vary from workshop to workshop, [9] describes the classical or expected remanufacturing process as given below in Figure 1.

The remanufacturing of cartridges starts with *Inspection* which provides information about the incoming cores. This helps in capacity control, deciding which further processes are required, and estimating process times. *Inspection* is followed by *Disassembly* where in the defective components are scrapped and sent for recycling and the re-usable components are passed on to the subsequent stages. *Disassembly* thus results in sorting of the different components which are then *Cleaned and Reprocessed* to restore them back to like-new condition. After *Refilling the Toner*, the components, (new and reprocessed) are *Reassembled* and then finally *Tested* for performance to ensure re-usablility before distributing them back into the market.

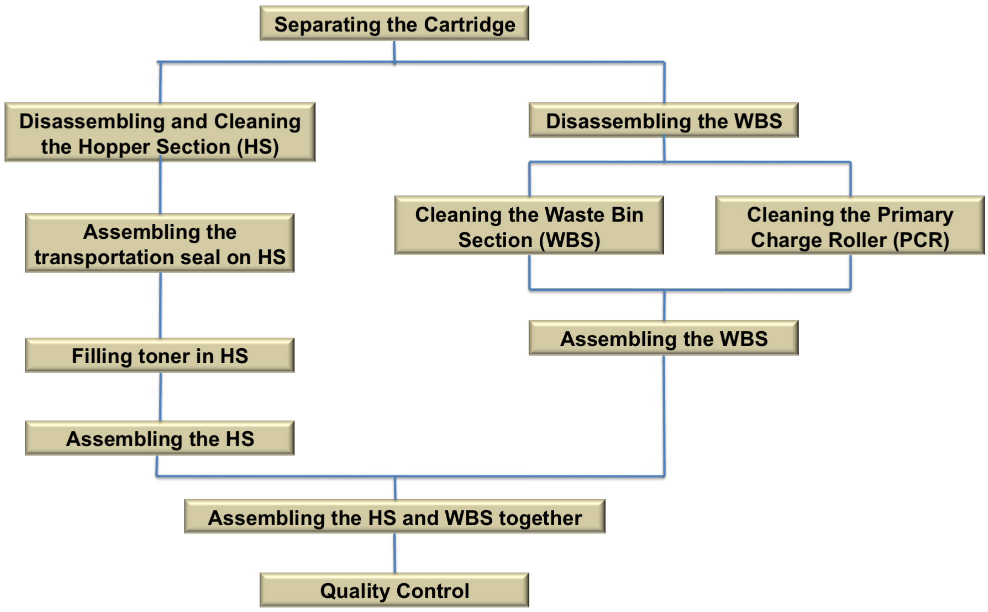

Figure 1: Calssical cartridge refilling / remanufacturing process as described by [9].

3 Scope of the Study

The aim of this study is to compare refilling of toner cartridges against using new ones from an energy saving perspective. While a remanufactured cartridge is sure to retain part of the energy embodied from its original manufacturing, its performance can be inferior to a new cartridge, diminishing its net energy savings. This decrease can be significant enough to lead to an eventual loss in relative (to using a new cartridge) energy savings (using more energy in total) when considered and evaluated over the life cycle of the entire product.

4 Methodology and Data Sources

The methodology adopted is the same as that for the other case-studies. Life-cycle assessment (LCA) is the major tool used. The boundary of analysis for LCA includes primarily four phases:

- Production - The energy used during the extraction and production of the raw materials added to the energy required in manufacturing the cartridge (which includes making the cartridge body as well as the toner), and finally combined with the assembly phase.
- Distribution - The energy entailed in the distribution of the cartridge to the consumer.
- Use - Use of the fully manufactured product by the consumer.
- End of Life - The energy consumed / recovered during the final stage of the product life. This could take several forms such as remanufacturing, recycling, reuse, incineration, landfilling etc.

