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Spring 6-6-2019

# Human-Centered Data Visualizations and Web Layouts for Life-Cycle Assessment Design Guides

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THAYER SCHOOL OF  
ENGINEERING  
AT DARTMOUTH

**HUMAN-CENTERED DATA VISUALIZATIONS AND WEB LAYOUTS  
FOR LIFE-CYCLE ASSESSMENT DESIGN GUIDES**

by

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Bachelor of Arts Independent Project

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## **Abstract**

### Human-Centered Data Visualizations and Web Layouts for Life-Cycle Assessment Design Guides

Jono Klein  
Professor Jeremy Faludi

*User tests with 30 Dartmouth Engineering and STEM undergraduates were performed to investigate preferences toward a set of data visualizations and web layouts showing life-cycle assessment data and corresponding uncertainty. The data was collected and synthesized from academic papers, corporate manufacturers, and self-generated using the LCA software Sustainable Minds. A variety of visualizations were produced to accurately and aesthetically represent the data graphically, and especially understand how non-technical audiences interact with different displays of uncertainty, which is a key component of data visualization that is lacking from most LCA design guides. Web layouts were produced to present key information about the product and suggest sustainable design strategies in a digestible way end users. Ultimately, these learnings will be applied towards the creation of a free, user-friendly, online guide that provides useful recommendations for designers to reference when considering the assembly of products.*

## **Acknowledgements**

This paper is an apt culmination of my Dartmouth curricular experience, as a blend of topics and skills learned from my double major in Engineering Sciences and Quantitative Social Science. It is also the outcome of significant collaboration with professors and students. First, I would like to acknowledge Professor Jeremy Faludi, who is my independent study advisor, a Sustainable Design guru, and a constant source of direction for the research focus. Next, I would like to acknowledge my peers and their contributions: Emily Martinez, Soon-Young Shimizu, and Lylia Eng. Finally, I would like to thank the many Thayer professors who inspired my commitment to completing the major and shared their own Engineering interests and knowledge through teaching.

## Table of Contents

|  |    |
|--|----|
| 1. Introduction.....                                   | 1  |
| 2. Methods.....  | 2  |
| • <i>LCA Data Collection &amp; Consolidation</i> ..... | 2  |
| • <i>User Interface Prototyping</i> .....              | 4  |
| • <i>User Testing</i> .....                            | 7  |
| 3. Results.....  | 8  |
| • <i>Final Designs</i> .....                           | 9  |
| 4. Conclusions.....                                    | 11 |
| 5. References.....                                     | 13 |

## Introduction

For designers and manufacturers of new products, gaining a clear understanding of product life-cycles is critical for making sustainable design decisions. Environmental impacts occur at all stages of a product's life-cycle. For instance, a refrigerator's major impacts are due to usage, while furniture's major impacts are due to raw materials and manufacturing (Lewis, et al., 2001).

Companies may consider a variety of approaches for greener product design and engineering. Life-cycle assessment (LCA), in particular, is a widely accepted tool (Hackett, 2015; Hoang, et al., 2009; Noon, et al., 2011; Wenzel, et al., 1997; Yu, et al., 2010) as it boasts a rigorous and credible system for measuring environmental impacts. LCA is especially useful for setting design priorities, benchmarking, determining improvement targets and measuring progress. One key problem is that acquiring relevant data is time-consuming. Achieving certifications like ISO 14040 for an LCA report ([iso.org/standard/37456.html](http://iso.org/standard/37456.html)) or ISO 14025 for product eco-labels ([iso.org/standard/38131.html](http://iso.org/standard/38131.html)) requires specific data that is only available at the end of the design process.

Design guides, by contrast, do not need such specific information, and thus offer usable advice for the early-stage design process, when most impacts are determined. Green guides are valued by corporations (Knight and Jenkins, 2009) but their usefulness is limited because they are usually generic rather than targeted to specific products, while businesses want customized advice that relates directly to their needs (Umeda, 2001). Performing detailed rigorous LCA is expensive (Hendrickson, et al., 1997), and results are typically published in proprietary systems for paid subscribers, such as The Sustainability Consortium ([www.sustainabilityconsortium.org](http://www.sustainabilityconsortium.org)) or academic journals, if they are shared outside the company at all.

