Environmental impacts of paper handouts vs. Online handouts-from a life cycle assessment prospective

Impactos ambientales que suponen la imprenta en papel vs. La difusion en una plataforma electronica - desde la prespectiva de un analisis del ciclo de vida

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Abstract

The purpose of this study was to address the concerns about sustainability between the uses of hard copy reference documents versus online copies. This project presents a Life Cycle Assessment (LCA) study comparing the production and use of a hard copy handout versus an online handout. For the purpose of this study, paper handouts and online handouts are two different and independent processes. This means that they not only have different outputs but also have different manufacturing stages in order to get to the final result. The scope of this study is "cradle to grave," starting with the extraction of the raw materials, followed by paper and computer production processes, transportation, product use and disposal/recovery. Results indicate that under the made assumptions, the use of a paper handout has more environmental impacts. At the same time among the evaluated processes, paper production has higher environmental impacts.

Keywords: Life Cycle Assessment, Life Cycle Inventory, Paper production, Electronic production.

Resumen

El propósito de este estudio fue abordar las inquietudes sobre la sostenibilidad entre los usos de los documentos de referencia impresos y las copias en línea. Este proyecto presenta un estudio de Evaluación del Ciclo de Vida (LCA) que compara la producción y el uso de una copia impresa con un folleto en línea. Para el propósito de este estudio, los folletos en papel y los folletos en línea son dos procesos diferentes e independientes. Esto significa que no solo tienen diferentes productos sino también diferentes etapas de fabricación para llegar al resultado final. El alcance de este estudio es de "cuna a tumba", comenzando con la extracción de las materias primas, seguido de los procesos de producción de papel y computadora, el transporte, el uso del producto y la eliminación / recuperación. Los resultados indican que bajo las suposiciones hechas, el uso de un folleto en papel tiene más impactos ambientales. Al mismo tiempo, entre los procesos evaluados, la producción de papel tiene un mayor impacto ambiental.

Palabras Claves: Evaluación del ciclo de vida, inventario del ciclo de vida, producción de papel, producción electrónica.

Recibido / Received:08 de Agosto del 2016 Aprobado / Aproved: 20 de Agosto del 2016

Tipo de artículo / Type of paper: Articulo de investigación cientifica y tecnológica.

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El autor declara que no tiene conflicto de interés.

Introduction

In the past two decades, the use of hard copy references (books, journal articles, magazines, newspapers, etc.) versus the use of online references of those same hard copies has generated divided opinions among scholars, industries and common people [1]. Since the beginning of the controversy, arguments for and against the two options have been made. Nevertheless, and without disregarding the validity of some of those arguments, an increasing concern has been rising based on the fact that in paper production and electronic production the use of natural resources is involved [2, 3,4 and 5]. That use of natural resources, and the implementation of industrial processes to supply a growing demand [6], has turned into concerns related to resource depletion and energy use [7].

Paper production dates back to the ancient Egyptians, who developed an artisan process to transform plants into a form of paper known as papyrus [8]. Since then, paper production has evolved, up to the point, that nowadays paper is made from tree fibers/wood pulp and involves a series of mechanical and chemical processes [9]. Production of pulp and therefore the following processes involved in the production of paper, release into the environment emissions that have an impact in global warming, ozone and fossil fuel depletion [10]. The majority of adverse impacts in paper production process is from the process stages and energy consumption rather than deforestation [11]. Energy consumption is responsible for both greenhouse gases emission (GHG) and Carbon dioxide (CO2) emission (74% and 75%, respectively) [5], as well as in changes to the wildlife diversity associated with wood cultivation and deforestation [12].

On the other hand, electronic production, more specifically massive computer and laptop production, is a relatively new process [4]. However, its production not only involves the extraction of rare metals (lead, mercury, silver and gold) but is also more energy intense [13]. Furthermore, the manufacturing and user stages are responsible for high CO2 emissions [14].

Taking that into account, in order to address the growing concerns about sustainability between the uses of hard copy reference documents versus online copies, this project will present a Life Cycle Assessment (LCA) study comparing the production and use of a hard copy handout versus an online handout. By doing this, not only will a better and detailed understanding of the environmental impacts associated with the production and use of these two products will be offered, but at the same time, a more educated decision could be taken about this controversial topic.

Goal and Scope

The goal of this LCA study is to identify the environmental impacts of printing, photocopying, distributing and using paper handouts for a class versus posting and using handouts entirely online.

Specific goals of this project included:

- Determined the environmental impacts of using a paper handout versus an online handout using a Life Cycle Inventory (LCI) approach.
- Determine which stage inside the two evaluated processes (paper handout and online handout) has higher environmental impacts.

The scope of this study is "cradle to grave," starting with the extraction of the raw materials, followed by paper and computer production processes, transportation, product use and disposal/recovery. Table 1 presents a summary of the system boundaries defined for each product.

Table 1. *Paper Handout and Online Handout Boundaries*

Paper Handout	Online Handout
Included	**Included**
Raw material extraction	
Transport to paper mill	
Wood handling	
Chemical pulping and bleaching	
Paper production	
Paper transportation	
Handout printing	
Paper disposal/recycling	
Energy consumption inputs	Raw material extraction
Computer production	

Computer transportation
Handout use
Computer disposal/re-cycling
Energy consumption inputs

For the purpose of this study, paper handouts and online handouts are two different and independent processes. This means that they not only have different outputs but also have different manufacturing stages in order to get to the final result. Figure 1 and Figure 2 present the processes flow diagrams for the paper handout and the online handout, respectively. These processes flow diagrams illustrate the flow of the paper handout and the online handout starting with the raw material input and material transformation, followed by different stages that are determined by the use of each product (transportation, use and disposal/recycle). It is important to note that for both assemblies all of the energy inputs required by each stage were taken into account.

For the LCA presented in this study the functional unit has been defined as the access to an 8.5" by 11" handout in order to obtain 17 pages of information before, during, and after a class. The impact categories considered in the Life Cycle Inventory Assessment (LCIA) are: Climate change, Ozone depletion, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Human toxicity, Photochemical oxidation formation, Particulate matter formation, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Ionizing radiation, Agricultural land occupation, Urban land occupation, Natural land occupation, Natural land transformation, Water depletion, Metal depletion and Fossil depletion.

