Life Cycle Assessment of Ordering Amazon Packages in Bulk to the Harvey Mudd College Mailroom

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1. Introduction

A Life Cycle Assessment (LCA) quantifies resource use and environmental and health impacts associated with the various life cycle stages of a particular process or product. In this study, we aim to evaluate the resource use, solid waste, and greenhouse gas emissions that result from ordering from Amazon.com. All references to Amazon packages refer to those dispatched by the wholesale distributor Amazon.com through Amazon's fulfillment centers.

2. Goals

The principal goal of this LCA study is to assess the environmental footprint of the average number of Amazon packages delivered every week to Harvey Mudd College, a small liberal arts college of science, engineering, and mathematics in Claremont, California. The intended audience for this study consists of students currently attending Harvey Mudd College, as well as faculty, staff, administrators, and any other party whose mail is facilitated through the College's mailroom and who might be ordering products from Amazon.com. These results will inform a broader understanding of the environmental impacts of purchasing textbooks to be delivered to the College, and motivate students to think more carefully about what items they order and to organize bulk ordering, when possible. Along those lines, the study aims to compare the

environmental impacts of bulk packaging, and to analyze whether or not it is beneficial to ship multiple textbooks in one box. The results of this study will be released to the public, and further used to optimize efficiency and limit the environmental impacts of ordering packages from Amazon.

3. Scope

3.1 System Studied

Amazon packaging is comprised of various sized cardboard boxes, along with packaging tape, printed shipping labels, and four accepted forms of dunnage: foam, air pillows, full sheets of paper, or bubble wrap[1]. The company dispatches four types of boxes, but for the purpose of this study, these will be regarded as a standard 200 lb./sq. inch burst strength cardboard box.

According to Amazon.com's Customer Service website, their packaging is "frustration-free," meaning that all boxes and fillers that the customer receives are "recyclable and come without excess packaging materials."[2] The company guarantees that all packages also come with the packaging that the original manufacturer included in their manufacturing process, which may be excessive depending on the manufacturer.

3.2 System Boundary

The LCA's system boundary will assess the environmental impacts of Amazon packages coming from Amazon's warehouse and distributor local to Claremont, California. The two fulfillment centers nearest to Claremont are located in San Bernardino, California, and Phoenix, Arizona. In this study, no outside manufacturers were considered; that is, if a package came from a manufacturer located in the United Kingdom, China, India, or any other location, the study disregarded the impacts of production and transportation to the fulfillment center. The study, therefore, uses the fulfillment center gate-to-grave model rather than cradle-to-grave, but cradle-to-grave on the box and dunnage materials.

[1] Amazon. (2015). Quick Reference Guide: Packaging and Shipping Inventory to Amazon. Retrieved November 19, 2015.

[2] Amazon. (n.d.). About Amazon Certified Frustration-Free Packaging. Retrieved November 17, 2015.

3.3 Assumptions

The study makes the following assumptions regarding packaging and transportation of Amazon purchases sent to students at Harvey Mudd College:

a. The study observes only *boxes* sent from Amazon.com, and not padded envelopes sent from Amazon.com.
b. All Amazon boxes are made of the same cardboard box material: standard 200 lb./sq. inch burst strength cardboard.
c. The selected small standard size Amazon box is of dimensions 12” x 9” x 4” or 432 cubic inches (BM5), while the large standard size Amazon box is of dimension 19.25” x 14” x 3.25” or 875 cubic inches (1BF).[3]
d. Although the reference flows (see section 3.4) are not exactly the size of the desired product(s), Amazon sends packages in boxes that are much larger than the shipped product, so these box sizes are realistic.
e. Smaller or larger sized Amazon boxes are scaled in weight and size to approximately equal the standard sized box.
f. All packaging material (dunnage) used to fill the extra space in the box is assumed to be air pillows. Although Amazon does use other packing materials such as whole sheets of paper, foam, and bubble wrap, the majority of boxes delivered to the College’s mailroom use air pillows to cushion the product. The air pillows are manufactured by Storopack, and made of low-density polyethylene plastic (see section 4.2) that can be curbside recycled or composted.[4]
g. All Amazon boxes are made from corrugated fiberboard (see section 4.1), manufactured by the Packaging Corporation of America (PCA). Although Amazon does utilize boxes from other manufacturers, namely Rock-Tenn, Sonoco Products, and International Paper, the majority of their boxes come from PCA.[5]

3.4 Function, Functional Unit, and Reference Flow

The function of the package box under study is to safely and securely hold products during transportation to the desired destination. The functional unit is a box that holds, secures, and protects three one-pound books (dimensions of a standard hardcover book are 6” x 9” x 2”, or 108 cubic inches) that do not fill the entirety of the box, and therefore need air pillows to cushion the product(s). The reference flows for the two box sizes examined in this study, therefore, are one large box with twelve air pillows and three small boxes with six air pillows in each, respectively. The following table categorizes and states the function and reference flows of each of the boxes:

[3] MacLeod, K. (2015, July 17). Amazon Boxes. Retrieved November 19, 2015.
[4] STOROpack. (n.d.). AIRplus Inflatable Packaging Systems and Air Cushion Packaging. Retrieved November 19, 2015.
[5] "Locations." PCA Locations. Packaging Corporation of America (PCA). Retrieved December 1, 2015.