This paper details an approach that can help bridge the gap between green design guides and LCA. The key question at hand is how to make LCA data accessible to designers and engineers without the time, software, and/or expertise to perform their own analyses, acknowledge and communicate the high degrees of uncertainty resulting from data not specific to their product, and ultimately lead to actionable strategies for early stage design.

First, we collected LCA literature for different product types, and averaged them into generic LCAs of product categories. This loss of specificity created high uncertainties, because products within a category have many differences. Second, we prototyped methods for visualizing LCA data and displaying uncertainty. To note, communicating uncertainty is critical because precision is impossible in early stage design and across entire product categories. Third, we prototyped a layout for an online guide that uses the LCA data to provide design recommendations for designers at zero cost and easy access. Fourth, we conducted 30 user tests with engineers, designers, and STEM-focused students at Dartmouth College; this included two rounds of testing and iterating the data visualization and web layout prototypes. The conclusion of this process is a user-friendly website for designers and engineers to provide LCA-based guidance for sustainable design strategies on a variety of products.

## **Methods**

### *LCA Data Collection & Consolidation*

The first phase of research involved collecting and calculating impact data on a variety of products ranging from electronics to furniture to clothing. For each product category, five or more published LCAs were gathered for analysis. Studies covering multiple environmental impact categories were strongly preferred, but publications of only CO<sub>2</sub>-equivalent emissions

were also accepted. Impacts were divided into the following life-cycle stages: materials and manufacturing, packaging, transportation, usage, and end of life. Products with large material and manufacturing impacts were further subdivided for increased level of detail. Wherever possible, peer-reviewed academic studies were used in order to maximize thoroughness and credibility, but publications from manufacturers were also used. In general, manufacturers have better access to their life-cycle inventory data than academics. Some studies neglected certain life-cycle stages, such as packaging. Additionally, many studies do not subdivide materials and manufacturing stages, which limited the precision of such recommendations.

For the office chair LCA, data from published literature was supplemented with original empirical data to break down the impacts of materials and manufacturing into steel, wood, plastic, fabric, and foam. The data gathering process was modeled on two existing peer-reviewed studies that had conducted LCAs for two variations of an office chair. Specifically, the eco-concept and LCA software Sustainable Minds was a key tool which properly conduct a life-cycle assessment for an office chair.

Next, LCA data from combined academic, manufacturer, and original sources were combined into one set of scores per product category. This step required computing the average percentage of lifetime impact by life-cycle phase, and the standard deviation as a measure of uncertainty. The uncertainty scores often resulted in large error ranges due to a number of reasons, including: missing inventory data (e.g. packaging), differences in time, location, product design variations, usage scenarios, inventory modeling methods, and usual database quality. When combining multiple impact categories, all were given equal weight. For example, if five product studies measured three impact categories each, the final impact score depended on the average and standard deviation of all fifteen data points. This is a limitation of our approach,



because some impact categories will have more emissions than others and some will be more harmful than others. If the existing sources had offered more specific data, a rigorous system of normalization and weighting would have been preferred, such as ReCiPe, CML, or TRACI (Aymard, et al., 2016). To accommodate this methodological weakness, uncertainty values were adjusted by a 10% increase, and no uncertainty value was allowed below 20%, regardless of data agreement.

### *User Interface Prototyping*

After synthesizing data on the environmental impacts for each product, the major next step was to effectively communicate the LCA data to non-experts. This was accomplished by developing a variety of data visualizations to accurately and aesthetically display the data and corresponding uncertainty. The goal was to render visualizations easily understandable and actionable for end users. Therefore, prototypes of different graphs of the same data were tested for three factors: overall user preference, clear display of uncertainty, and acceptable information density.