The primary sources of data are [4, 2]. [4] is a report prepared by Four Element Inc for HP which provides information for the manufacturing, distribution and end of life energies for new and remanufactured cartridges. [2] does the same for the toner used. The use phase calculations are along the lines of those conducted in [4].

4.1 Printer Cartridge Performance

The performance of a printer cartridge can be characterized by several parameters like mechanism of printing (toner and ink-jet) which impacts the resolution and print-rate, print quality, page yield, printer compatibility etc. In this report we are interested in print quality of the printed paper. One way to define print quality is the percentage of useful pages (pages useful for a particular purpose, example for distribution to seniors officials) printed by the cartridge. This parameter has been adopted from the report for HP [7], in its definition and use, wherein the usability of printer outputs was classified based on different standards of output desired, which further depend on the final application of the printed pages.

5 Life Cycle Assessment

5.1 Production - Materials production + Manufacturing + Assembly

[4] reports that the energy to manufacture its LaserJet Q2610A Black Print Cartridge is 1.54 MJ, when normalized to the functional unit of 100 usable monochrome one-sided pages. Scaling this up to the page yield (6000 pages [10]) for the cartridge, the total energy to manufacture one cartridge is 91.49 MJ. As per the report, this number takes into account close to 99.5% of the materials. For the manufacturing of the cartridge, injection molding data is used for the housing component and steel and aluminum parts forming processes are included as data proxies to cartridge part manufacturing [4]. Assembly data was not modeled by [4] and was left out in this study as well.

Another essential component of the cartridge is the toner used for printing. [2] reported, in detail, the total energy required to produce the toner. This data was used to estimate that the energy needed for producing the toner for one unit of HP LaserJet Q2610A Black Print Cartridge is approximately 6.8 MJ.

Figure 2 shows the breakup of the total manufacturing energy embodied in a new cartridge into the cartridge casing and the toner added. While toner is what gets used completely, the embodied energy in the cartridge is what the Remanufacturing or Refilling process attempts to recover. The figure shows that the toner comprises of only 6.1% of the total energy embodied in a new cartridge.

For the remanufactured cartridge, it is common for the photoconductor drums and toner seals to be replaced, which entails production energy. Further, there is an energy associated with disassembly, cleaning etc as well. The HP report gives a conservative estimate of the energy required to remanufacture a cartridge, equal to 39.7 MJ.

5.2 Distribution

Similar to the manufacturing energy, the energy corresponding to the distribution phase of the new cartridge is 13.07 MJ [4]. The distribution energy for the remanufactured cartridge is hard to model and is left out for this point of time.

5.3 Use Phase

A printer cartridge is only a component of the entire printer. Inputs into the system (printer) are electricity and paper. Technically the use phase energy of the cartridge would include the electricity consumed specifically for the functioning of cartridge. However it is very difficult to quantify this contribution and no literature on this was found. Also most reports on the LCA of printer cartridges [4, 6, ?] use the electricity consumed during printing and the paper consumed as well to be a part of the use phase. This means that the energy associated with the production of the paper is also included. Having limited knowledge of what contribution of the total input to a printer can be corresponded with