Product	Dimensions of box	Volume (cubic inches)	Function	Reference Flow
1 small box	19.25” x 14” x 3.25”	432	Transport 3 one-pound books of dimensions 6” x 9” x 2”	3 boxes with 6 air pillows each
1 large box	12” x 9” x 4”	875	Transport 3 one-pound books of dimensions 6” x 9” x 2”	1 large box with 12 air pillows

3.5 Data Quality and Completeness

The primary data used in this report, pertaining to the number, types, and dimensions of boxes received by the Harvey Mudd College mailroom was obtained from a mailroom attendant. It was observed on the cardboard box that Amazon’s boxes are manufactured by the Packaging Corporation of America, while the air pillows that are used as dunnage are labelled as manufactured by STOROpack. In addition, information on Amazon packaging recyclability and characteristics were found on the official company website. Although an Amazon representative was contacted with specific questions about the packaging, they did not respond in time for their input to be included in this report. An extension of this investigation might include contacting more Amazon representatives to verify data found online. The data used in the Inventory Analysis section is from SimaPro’s ecoinvent database, and all figures used are no less recent than five years prior to the date of this analysis.

4. Inventory Analysis

Harvey Mudd College's mailroom records show that the college receives an average of 30 Amazon packages every day for students, faculty, and staff. Since the mailroom is open 5 days a week, it can be estimated that the mailroom receives approximately 150 Amazon packages per week.

4.1 Production and transportation of cardboard

This study uses the cardboard boxes manufactured and supplied to Amazon by the Packaging Corporation of America (PCA) from corrugated fiberboard. Amazon purchases PCA's Regular Slotted Container (RSC), which is PCA's most common box type. This assessment uses SimaPro's corrugated cardboard manufacturing process with its included impacts and damages.

The manufactured cardboard boxes are assumed to be shipped in bulk via freight lorry from corporate headquarters in Lake Forest, IL to Amazon's fulfillment center in Phoenix, AZ, a distance of 1,742 miles.

4.2 Production and transportation of air pillows

The air pillows utilized by Amazon packaging are produced by STOROpack Packaging Systems [6], based in Cincinnati, OH, and made of polyethylene film. The LCA uses SimaPro's manufacturing process for low density polyethylene packaging film, filled with compressed air of 7 bar pressure, under the SimaPro process of high efficiency production mix, at low power consumption.

The shipment of air pillows in bulk is assumed via freight lorry, from Cincinnati to Phoenix, a distance of 1,815 miles.

4.3 Production and transportation of labeling and sealing material

Standard Amazon packages contain a paper receipt summarizing the purchase, specialty tape that seals the boxes, and labels that address and identify each package. As per LCA convention, since the receipt, tape, and labels comprise less than 5% of the total mass and are assumed to not contribute substantially to the end of life environmental burden of the package, this analysis excludes these items.

[6] "Air Bag Packaging." STOROpack Perfect Protective Packaging: Air Bag Packaging. STOROpack, Retrieved December 01, 2015.

4.4 Reuse, recycling, and end of life

Amazon's "frustration-free" packaging states that all boxes and dunnage materials are completely recyclable. Indeed, the corrugated cardboard boxes from PCA are recyclable, as are the air pillows from STOROpack. The tape and labels are made from recycled-content paper, and are therefore recyclable as well.

The recyclability of these components has two implications: first, the probability of *recycling* is slightly higher for consumers because they are not required to separate and sort the discrete parts of the package; second, consumers are less likely to *compost* the cardboard because they can simply recycle the entire box they receive.

In accordance with this, the recycling rate of the cardboard boxes was assumed to be about 70 percent, slightly higher than the U.S. average recycling rate for paper and paperboard recycling rate of 62 percent. Although the U.S. average recycling rate for plastics is about 8 percent, the recycling rate of the air pillows used in Amazon packaging was assumed to be 70 percent also. It is assumed that, because of Amazon's entirely recyclable packaging strategy, most consumers will recycle the entirety of their box and *not* separate the materials. Logically, therefore, the recycling rate for these plastic air pillows would be much higher than the typical recycling rate for plastics in the United States.[7]

5. Impact Assessment

Three scenarios were observed in the impact assessment phase.