Initial data visualization prototypes were generated for two standard graph formats (“bar with whiskers” and “dolphin”) and two new graph formats (“slant” and “blur”). The bar graph shows error bars for the standard deviation range; the dolphin graph shows a “dolphin” tail in the uncertainty region, where the inflection point represents the average; the slant graph is similar to the dolphin graph but with a line of constant slope; the blur graph shows uncertainty within a range of increasingly faded color. See Figure 1 below.

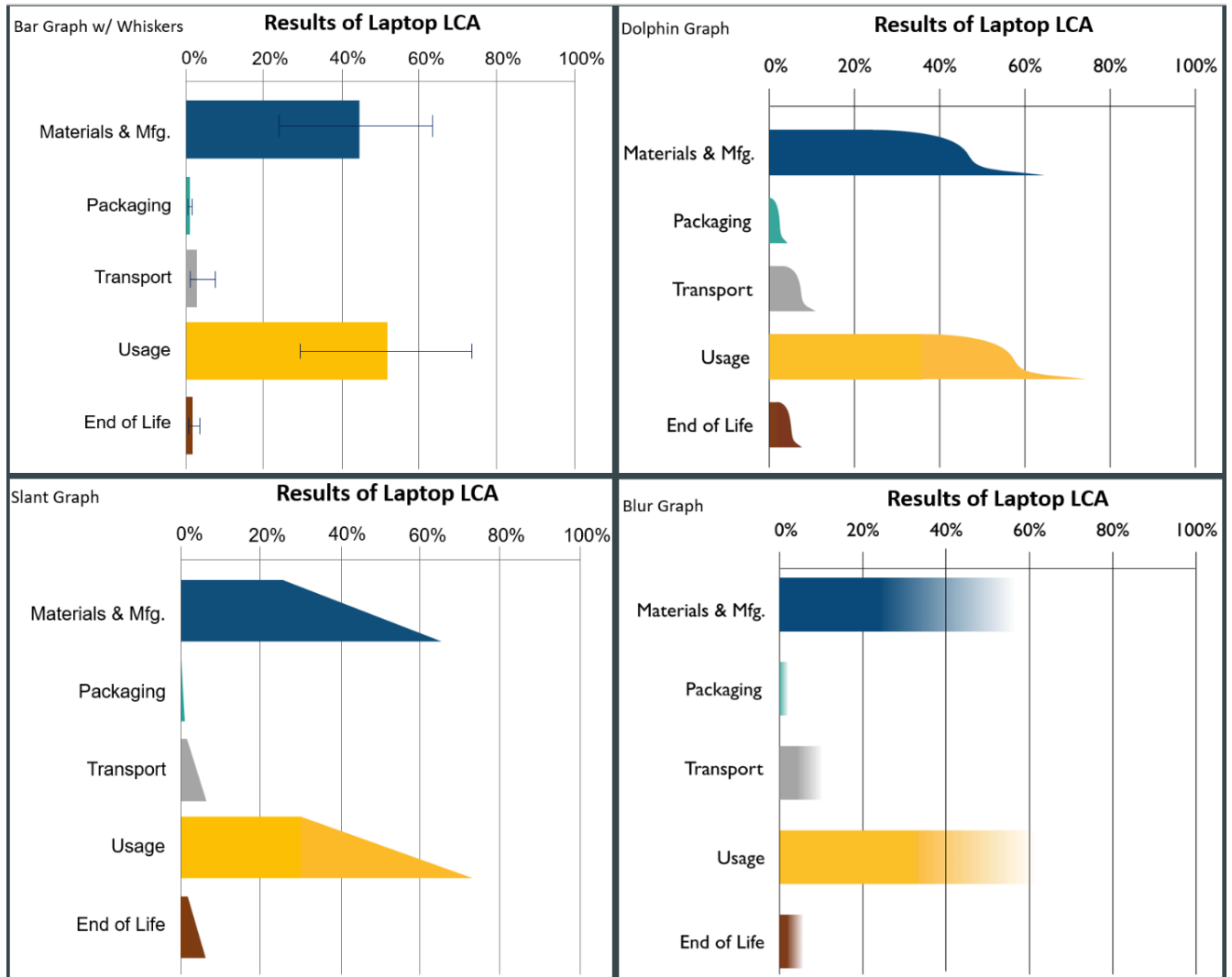