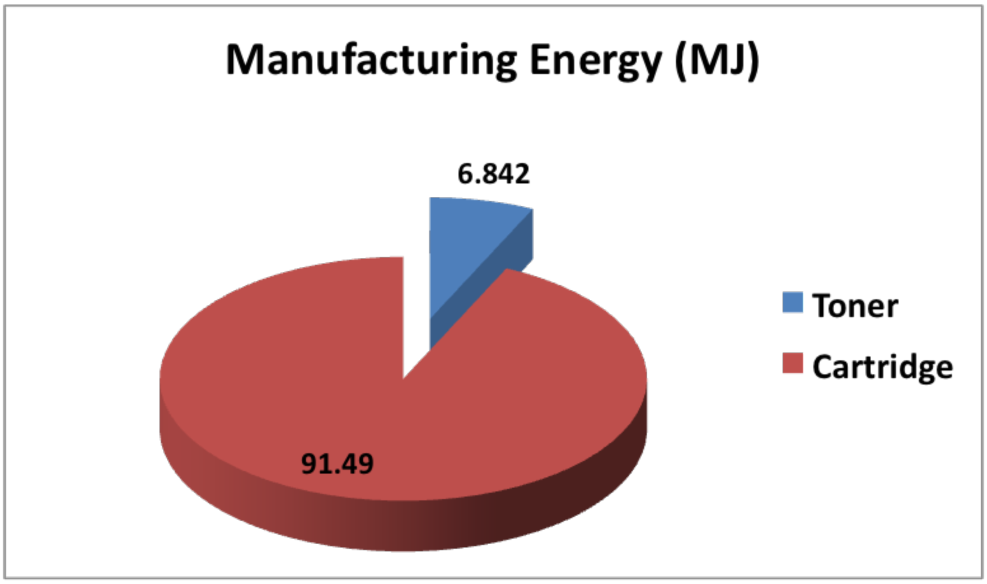

Figure 2: Manufacturing energy distribution into the cartridge and toner for a new cartridge [4].

the cartridge alone, this study follows the same line as other reports and assumes the use phase to include both the electricity and the paper consumed by the printer during printing.

The electricity used is a function of the power used while printing and the time taken to print all the pages that a toner cartridge can print. This time is estimated from the page yield and the print rate (pages per minute). The HP LaserJet Q2610A Black Print Cartridge is used for the HP 2300 printer which has a 24 page per minute output and a 426 Watt power rating while in print mode. These statistics are used for this report.

Since both, new and remanufactured cartridges contain the same amount of toner, the total number of pages printed out or the page yield of one cartridge is expected to be the same. This means that the use phase for both the cartridges are the same. However, the two may perform differently as the total number of useful/usable pages out of the total pages printed may be different.

5.4 End of Life

HP has a recycling facility which sorts retired cartridges for recycling or incineration. The energy associated is 39.2 MJ per cartridge (on an average) in savings. This figure includes the energy associated with the transport of the used cartridge to the recycling center. Though [4] assumes that the EOL energy for remanufactured cartridges is negligible, this study assumes that a remanufactured cartridge can be recycled / incinerated equivalently.

5.5 Life Cycle Inventory

Apart from the above mentioned differences in the new and remanufactured, another major distinguishing factor is the percentage of printed-out paper that are "useful." The *usefulness* depends on the application. Some printed out sheets are used personally while others may be externally distributed. The print quality can thus vary a lot as per application. [7] have evaluated the reusability of print out quality for HP, and this is continued to be used in this study as well. As per [7], it takes 101 pages to print 100 "useful" pages with a new cartridge and 114 pages with a remanufactured cartridge (using the base case of the report by [4]).

This leads to two cases, one relatively in favor of the new cartridge, while the other in favor of the remanufactured. Lets call them Case N and Case R respectively.

Given below is a short description of the two cases:

- *Case N*: This case assumes that the remanufactured cartridge performs as reported by [4]. That is it takes 114 print out pages to obtain 100 "useful" printouts.

- *Case R*: This case assumes that the remanufactured cartridge performs as well as the new cartridge and that it takes 101 print out pages to obtain 100 "useful" printouts.

In both cases the performance of the new cartridge is taken to be as per [4], that is, it takes 101 print-out pages to obtain 100 "useful" pages.

Figure 3 gives the life cycle inventories for the new and remanufactured cartridges.