Figure 1. *Paper Handout Process Flow Diagram*

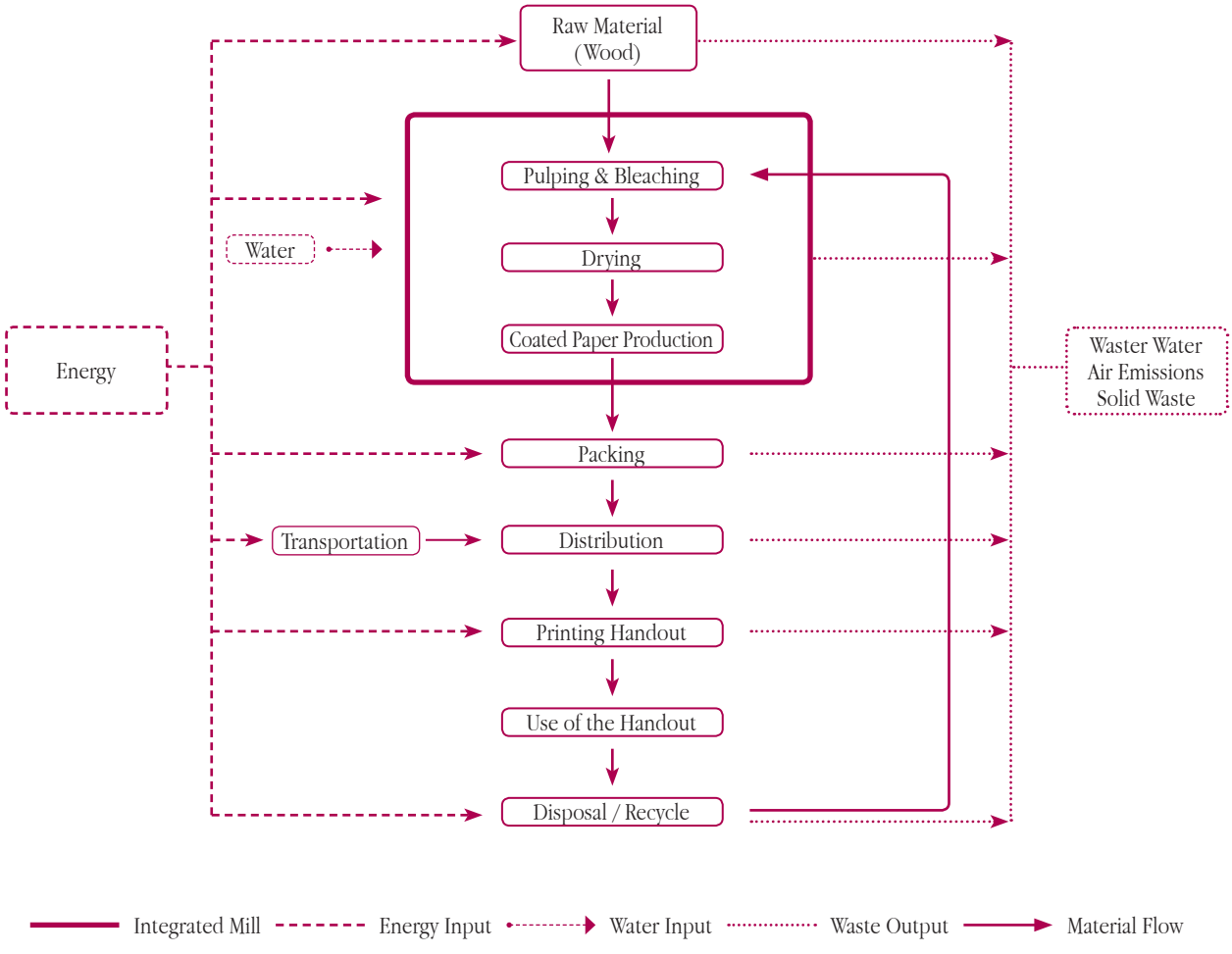
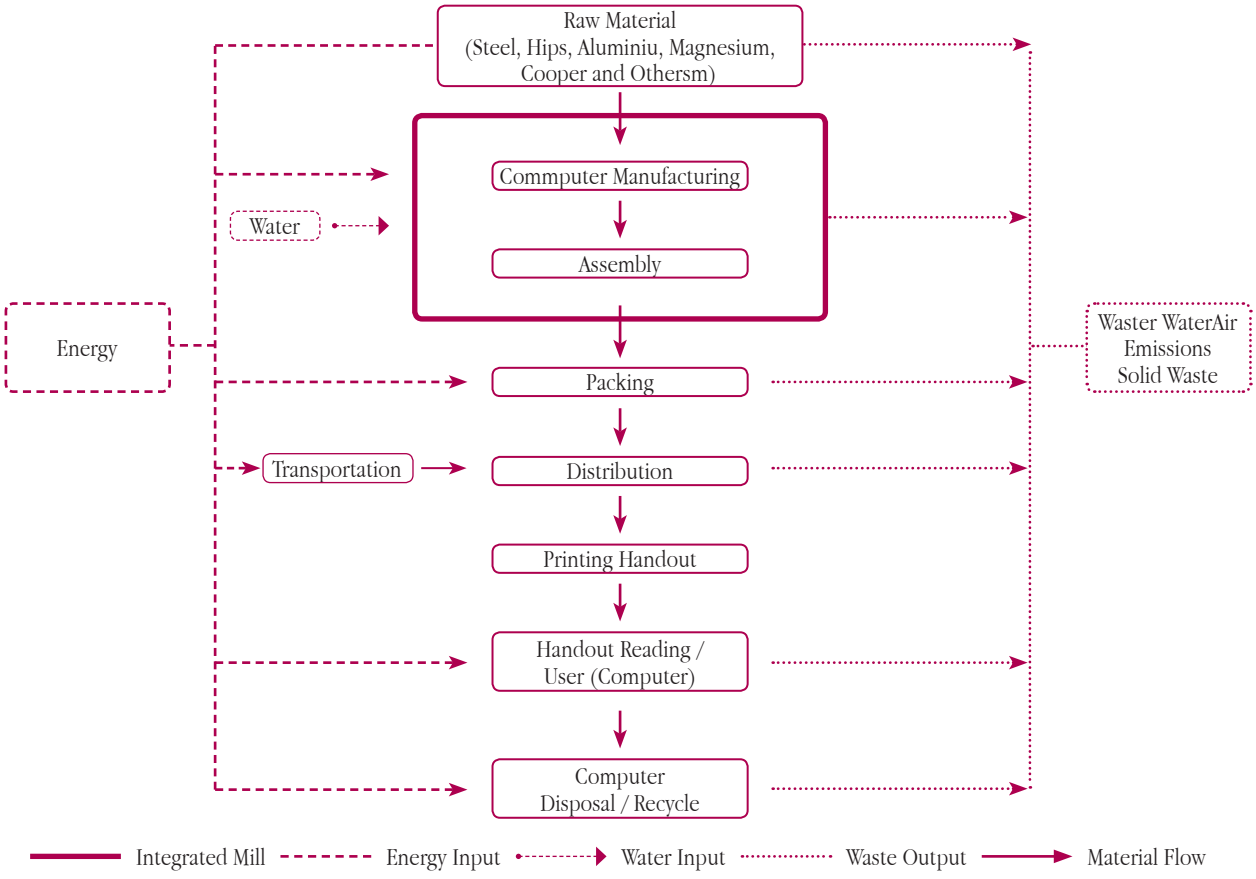