Figure 1: Initial Data Visualization Prototypes for Uncertainty of Laptop LCA

In addition, prototypes were developed to display the subdivided material and manufacturing impacts, and then tested for information density. These included three variations: “non-embedded”, “embedded waterfall”, and “embedded on axis”. In this first iteration, the blur and slant graphs were used. See Figure 2 below.

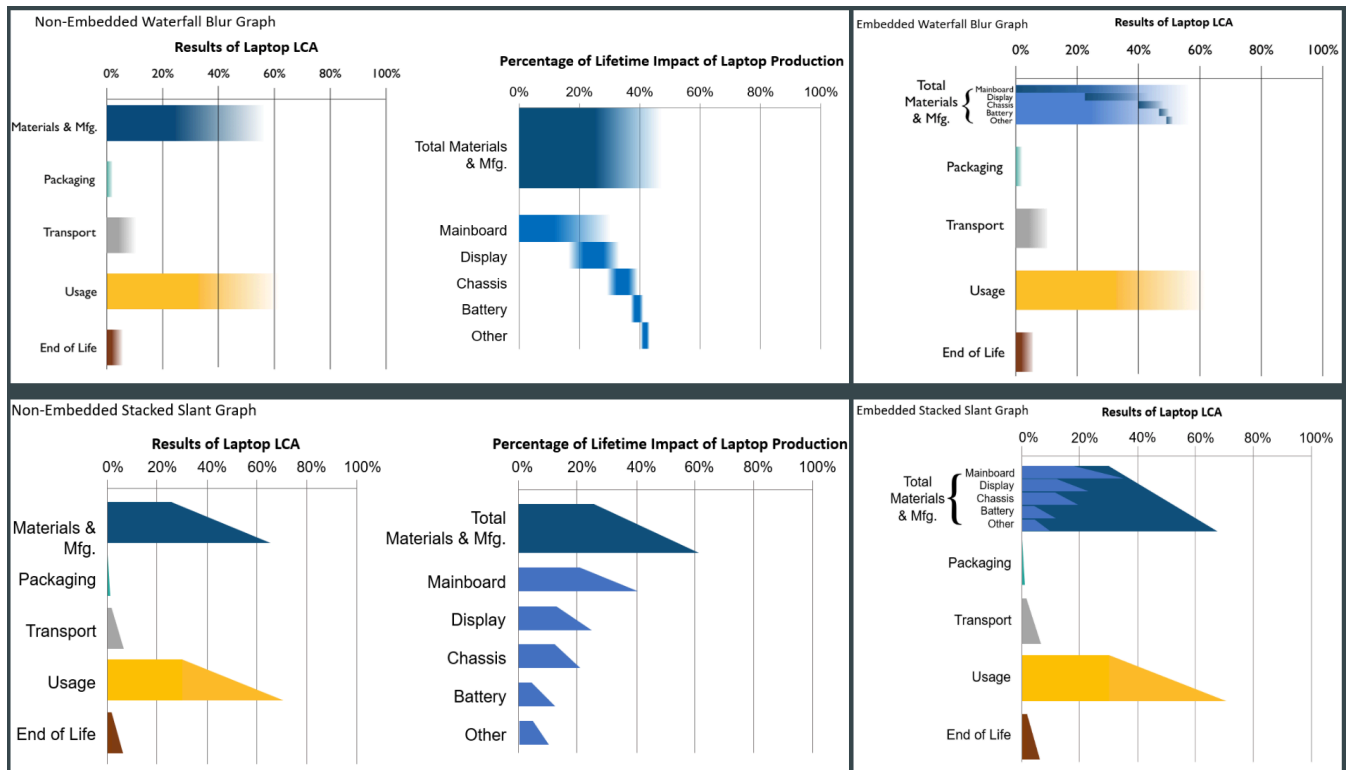


Figure 2: Initial Data Visualization Prototypes for Materials & Mfg. Components of Laptop LCA