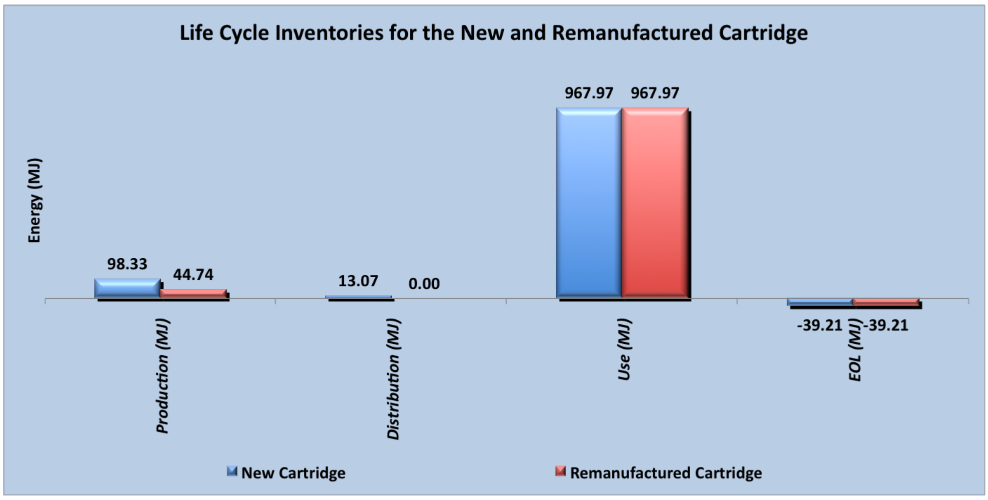

Figure 3: Life Cycle Inventory of New and Remanufactured Cartridge.

Clearly, the major savings are in the production phase, and are equal to more than 50% (of the manufacturing energy) in this case. Also note that the use phase for both is the same since they both yield the same number of print out paper (total amount of toner is equal in both). Only the number of useful pages is different. In order to bring out this difference Figure **??** shows the *Life Cycle Inventories* normalized by the useful output (fraction of useful output). The LCI are normalized by (5,940.6 / 6,000) (5,940.6 useful pages out of the total cartridge page-yield of 6,000) for the new, and (5,263.2/6,000) for the remanufactured in Case N while they are both normalized by (5,940.6/6,000) in Case R.

Case R, where the remanufactured cartridge performs as well as the new cartridge, the use phase for the two is identical. On the other hand, if the remanufactured cartridge performs as inferiorly as claimed by [4], as depicted in *Case N*, the remanufactured cartridge can require 12.9% more energy during the use phase alone. Overall, Figure 4 exhibits the influence of the cartridge performance on the total life cycle energy consumption of a cartridge.

Another interesting aspect of all the LCIs is the predominance of the use phase over the total life cycle of a cartridge. The use phase, as described in Section 5.3, comprises of electricity and paper. Electricity is less than 2% of the total use phase, while the rest 98% is due to the paper. Thus the input-paper is clearly the dominant energy consumer during the life cycle of a cartridge. This result conforms with the studies by [4, 6] as well.

For a consumer who has a choice to buy either a new or a refilled / remanufactured cartridge, the decision seems to depend on the performance of the remanufactured cartridge relative to the new. The