- Scenario #1: all 150 boxes received by the mailroom were large boxes.
- Scenario #2: all 150 boxes received were small boxes.
- Scenario #3: 75 boxes received by the mailroom were large; 75 boxes were small.

[7] Data for the average U.S. municipal solid waste recycling rates were obtained from a 2010 EPA factsheet: http://www3.epa.gov/epawaste/nonhaz/municipal/pubs/msw_2010_rev_factsheet.pdf

5.1 Network Diagrams

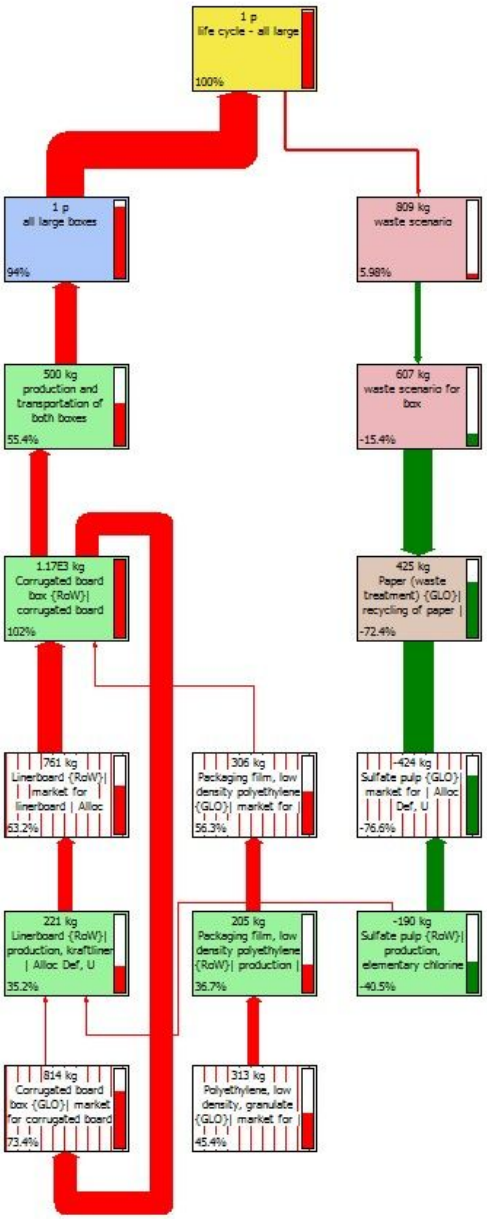

Fig. 1: Network diagram for scenario #1, in which all 150 boxes that the mailroom receives are “large” boxes.

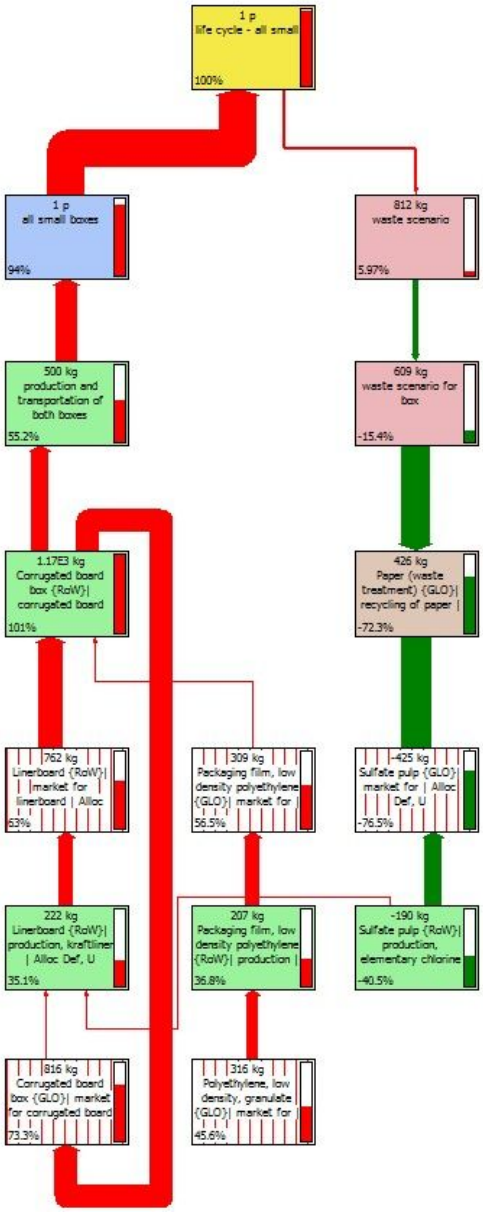

Fig. 2: Network diagram for scenario #2, in which all 150 boxes that the mailroom receives are “small” boxes.