Figure 2. *Online Handout Process Flow Diagram*



Project Assumptions

In order to complete this study, the following assumptions were made:

- One handout is composed of 17 pages. This number was determined by averaging the number of pages of the 12 handouts that were distributed through the spring 2016 semester in a class at the University of Oklahoma.
- One coated sheet of paper has a length of 11 inches, a width of 8.5 inches and a thickness of 70 grams per square meter (gsm) [5 and 14]. Based on that, a single sheet of paper has the weight of 4.2224 g.
- Paper production in Europe is the same as in the United States of America (U.S).
- For transportation purposes, paper production takes place in the U.S, more specifically in Maplesville, Alabama, where South Coast Paper (a paper company) has its main paper production facility. According to Google Maps, the distance from this factory to The University of Oklahoma (OU) is 1287.48 km (800 miles).
- For transportation purposes, computer production takes place in the southeast coast of China, in a city call Xiamen; where DELL Inc. has one of its many computer manufacturing and assembly facilities. According to Google Maps, the distance from Xiamen to Long Beach, California and from Long Beach to OU is 13404.708 km (8326.299 miles).
- Wallot et al. (2013), identified adult readers take an average of 5 minutes to read one page of information. However, based on the personal experience of the authors of this study, it has been determined that a total of 25 minutes is a more representative time in order to read and understand the information provided in 1 page.

- The average weight of a laptop computer is 2.544 kg. This weight was obtained by weighing an Apple MacBook Pro and a Toshiba Satellite C-75 laptop (laptops of the authors of this study).
- According to Apple, DELL, Hewlett Packard (HP) and Toshiba (all computer manufactures), laptops have a life span of 2-3 years. Based on that and taking into consideration an average college student's financial inquisitional power of new goods, a 3-year life span is the most representative number for this study [15].
- The total time and weight allocated from the computer to the actual use (reading) of the handout, is based on assumptions 5, 6 and 7. This means that the weight and time inputs for the online handout processes are calculated on the basis that an individual takes 25 minutes per page to read a handout.

Life Cycle Inventory

The LCI for both processes (paper handout and online handout) was completed using SimaPro 8.10.60. In order to do that, two assemblies composed by different datasets that mimic the production, transportation, use and disposal/recycle stages were created. Table 2 and Table 3 present the selected dataset for each product, with their respective units and assigned values for the paper handout and online handout, respectively

Table 2. *Paper Handout Assembly*

Category	Dataset	Amount	Unit	Source
Material	Paper, Woodfree, coated, at integrated mill/RER U	0.071781	kg	Ecoinvent
Processes	Transport, single unit truck, long-haul, diesel powered, Southeast/ tkm/RNA	0.101871	tkm	USLCI
Processes	Use, printer, laser jet, b/w, per kg printed paper/ RER U	0.071781	kg	Ecoinvent

Data for the paper handout assembly is composed of 3 parts. The first part is the paper production, this stage is being model by the Paper, Woodfree, coated, at integrated mill/RER U dataset. The processes included in this dataset are: wood handling, chemical pulping and bleaching, paper production, energy production on-site, recovery cycles of chemicals internal, waste water treatment and the transports to paper mill [5]. The value for the paper production was calculated using assumptions 1 and 2. Based on that the 0.071781kg value for paper weight was calculated by multiplying the number of pages in a handout by the weight of a sheet of paper.

The second part is the transportation from the paper factory to OU, this stage is being model by the Transport, single unit truck, long-haul, diesel powered, Southeast/ tkm/RNA data set. This dataset represents the average airborne emissions generated by the vehicle operations (USLCI). As stated in the project assumptions, for transportation purposes, paper production takes place in Maplesville, Alabama where South Coast Paper (a paper company) has its main paper production facility. According to Google Maps, the distance from this factory to OU 1287.48 km (800 miles). Based on that, the 0.101871 tkm value for transportation distance was calculated by multiplying the weight of the handout in tons by the distance from the factory to OU in km.

The third and final stage is the printing of the handout, this stage is being model by the Use, printer, laser jet, b/w, per kg printed paper/RER U dataset. This dataset includes the electricity consumption of an active mode printer, printer production and transportation (Ecoinvent 2.2). The value for this dataset was the same one as the paper production, because 17 pages are being printed which means that the weight is still the same.

The only dataset taken from the Ecoinvent database were the Unit processes (symbolized by letter "U" at the end title). The reason for that is because the contribution from the different sub-processes wanted to be obtained. At the same time, when possible data generated in the US was used, unfortunately most of the processes from this database were generated in Europe (RER).

Table 3. *Online Handout Assembly*

Category	Dataset	Amount	Unit	Source
Material	Laptop Computer, at plant /GLO U	0.000270	P	Ecoinvent

Category	Dataset	Amount	Unit	Source
Processes	Transport, transoceanic freight ship/OCE U	0.007691	tkm	Ecoinvent
Processes	Transport, single unit truck, long-haul, diesel powered, West /tkm/RNA	0.001501	tkm	USLCI
Processes	Use, computer, laptop, active mode/RER U	7.083	hr	Ecoinvent

Data for the online handout assembly is composed by 4 parts. The first part is the computer production, this stage is being model by the Laptop Computer, at plant /GLO U dataset. The processes included in this dataset are: the material acquisition (mainly metals and plastics), the energy consumption for the assembly, the water consumption and industrial waste water, the required ship, rail and road transport for input materials and the disposal process of the laptop (Ecoinvent 2.2). The value for the computer production was calculated using assumptions 6, 7 and 8. Based on that, the 0.000240 P value for the computer amount, was calculated by dividing the time that takes to read one handout in minutes by the life span of the laptop in minutes.