Next, page layouts were designed to present product overviews, show the data visualizations, and suggest strategies for minimizing environmental impact when designing, building and using each product. The end goal was to build an easily navigable website or booklet that presents relevant information in a digestible way for end users. Layout prototypes included several variants, with different orientations (horizontal / vertical information flow), different locations of header and product specifications, and different displays of sustainable design strategies -- either directly linked to graph data or color-coded to match life-cycle stages. See Figure 3 below.

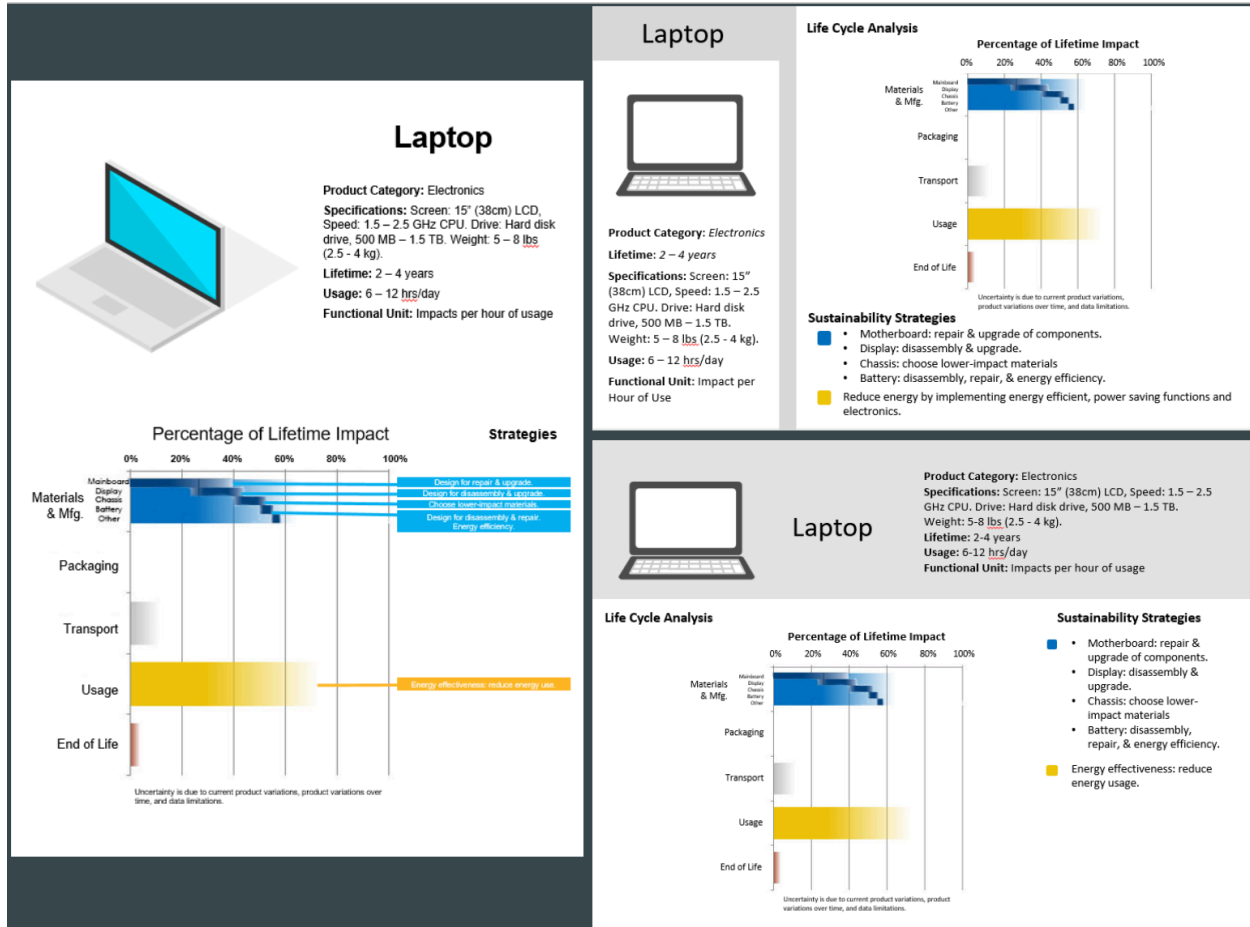


Figure 3: Initial Web Layout Prototypes for Laptop LCA

### User Testing

Initial data visualizations and web layouts were tested with Engineering and STEM undergraduate students at Dartmouth College, who were assumed to be representative of the target audience: educated and numerate, but not necessarily familiar with LCA and eco-design.

Table #1: User Test Profile Breakdown by Major

| User's Major         | Total Number of Users |
|----------------------|-----------------------|
| Engineering Sciences | 21                    |
| Other STEM           | 4                     |
| Non-STEM             | 5                     |

Across two rounds of testing, a total of 30 user tests were conducted, with 12 tests in the first round of prototypes, 18 tests in the second round (after iterating prototypes). Each user test was structured as a one-on-one interview that took 20 minutes to complete on average. The data

visualizations and layouts were shown one at a time on a computer screen, while the interviewer took down notes on the subject's responses to a standard set of questions. Up front, interviewers acquired IRB and CITI certification and used a standardized script to contextualize the product information so that users were better informed about the data provided. During user testing, the questions about data visualization prototypes included the following: *Which do you like best? Which life cycle stage has the biggest environmental impact? How sure of your response are you (please quantify a percentage of certainty). What is the best level of detail?* Questions about layout prototypes included: *Which layout do you like best? Which do you find it easiest to make a design decision based on? Which is most clearly organized? What is the best level of detail?*

## **Results**

Results of user testing were compiled, synthesized, and implemented into a second phase of prototypes which incorporated user sentiments and preferences. Based on specific user feedback, key updates to data visualization included adding a legend with text explaining uncertainty, descriptive plot titles, eliminating the slant and dolphin graphs, and providing more options with the bar graph with whiskers and blur graph. Key updates to the layout included orienting all prototypes horizontally, and exploring different formats for product specification placement and sustainability strategies linked to data.