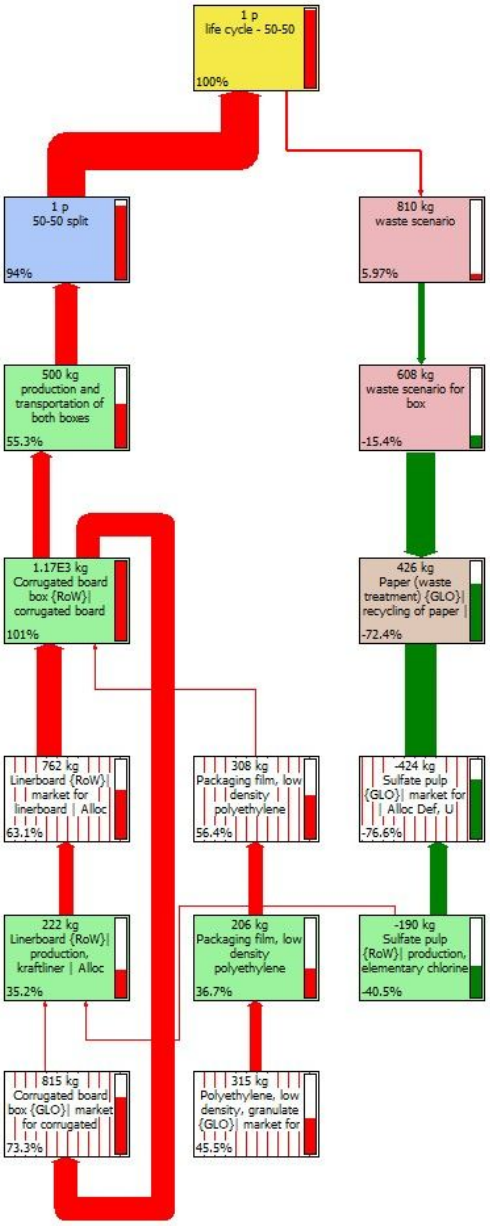

Fig. 3: Network diagram for scenario #3, in which 75 boxes that the mailroom receives are “large” boxes, and the remaining 75 boxes are “small” boxes.

5.2 Characterization Diagrams

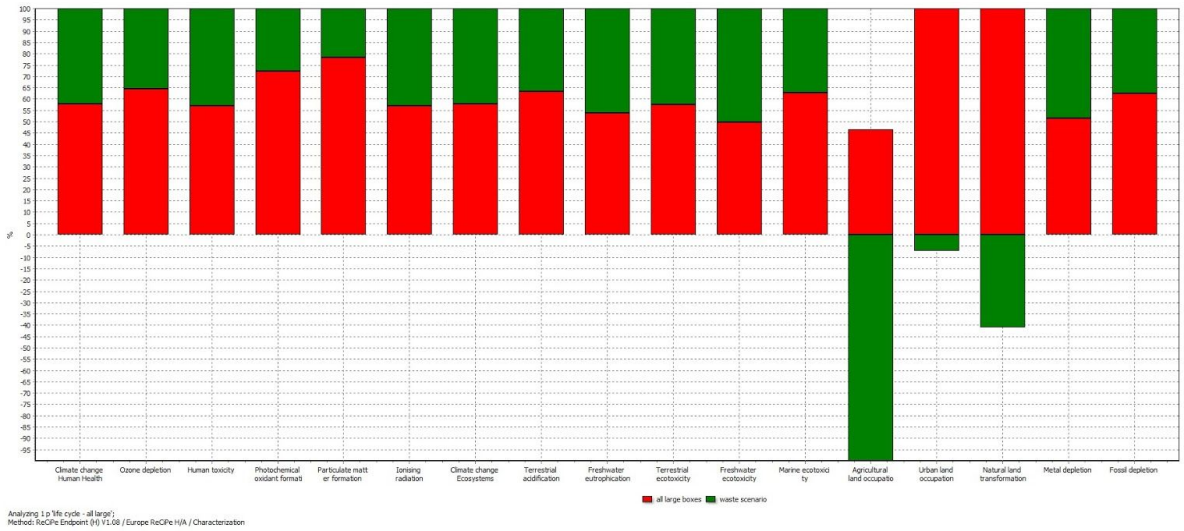

Fig. 4: Characterization chart for Scenario #1 on all midpoint categories.