The second and third part is the transportation from the factory to OU. As stated in the project assumptions, this transportation component has two parts. The first one is the transportation by boat from China to the U.S (given that the selected laptop manufacturer is in the city of Xiamen) and the second one is the transportation by truck from Long Beach, California to OU (domestic transportation from a port of entry in California to OU). These stages are being model by the Transport, transoceanic freight ship/OCE U and Transport, single unit truck, long-haul, diesel powered, West /tkm/RNA. These datasets represent the average airborne emissions generated by the different vehicles (freight and truck) operations (Ecoinvent 2.2; USLCI). In order to calculate the distance in tkm for the transport by freight, the allocated weight of the computer in tons was multiplied by the distance from Xiamen to Long Beach. To calculate the distance in tkm for the transport by truck, the allocated weight of the computer in tons was multiplied by the distance from Long Beach to OU.

The fourth and final stage is the use of the computer in order to read the handout. This stage is being model by the Use, computer, laptop, active mode/RER U dataset. This dataset takes into account the energy use of a laptop in the active mode. The value for this dataset was established as the time required in hours to read one handout.

Resembling the logic established in the paper handout, the only dataset taken from the Ecoinvent database were the Unit processes. The information was based on the data generated in the countries where the process was taking place.

Life Cycle Impact Assessment

ReCipe Midpoint (H) was the selected method in order to determine the LCIA for the two products. As mentioned before, the impact categories considered in this process were: Climate change, Ozone depletion, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Human toxicity, Photochemical oxidation formation, Particulate matter formation, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Ionizing radiation, Agricultural land occupation, Urban land occupation, Natural land occupation, Natural land transformation, Water depletion, Metal depletion and Fossil depletion.

Figure 3 and Figure 4 presents the impact assessment for the paper handout and the online handout, respectively. As mentioned in the goal and scope section, one of the specific goals of this study was to determine which stage inside the two evaluated processes had higher environmental impacts. Based on that, from Figure 3 it can be determined that for a paper handout product, the paper production (blue) contributed in a more significant way with higher environmental impacts in 16 out of the 18 impact categories. Followed by transportation (red). On the other hand, from Figure 4, it can be determined that for the online handout, the use of the laptop (red) is the most significant contributor to the adverse environmental impacts in 16 out of the 18 impact categories. Followed by the laptop production (blue).

Correspondingly, another specific goal of this study was to present a comparison to determine which of the two products had higher environmental impacts. Figure 5

presents a comparison between the paper handout and the online handout. From this figure, it can be determined how the paper handout has higher negative environmental impacts than the online handout. Figure 5 shows that in 12 out the 18 impact categories, the paper handout effects are 50% (or more) higher than the online handout.