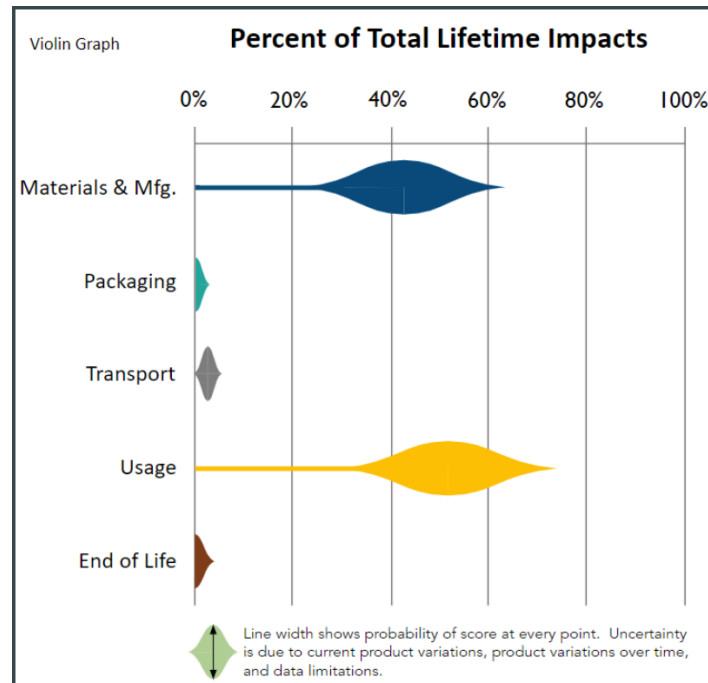


Figure 4: Violin Graph Added to Second Round of Data Visualization Prototypes

### Final Designs

Collectively, users expressed preference for the simplest, clearest examples of data visualizations and layout. After two rounds of user testing, a final iteration of prototype design was performed and the results are as follows.

Across all user tests, when users were asked to quantify their level of certainty that a laptop's "Usage" had larger environmental impact than "Materials & Manufacturing", the average response was 66.23%, compared to a correct baseline of about 20-25%. While this indicates that users are less uncertain than they should be about the data, quantifications for the blur graph were significantly lower on average, at 46%. Generally speaking, uncertainty across all life-cycle stages for all products studies was high. Most product LCAs showed clear priorities for which stage caused the greatest environmental impact, but when uncertainties overlap, users should be aware that both impacts should be addressed. Thus, even highly imperfect data can still be useful data.

The final design for data visualization was based on the total number of users in favor of a certain prototype combined with the most accurate estimation of uncertainty. The winning design was the blur graph with embedded materials and manufacturing components stacked on the axis. See Figure 5 below.

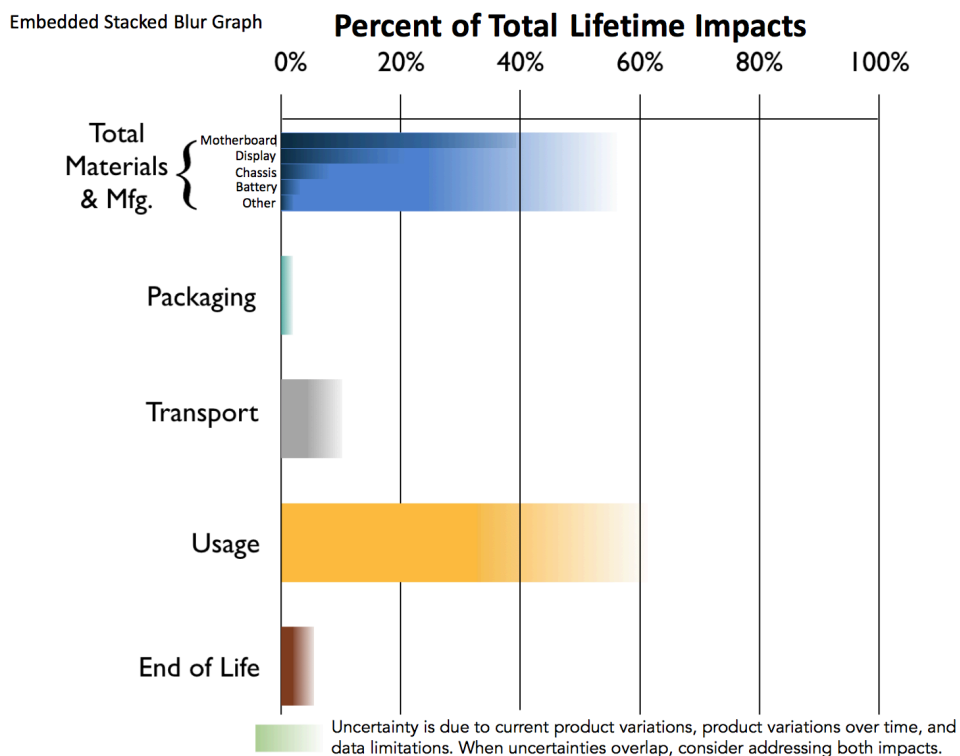


Figure 5: Winning Design for Data Visualization Prototypes

The final design for web page layout was based on total number of users in favor of a certain prototype combined with final recommendations from users. The winning design was the layout with the product specifications at the top of the page, with sustainability strategies linked directly to the visualization, and an embedded graph version. See Figure 6 below (note, when the web site goes live, the winning data visualization will replace the existing graph used on the layout).