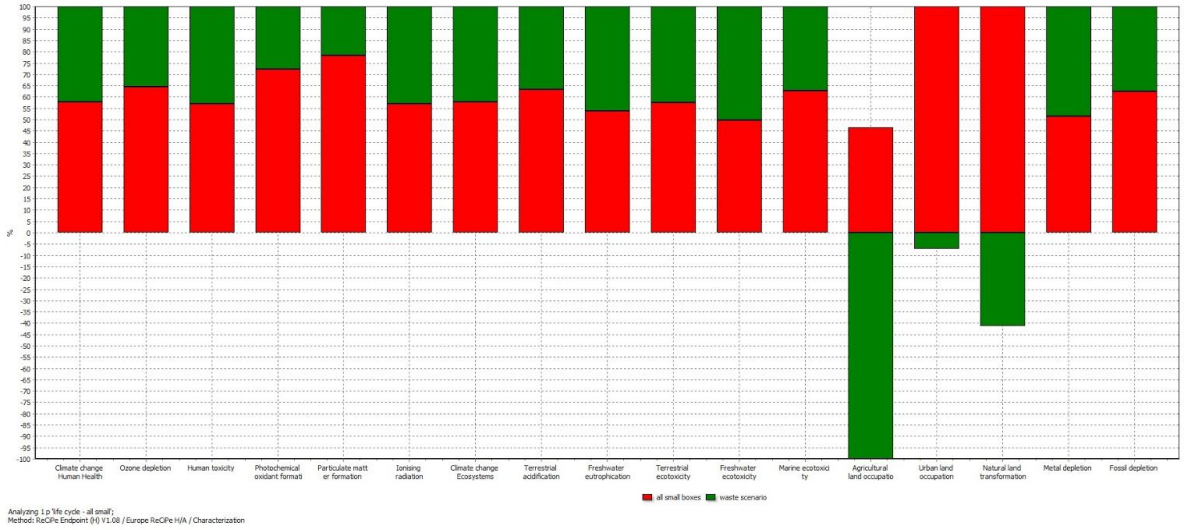

Fig. 5: Characterization chart for Scenario #2 on all midpoint categories.

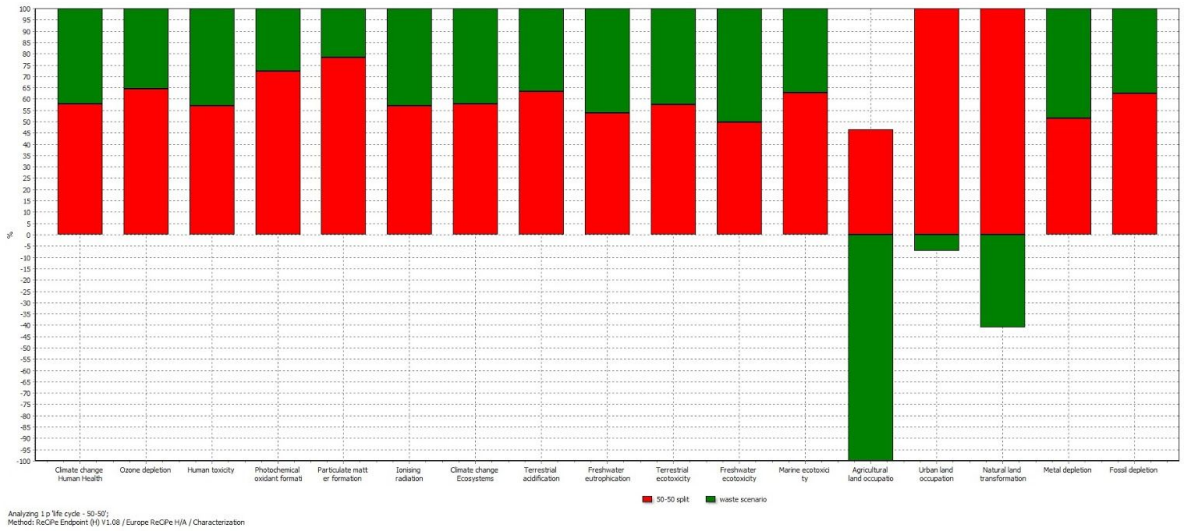

Fig. 6: Characterization chart for Scenario #3 on all midpoint categories.