Figure 3. *Paper Handout Life Cycle Impact Assessment.*

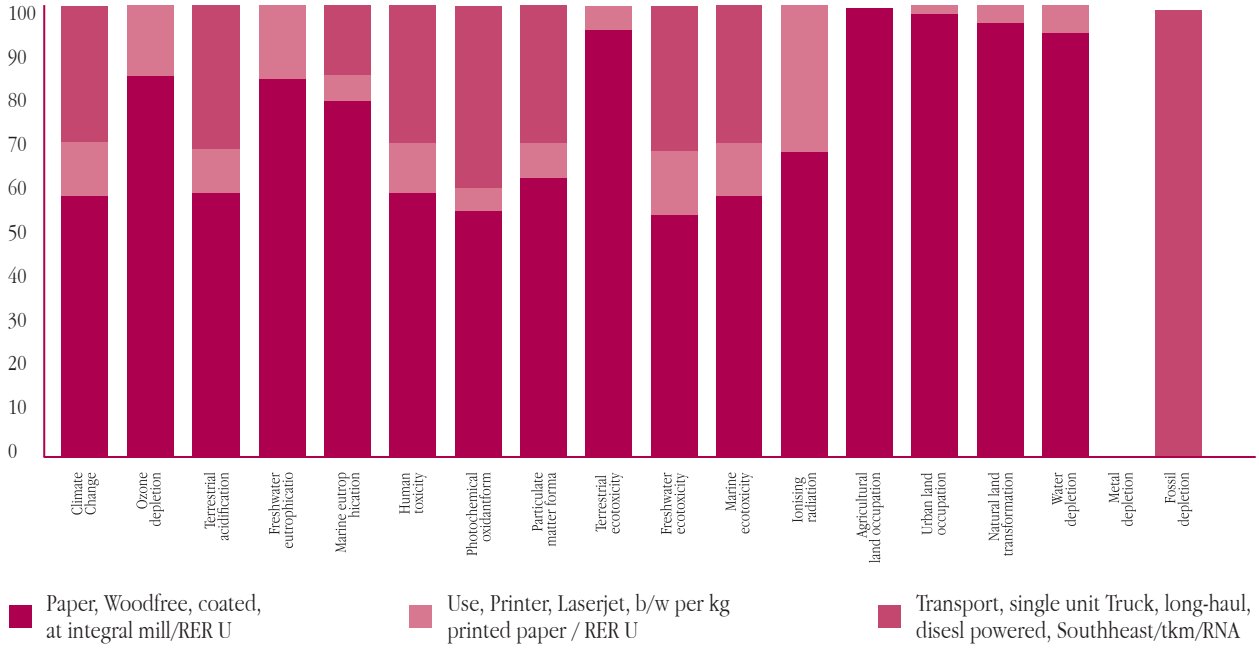


Figure 4. *Online Handout Life Cycle Impact Assessment.*

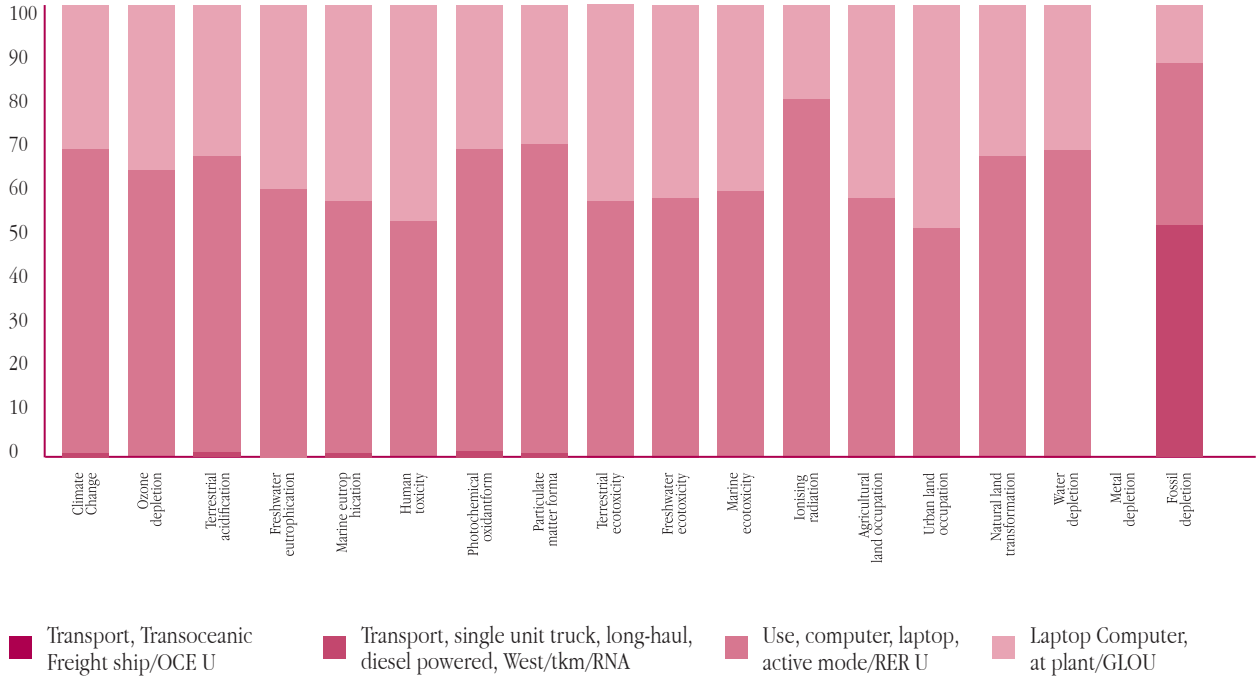
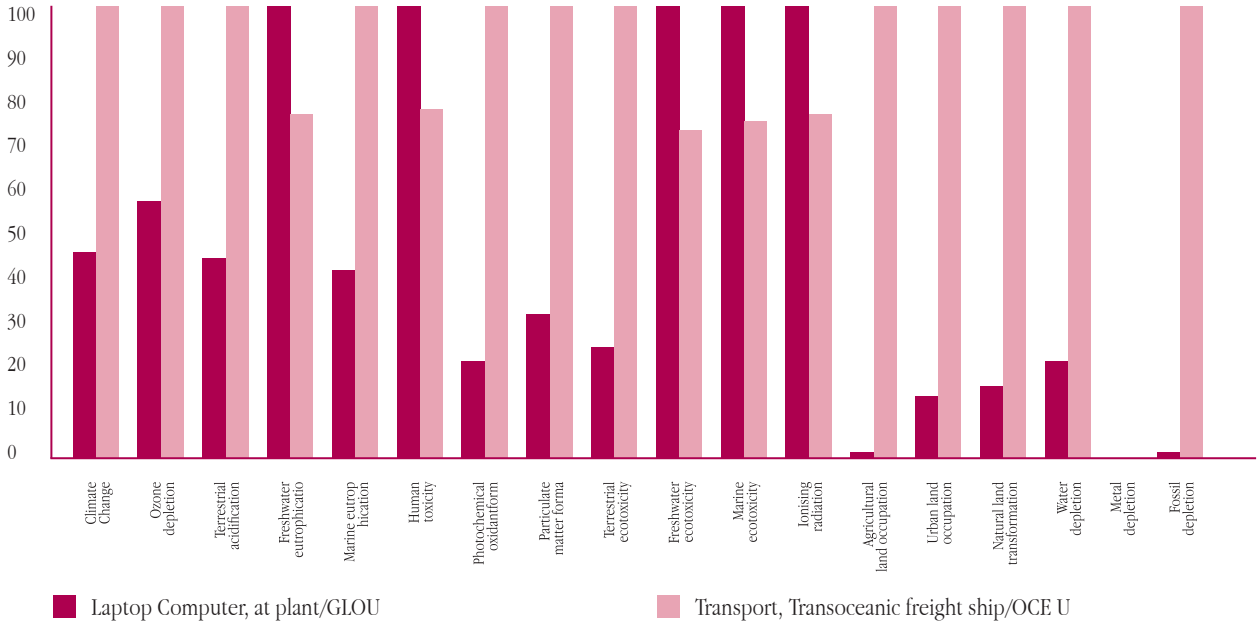


Figure 5. *Comparison between Paper Handout and Online Handout*



Interpretation

In order to better understand the results presented in the LCIA section, a comparison between ozone depletion and the three most affected impact categories in each process was performed for both products. Table 4 and Table 5 summarize those values.

Table 4. *Higher impact categories affected by paper handout production, plus ozone depletion*

Impact Category	Total	Unit
Agricultural Land Occupation	0.29147	m2a
Climate Change	0.13755	kg CO2 eq.
Human Toxicity	0.07503	kg 1,4-DB eq.
Ozone Depletion	6.50x10-9	kg CFC-11 eq.

Table 5. *Higher impact categories affected by online handout production, plus ozone depletion*

Impact Category	Total	Unit
Human Toxicity	0.29147	kg 1,4-DB eq.
Climate Change	0.13755	kg CO2 eq.
Ionizing Radiation	0.07503	kBq U235 eq.
Ozone Depletion	6.50x10-9	kg CFC-11 eq.

By analyzing the results presented in Figure 3 and Table 4, it is interesting to note that the top three impact categories that are being affected by a paper handout are the ones directly related to the material extraction and production of paper.

The most impacted impact category is agricultural land occupation. This phenomenon could be explained by the fact that wood (principal component/material of paper) comes from trees, so the bigger those trees are (so more material could be obtained from them), the greater the area of land they occupy [16] (Figure 6). The second most impacted impact category is climate change. Figure 8 presents the distribution of the air emissions being released by the paper production process. Paper production is energy demanding [11]. Energy consumption is responsible for both GHG and CO2 emission (74% and 75%, respectively) [5]. Finally, human toxicity is the third most impacted impact category in a handout production process. Figure 8

presents the distribution of the chemicals used/generated by paper production that impact human health. From this figure it can be observed that chemicals like barium (Ba), mercury (Hg), selenium (Se) and manganese (Mn) account for 91% of the used/generated chemicals. If it is true that most of these elements can be natural occurring in the environment [17], it is also true that health effect concerns have been determined by continuous exposure to some of those elements such as Hg and Se [18].