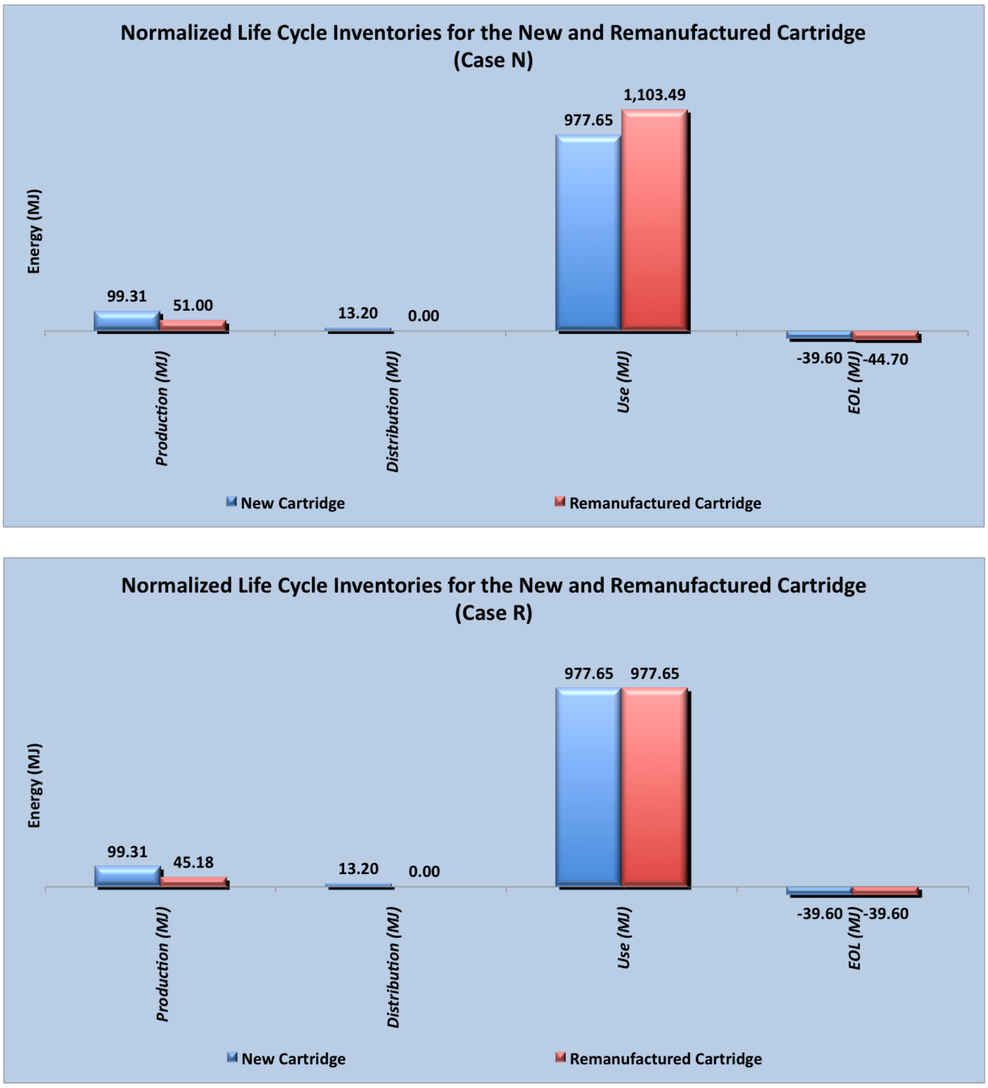

Figure 4: Normalized LCIs of the new and remanufactured cartridge for (a) Case N and (b) Case R

above figures, to an extent, indicate the life cycle energy impacts of the two choices, wherein *Case N* and *Case R*, collectively exhibit the influence of the the performance of the remanufactured cartridge on its energy savings potential. This is better understood by Figure 5.