5.3 Normalization Diagrams

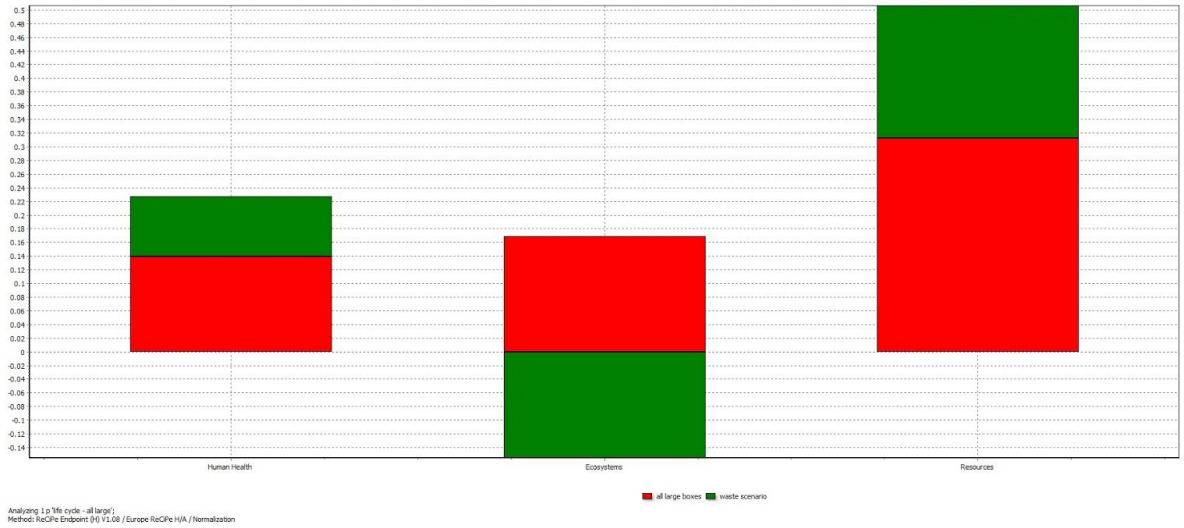

Fig. 7: Normalization chart for Scenario #1 on all endpoint categories.

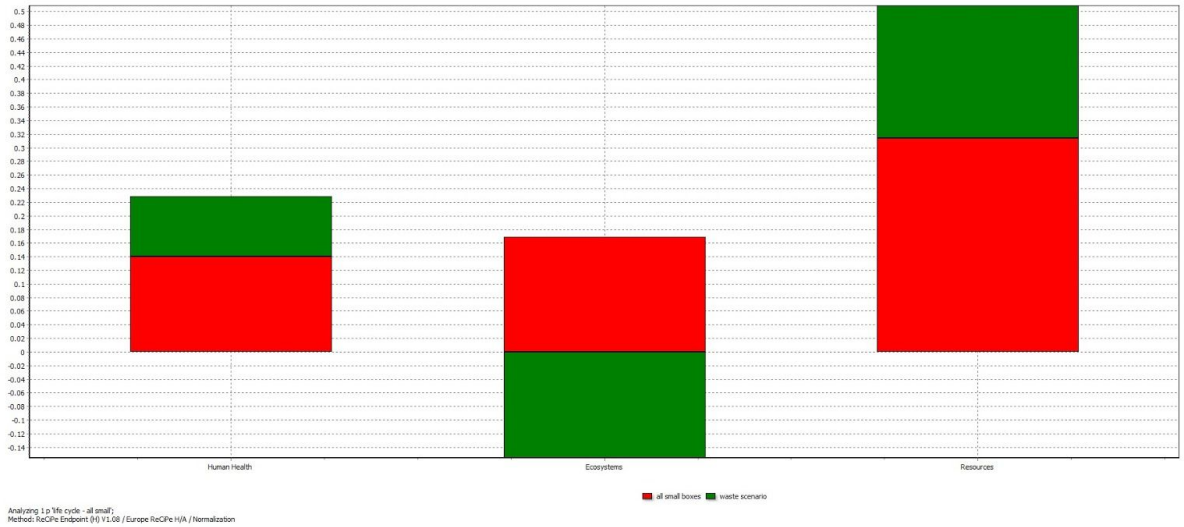

Fig. 8: Normalization chart for Scenario #2 on all endpoint categories.

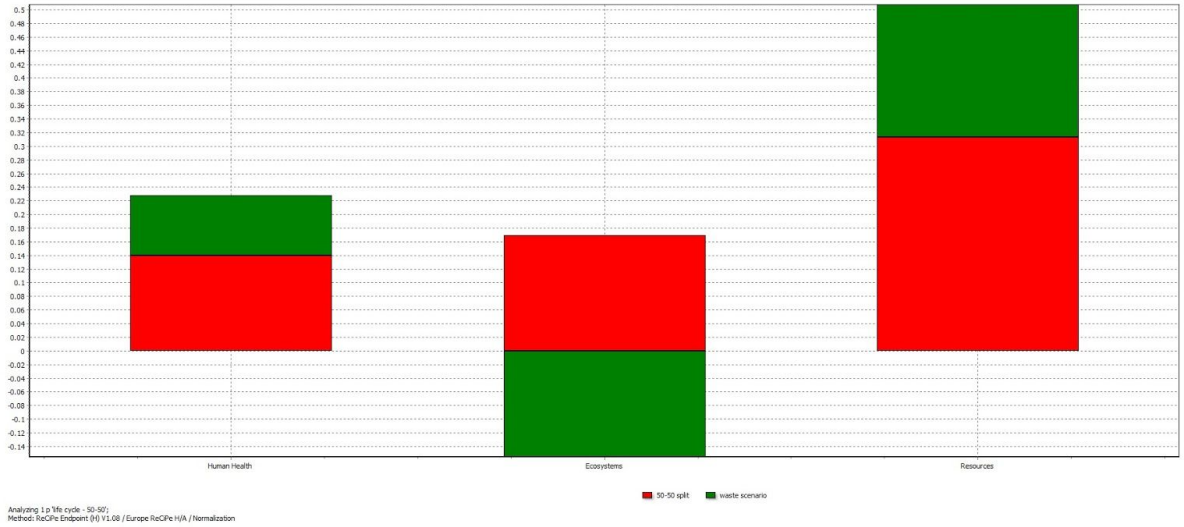

Fig. 9: Normalization chart for Scenario #3 on all endpoint categories.