Figure 9. *Effects on Human Health – Online Handout*

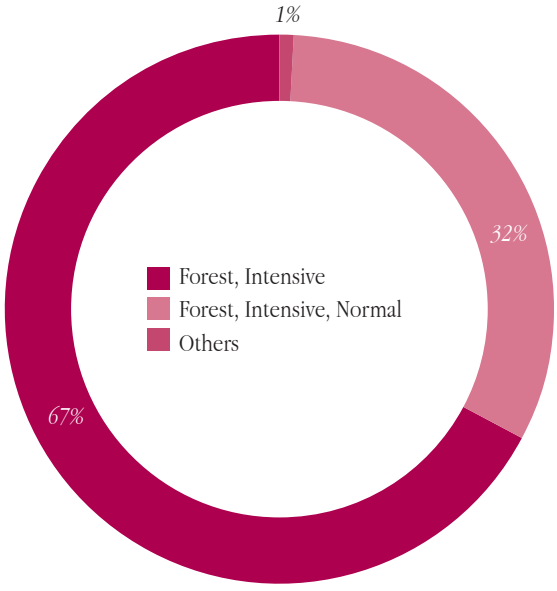


Figure 7. *Effects on Climate Change – Paper HandoutDiagnóstico*

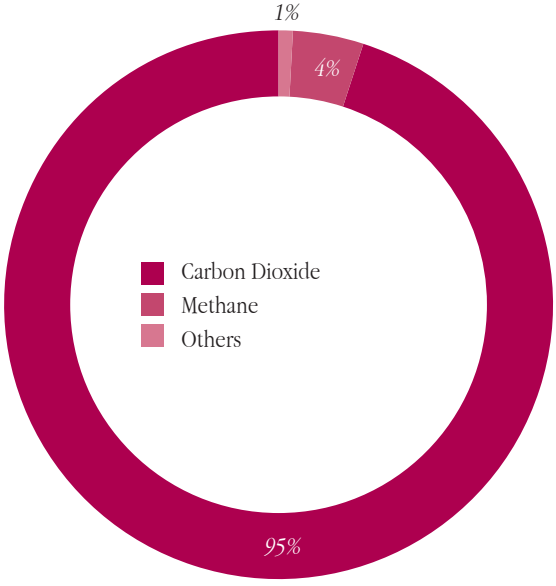
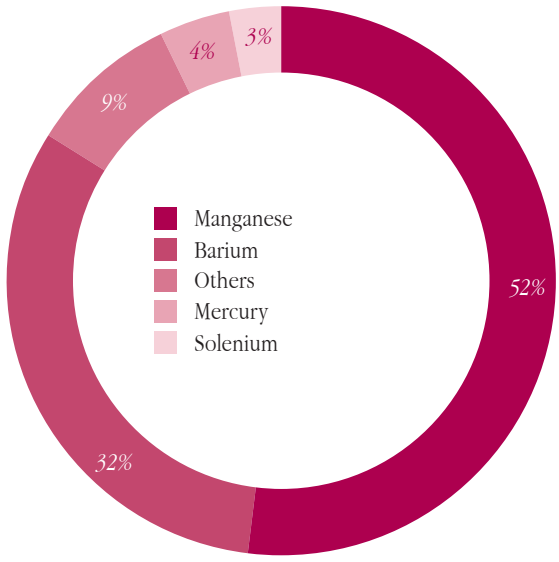


Figure 8. *Effects on Human Health – Paper Handou*



For the online handout, differences in the relationship can be found by comparing Figure 4 and Table 5. The reason for that is because the top three most impacted impact categories are not only related to one single process.

The most impacted impact category is human health. Figure 9 presents the distribution of the chemicals used/generated by computer production that impact human health. From this figure, it can be observed that chemicals like Mn, Se, Arsenic (As) and Lead (Pb) account for a 94% of the total chemicals that affect human health. The reason behind this, lies under the fact that those chemicals (and many more) are present in the laptop manufacturing process [18, 19 and 20]. Continuous exposure to those chemicals, have been related to different health issues [18]. The second most impacted category is climate change. Figure 10 presents the distribution of the air emissions being released the atmosphere most likely by the production process and user use. This phenomenon could be explained because computer production and use requires a great amount of energy [13].

Finally, ionizing radiation is the third most impacted impact category in an online handout production process. Figure 11, presents the distribution of irradiated radiation generated by a laptop. The use of a laptop generates magnetic fields [21]. The generated fields are within the International on Non-Ionizing Radiation Protection (ICNIRP); however, its presence cannot be ignored [22].

Figure 9. *Effects on Human Health – Online Handout*

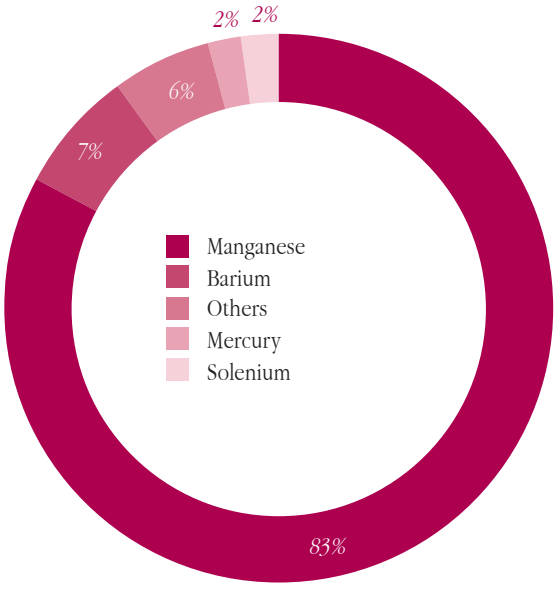
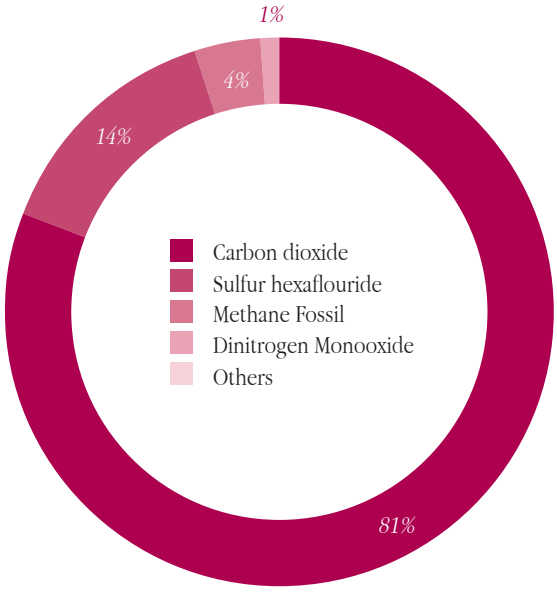


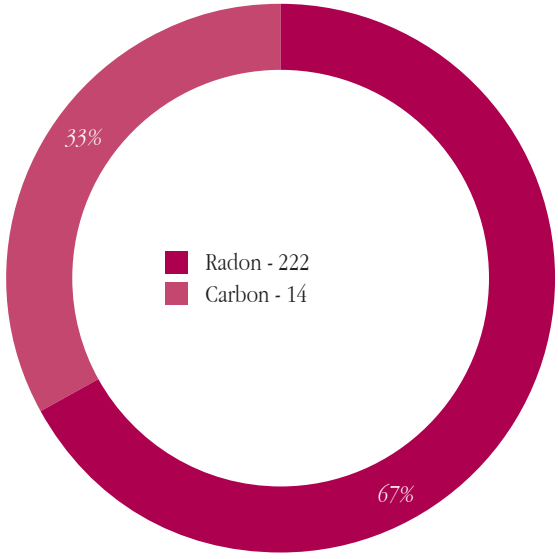
Figure 10. *Effects on Climate Change – Online Handout*



Sensitivity Analysis

In order to evaluate the validity of the results, several sensitivity analyses (different scenarios) altering some or all of the assumptions made for this study were considered. This was performed with the only purpose of getting a more complete understanding of the effects that could affect the results of this LCA.