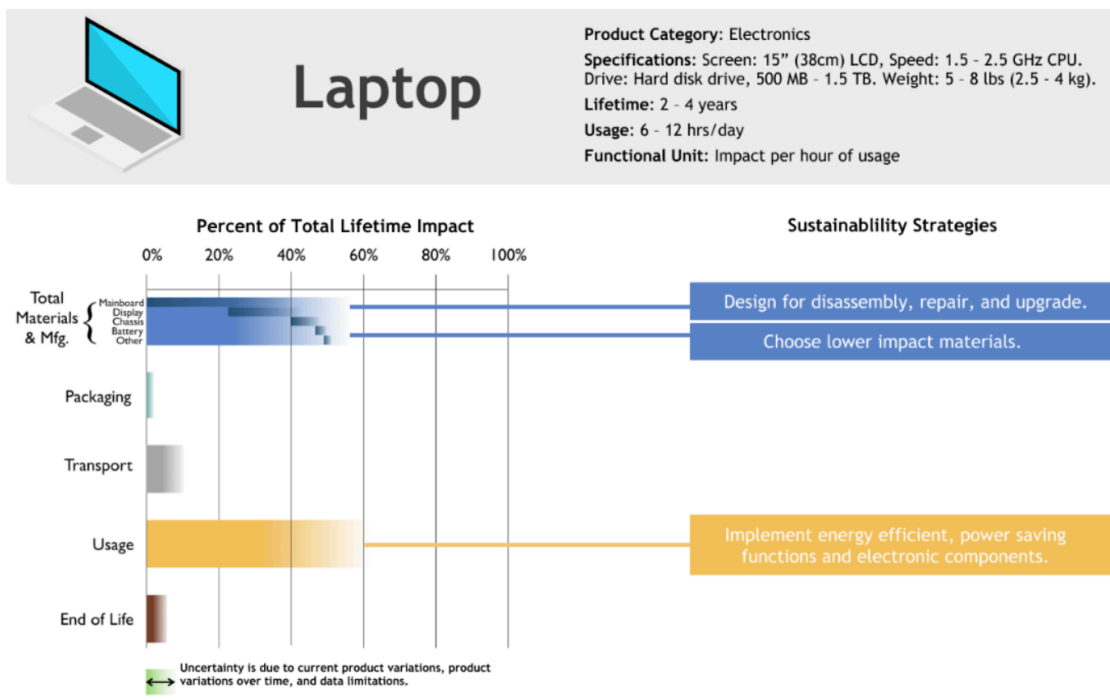


Figure 6: Winning Design for Web Layout Prototypes

## Conclusion

To briefly summarize this research paper, the key question at hand was how to bridge the gap between green design challenges and existing LCA guides. The goal was to make complex technical information easily digestible and accessible for green designers, and ultimately lead to actionable strategies for early-stage sustainable design. The end solution is an online guide for designers to use when assembling new products.

The method included gathering and analyzing LCA data for a set of product categories, prototyping data visualizations with different ways to display uncertainty, prototyping graphic layouts of visualizations and design recommendations, user testing the prototypes with STEM students and iterating the designs.

The user tests brought out important insights related to people's intuitive understanding of data, uncertainty and how these are visualized. While there was no single preference across all



users, in general it can be stated that users prefer simplicity and clarity over aesthetics. Aesthetic benefit is an additive feature if the graphs are easy to understand. This wedding of psychological factors determined that the blur graph was a winning visualization, and will be implemented directly onto the web layout for all product categories.

As research progresses in the field of LCA and quantifying environmental impacts of different products, it remains critical to target the personas -- designers, manufacturers, teachers, researchers -- who can improve the current process of product design and ultimately aim to reduce environmental harm.

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