5.4 Comparison

Fig. 10: Single score comparison chart of Scenarios 1-3.

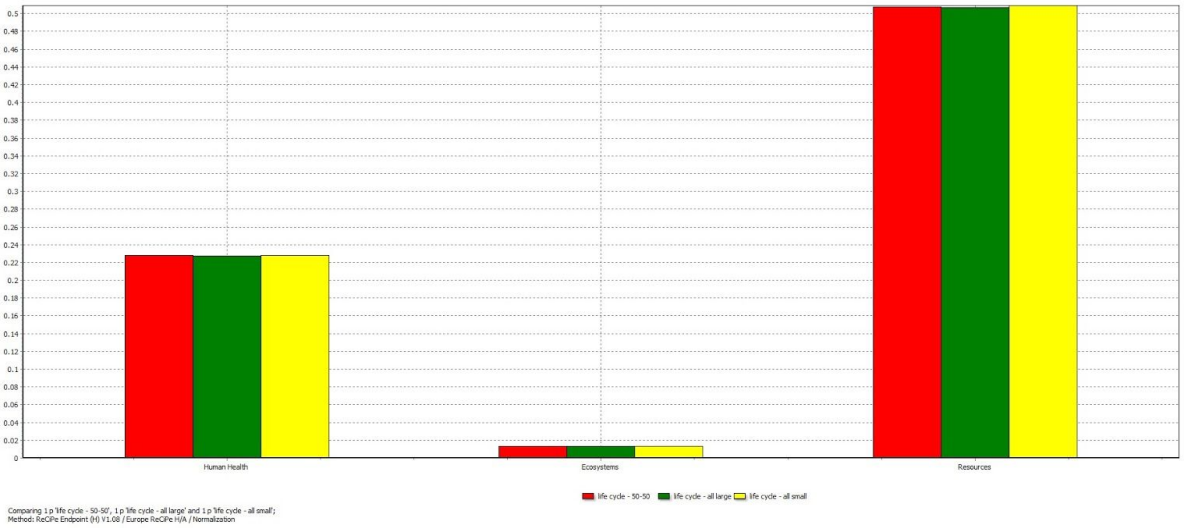

Fig. 11: Normalization comparison chart of Scenarios 1-3.

6. Interpretation

A life cycle assessment on SimaPro was conducted, comparing the environmental impacts of each of the different scenarios: 1) all 150 boxes received in a one week period were large; 2) all 150 boxes received in a one week period were small; or 3) a 50-50 split between large and small boxes per week, resulting in 75 of each.

When comparing against the impacts that the Amazon packages had on human health, resource consumption, and ecosystems, it is apparent that there is very little difference between each of the three scenarios described above. Each of the impacts, for each category, are comparable possibly because the more small boxes that are packaged, the fewer large boxes necessary to match the environmental impacts. This suggests that when ordering Amazon packages to a college campus, it makes little difference whether products are ordered in bulk, resulting in the mail room receiving a large package, or ordered individually, where the mail room would receive a small package. All the packages were recorded as shipped from Amazon's fulfilment center in Phoenix, AZ to their center in San Bernardino, CA, to Claremont, CA, and the values entered into SimaPro were calculated (see Appendix) to ensure that the weight, specifications of the products, and the reference flows were all standardized for each of the different sized packages. It is useful to note that even though the products make up the most of the weight of each package and therefore the weight of the cardboard and air pillows is negligible in comparison, it is the transportation in bulk of each of the boxes from their manufacturing plant to the fulfillment center that contributes the most to their environmental impacts.

The characterization and normalization charts (Figs. 4-9) show an environmental credit in three midpoint categories: agricultural land occupation, urban land occupation, and natural land transformation. This is likely due to the high assumed recycling rate for the cardboard and plastics shipped en masse to Phoenix from Ohio and Illinois. Similarly, much of the environmental impact of the transportation and cardboard production is transferred back down to an environmental credit to due the 70 percent recycling rate, as observable in the network diagrams of each scenario (Figs. 1-3).

7. Conclusions

Revisiting the goal and scope, the analysis fulfills the function of assessing the impacts of solely the box and air pillows used in Amazon packaging, with many other variables standardized. Based on these findings and an investigation of three bulk and individual shipping scenarios using two standard box sizes, there is no substantial difference in environmental impact if three textbooks are delivered in three separate boxes or all packaged in one box.