Figure 11. *Effects on Ionizing Radiation – Online Handout*



Paper Recycling

Paper recovery for recycling is a common practice among the major paper producing companies throughout around the world (Arafat et al., 2015; Hong and Li, 2012). The basis of this practice lies under the belief that virgin raw material is highly connected to global warming and high energy use [23]. In order to evaluate the environmental impacts generated by recycling paper, an LCIA was performed in order to compare four different recycling paper percentages.

Figure 12 presents the results of the comparison between 100% recycle paper (orange), 75% recycle paper (dark blue), 50% recycle paper (red) and 25% recycle paper (light blue). The LCIA method was ReCiPe Midpoint (H) and the dataset was from the Ecoinvent database. From Figure 12 it can be determined that using a 100% recycled paper presents the worst impacts for most of all of the impact categories (11 out of 18), followed by 75% recycle paper, 50% recycle paper and 25% recycle paper, respectively.

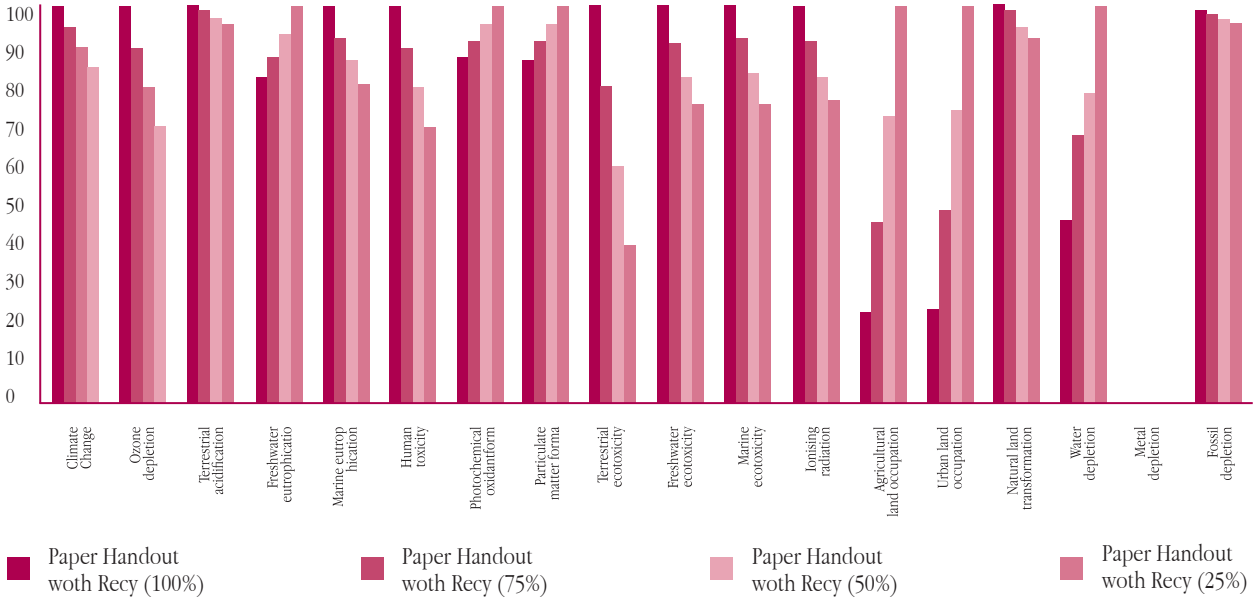
The results from Figure 12 are not surprising, given the fact that the paper recycling process, is a process that involves re-pulping and deinking the waste paper, processes that involve energy use and chemicals input [24]. Based on that, a recycling process stage was added to the paper handout assembly, and compared to the online handout using a LCIA with ReCiPe Midpoint (H) as the method.

Results for that show that between the use of a paper handout versus an online handout, a paper handout is still

the one that has more negative impacts in the environment. However, notable reductions in the concentration of most of the chemicals was found by adding a recycling paper stage. More specifically, in the recycling of 50% and 25% of the waste paper.

This finding suggests that paper companies should implement a 25-50% waste paper recycling process in their respective operations, so that the concentrations of different chemicals that are being released to the environment decrease.

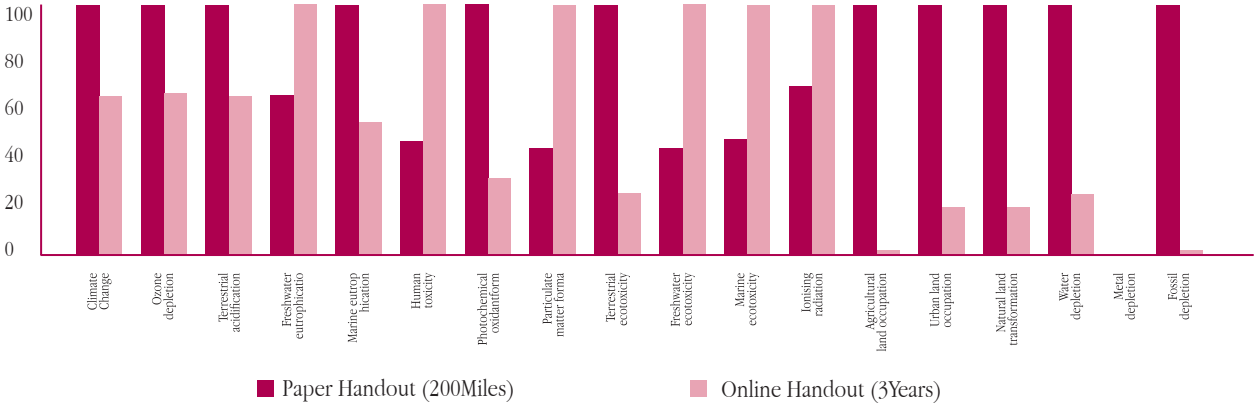
Figure 12. *Recycling Scenarios*



Transportation

As stated in assumption 4, for transportation purposes a paper company located in Maplesville, Alabama (800 miles from OU) was selected. In order to determine if transportation of the paper plays a major role in the results, that millage was changed to 200 miles. Figure 13 presents the results of a 200-mile scenario. The goal of this scenario was to reduce the number of miles that the paper had to travel in order to arrive to OU. Based in the obtained results, it can be observed that between the uses of a paper handout (orange) versus an online handout (blue), a paper handout is still the one that has more negative impacts in the environment. This finding suggests that transportation does not play a major role in this LCIA.