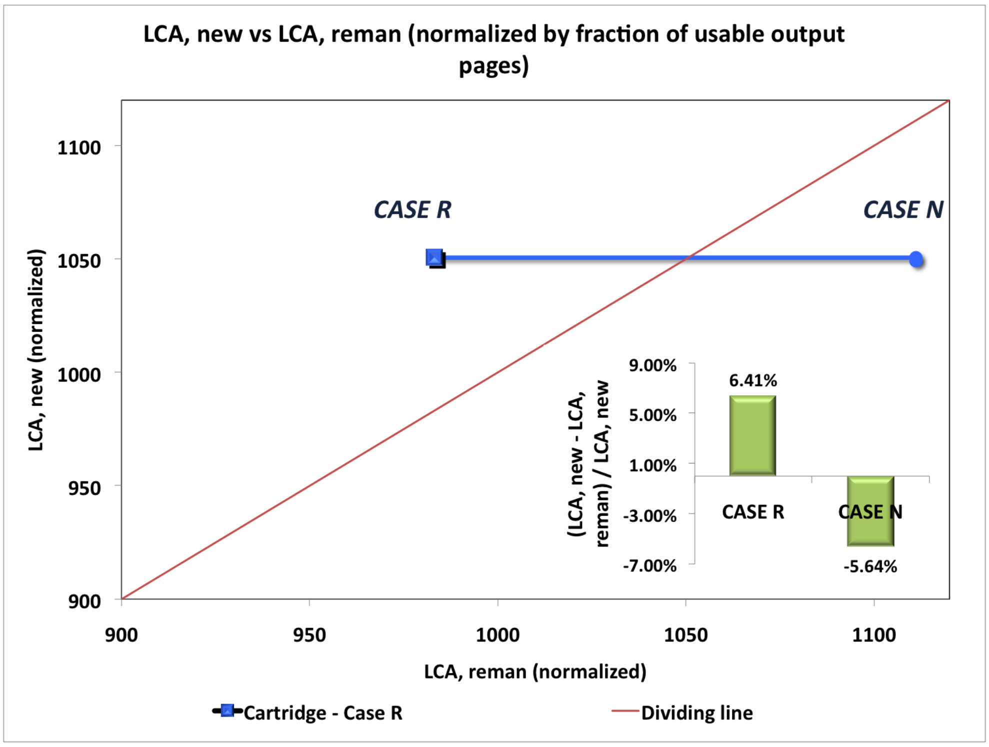

Figure 5: Comparing the normalized life cycle energy assessment for new and remanufactured / refilled cartridges. Note: Both *Case N* and *Case R* are shown. The insert shows the percentage saving of choosing new over refilled cartridges.

The result obtained is very interesting indeed. It shows that when the remanufactured cartridge performs as well as the new cartridge, it makes sense to choose a refilled cartridge compared to a new, as an energy savings strategy. This choice can save over 6.4% of the energy required during the life cycle of a new cartridge. On the other hand, if the cartridge performs as badly as claimed by [4], then choosing a new cartridge will lead to less energy consumption, close to 5.6% lesser.

One should also consider the general error associated with Life Cycle Assessment as a tool. If this error is assumed to be 5-10%, then the above comparison is nuanced. In other words, through the Life Cycle Assessment conducted above, it is hard to decide whether choosing a new cartridge or a remanufactured cartridge is better to help reduce total energy consumption.

6 Assumptions and Comments

Though most of the above study is based off other reports and studies, there are a few assumptions made along the way which must be highlighted.

- The energy to assemble the cartridges has not been taken into account. Assuming that this energy will be the same for the new and remanufactured cartridge, it can be predicted that relaxing this assumption will not have a major influence on the relative results (relative energy differences between the two versions of the cartridge, new and remanufactured), like those shown in Figure 5.

- The energy for the distribution of the remanufactured cartridge is not taken into account during this study. This makes the study slightly in favor of refilling, as the energy savings strategy.
- It is assumed that the refilled cartridge can be recycled / incinerated to the same extent as a new cartridge and overall returns the same amount of energy as a new one.
- The decrease in performance of the remanufactured cartridge is characterized as per the *Base Case* in the report by [4].
- The use phase, like in the case of [4, 6, **?**], is assumed to be the total energy used by the printer while printing and the energy embodied in the paper used for printing.

7 Conclusion

The life cycle energy assessment for the toner cartridge shows that the energy stored in the paper used is the dominant factor over the entire LCA. As a result, the net energy savings of choosing to use a remanufactured cartridge over a new one strongly depend on its performance, which is characterized by the efficiency of the cartridge to produce "useful" print outs. In this study, two cases were considered - (1) when the remanufactured cartridge performs as well as the new; (2) when it performs as indicated in a report for HP [7]. In the prior case, the energy savings were close to 6.5%, indicating refilling to be the *net energy savings strategy.* On the other hand, if the refilled cartridge prints out several non-"usable" pages, as in the later case, choosing a refilled cartridge over a new one leads to consumption of higher energy over the life cycle. Another key aspect to account for is the error associated with using *Life Cycle Assessment* as an error of 5-10% will make the above calculations nuanced.

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