However, there is limited applicability of this analysis to the scope of general bulk packaging versus individual packaging. This analysis must be limited to book ordering at Harvey Mudd College (HMC) for several reasons. First, the HMC mailroom receives many hundreds of packages per week from sources other than Amazon, and shipping companies deliver to HMC in bulk already. If comparing bulk versus individual packaging delivered to a house or apartment that does *not* receive packages in bulk, the impacts of transportation would likely be much higher.

Second, the weight and product in each box was standardized to be three one-pound textbooks of the same dimensions. In reality, students, faculty, and staff order all different sorts of products of larger or smaller size, weight, and shape, that will come in a huge variety of box sizes, not just the two sizes selected for this analysis. Aggregating a very heavy product with a very light product versus shipping those two products separately would likely have different environmental impacts; these discrepancies in the reality of products ordered in reality were not covered by this analysis. In addition, textbooks need no additional packaging or cushioning. Often, products ordered may be fragile and need other forms of dunnage to safeguard the item, thus making bulk packaging implausible or adding more of an environmental burden due to the excess material in the box.

Third, this analysis assumed that all packages were transported through Phoenix and San Bernardino. Although this assumption was founded in reality—many packages received by the HMC mailroom follow this same route, since the aforementioned fulfillment centers are two of Amazon's largest in the country—packages may come from all over the United States and disproportionately affect transportation impacts. Further, the analysis disregarded the original location of the product. There is a high probability that many products ordered originate in China, India, or elsewhere in the world, and the transportation burden would no doubt be much higher if those factors were taken into consideration.

Given these limitations, the analysis is still useful for the purposes stated in the goal definition. Most students at Harvey Mudd College order textbooks of a similar size to the chosen dimensions, and students often order multiple books at the same time (that is, at the start of a given semester). This assessment informs the decision to order or not order books to be delivered in one shipment or multiple—there is no substantial difference between the two options in this case. Students should, however, be wary of their orders on a general basis, and

strive for bulk packaging if they are ordering different sized products, fragile products, or products of which they know originate further than Phoenix or San Bernardino.

8. Appendix

8.1 Calculations

The following calculations were made while performing the life cycle assessment of the Amazon packages in SimaPro.

Mass of one air pillow:

Estimating the volume of one air pillow to be 0.000042 m^3, and taking the density of air to be 1.225 $\frac{kg}{m^3}$:

$M_{\text{air in air pillow}}$ = (volume$_{\text{air pillow}}$)(density$_{\text{air}}$)

$= (0.000042\ m^3)(1.225\ \frac{kg}{m^3}) = 5.145 * 10^{-5} kg = 0.05145\ g$

Then, taking the plastic encasing the air in the air pillow to be 2 g,

$M_{\text{1 air pillow}}$= $M_{\text{air in air pillow}}$+$M_{\text{plastic encasing air}}$ = 2.0514 g

Thus, one air pillow weighs **2.05145 g**.

Mass of one empty, small cardboard box:

Since the density of standard cardboard is 0.7 $\frac{kg}{m^3}$, and taking the dimensions of a single, small cardboard box to be 0.007 m^3:

$M_{\text{1 cardboard box}}$= (volume$_{\text{cardboard box}}$)(density$_{\text{cardboard}}$)

$= (0.007\ m^3)(0.7\frac{kg}{m^3}) = 0.0049\ kg = 4.9\ g$

Thus, the mass of one empty, small cardboard box is **4.9 g**.

Mass of one empty, large cardboard box:

Since the density of standard cardboard is 0.7 $\frac{kg}{m^3}$, and taking the dimensions of a single, large cardboard box to be 0.014 m^3:

$M_{\text{1 cardboard box}}$= (volume$_{\text{cardboard box}}$)(density$_{\text{cardboard}}$)

$= (0.014\ m^3)(0.7\frac{kg}{m^3}) = 0.0098\ kg = 9.8\ g$

Thus, the mass of one empty, large cardboard box is **9.8 g**.

Mass of complete small package:

The small sized Amazon package consists of one small cardboard box, a one pound book, and six air pillows.

From the calculations above, it is known that six air pillows weigh 12.3087 g in total, and that the one pound book weighs 0.453592 kg = 453.6 g. In total, the small package weighs 470.8087 g.

Thus, the mass of one complete small package is **0.4708087 kg.**

Mass of complete large package:
The large sized Amazon package consists of one large cardboard box, three one pound books, and twelve air pillows.

From the calculations above, it is known that twelve air pillows weigh 12.3087 g in total, and that the twelve air pillows weigh 24.6168 g in total, and three pound books weigh 1360.8 g together.

Thus, the mass of one complete large package is **1.3977255 kg**.