Figure 13. *200 miles Scenario*



Laptop Life Span

As stated in assumption 8, a 3-year laptop life span was selected in order to complete the project. However, one has to be aware that we live in a society that is constantly consuming goods [25]. So, in order to address that consumption state, the laptop life span was analyzed under two scenarios. 1-year life span (minimal use) and 5-year life span (maximum use).

Figure 14 and Figure 15 present the results obtained by those two scenarios. Interestingly enough, the trend between the paper handout versus the online handout is the same (paper handout is still the one that has more negative impacts in the environment). However, it is important to note that by decreasing the life span to 1 year, a drastic increase of the environmental impacts can be observed. This means that most of the impact categories of the online handout double (or more) their size, up to the point that in some impact categories the results were almost the same.

This finding suggests that if society starts to consume more and more electronics (especially laptops), disregarding their maximum life span, in the long run this practice will become environmentally unsustainable.

Figure 14. *1 Year Life Span*

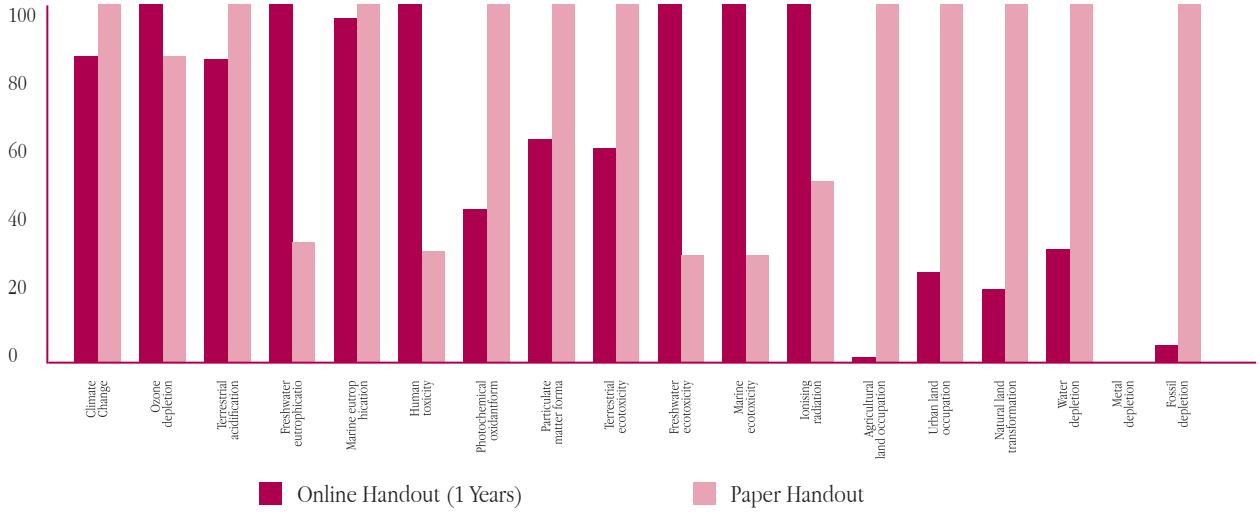
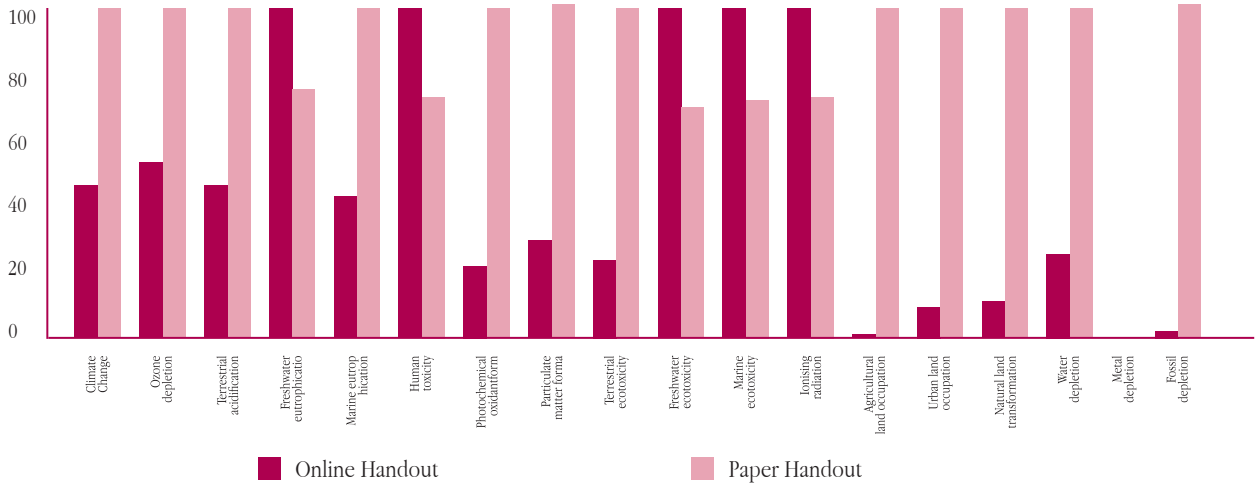


Figure 14. *5 Year Life Span*



Conclusions

After completing this study, it can be concluded that:

- Under the made assumptions, the use of a paper handout has more environmental impacts, than the use of an online handout.
- Among the evaluated processes in the paper handout, paper production has higher environmental impacts.
- Among the evaluated processes in the online handout, laptop use has higher environmental impacts.
- In both of the evaluated assemblies, transportation did not play a huge role in terms of environmental impact.
- Paper companies should implement a recycling stage in their production, capable of recycling 25–50 % waste paper.
- The use of different LCIA methods does not change the results of a study.
- Laptop users should use their devices up to its maximum life span. Otherwise, the use of this instrument will become an unsustainable practice.
- The time of use of the laptop a computer plays a vital role in the results of these type of studies.
- LCA is a great and advanced methodology, in order to compare different products in terms of their contribution to environmental impacts.

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