GUIDANCE DOCUMENT

Understanding Effective Ways to Visualize Life Cycle Assessment Results

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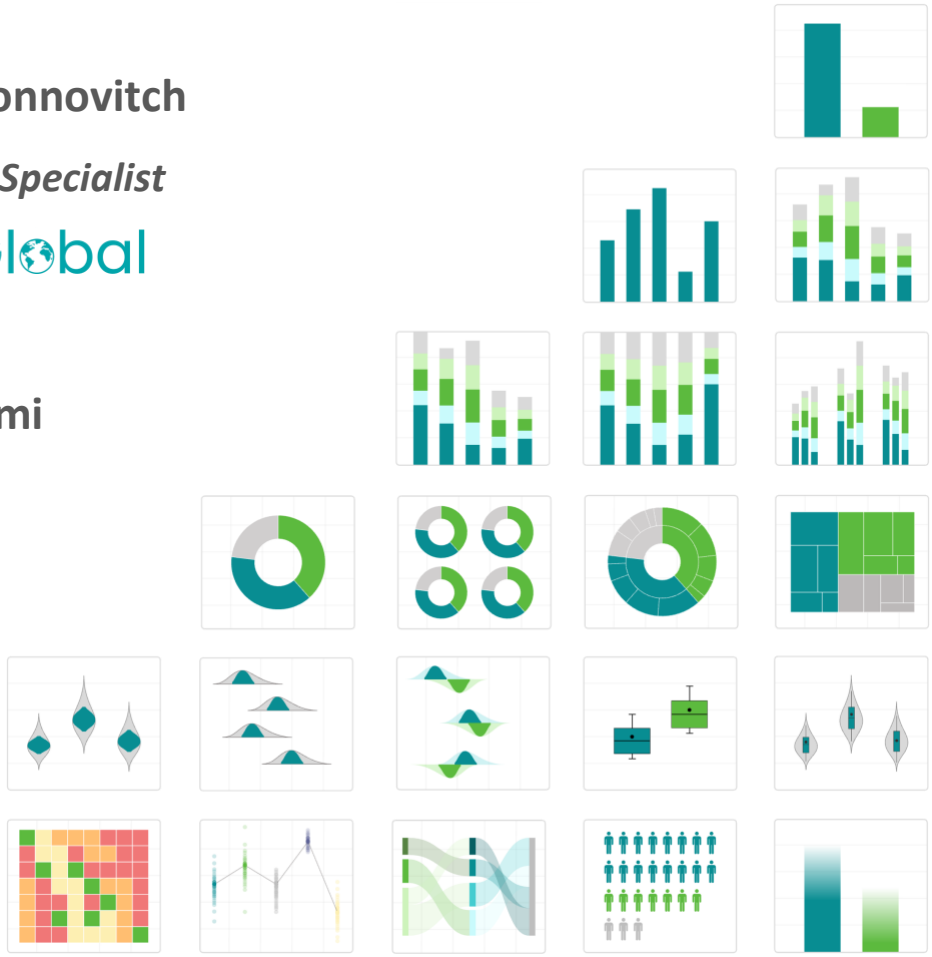
KEYLOGIC



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Meet Tess and Gianni!

Hi! I'm Tess! I am the Data Visualization Specialist at EarthShift Global.

I apply a combination of scientific knowledge and experience in art, design, and teaching to the development of data visualizations that uncover insights and convey essential findings to broad audiences.

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I have a background in Environmental Engineering and experience in Life Cycle Assessment (LCA) research and methodology. My graduate work was focused on understanding how to improve the visualization of LCA results depending on the specific scenario one is involved in. I currently work at KeyLogic, a System One Company, as a subcontractor for the National Energy and Technology Laboratory (NETL), where I work on developing various unit processes, and LCA models with a focus in the energy and carbon capture and utilization and storage fields.

Introduction

Visuals are essential to effectively communicating and understanding all types of information, but particularly important in fields where data is vast, complex, and numerical. In life cycle assessment, where data is not only complex but also uncertain, the use of data visualizations are imperative in determining whether people comprehend the information. Given that life cycle assessments and subsequent findings are intertwined with environmental and societal change, it becomes even more critical that the results are presented in a clear and easy-to-understand manner.

General Visualization Tips

Principles from Tufte

Edward Tufte is considered one of the most notable figures in data graphics and visualization. His work involves the study of graphical theory, including graphical design, graphical integrity, multi-functioning graphical elements, and minimalization of graphics (which is explained in a later section). Some key lessons that can be useful for the LCA community includes his points to achieve a "graphical excellence" which include (Tufte, 2001):

- "Avoid distorting what the data have to say".
- "Make large data sets coherent".
- "Encourage the eye to compare different pieces of data".
- "Have the visual be integrated with the numerical and verbal descriptions of the data set".

Another lesson that is useful is the five principles of data graphics, which are (Tufte, 2001):

- "Above all else show the data".
- "Maximize the data-ink ratio".
- "Erase non-data ink".
- "Erase redundant data-ink".
- "Revise and edit".

While some of his principles are meant for handwritten visualizations, these can be applied towards making efficient digital visuals as well.

Balancing Data, Space, and Time

Pie or Bar Chart?

When creating a data visualization, there are many options. Two common data visualizations are bar and pie charts. Both bar and pie charts are used to display numerical data; bar charts are better suited for comparing datasets, whereas pie charts are better suited for displaying proportions of a whole.

The pie chart is notorious in the scientific community due to its potential to mislead audiences. However, people LIKE pie charts. A study by Siirtola (2014) found that most participants found the pie chart "quicker" and more "pleasing" to read, even though the results of their study showed the stacked bar was actually "quicker" (ie., participants took less time to complete the task of reading and interpreting the chart). Despite this preference, we recommend using a bar chart to clearly communicate LCA results, especially a stacked bar, unless there is a specific reason to use a pie chart (e.g., client request, it fits in a design space better, etc.).

Ultimately, the type of data visualization you choose will depend on the type of data you are working with and the story you want to tell, and most importantly – on your audience!

Using Appendices

Life cycle assessment reports, at first glance, can feel intimidating due to the immense number of pages. However, this is misleading because most of these pages consist of tables, charts, and appendices. We recommend trying to keep the length of the main document low and less overwhelming (and therefore more likely to be read!). This can be achieved by placing tables and charts that are not essential to the main storyline in the appendix, and even separating the appendix from the document altogether.

Data Groupings

LCA reports are full of data, and this often manifests as page after page of bar charts which is repetitive, and even boring, for readers. To save space and increase attention, we recommend grouping data in a grid (also known as "lattice" or "trellis), a hierarchical design (also known as an infographic), or in an interactive dashboard. We recommend using data groupings, rather than individual tables and figures, for the following reasons:

(1) **Data groupings decrease the amount of repeated text** (e.g., axis labels, legends), which in turn decreases the number of pages in reports. This will make your reports feel less intimidating!

(2) Data groupings have been shown to be **more visually appealing** and "enjoyable" to read (Lyra et al., 2016)

(3) Data groupings can **increase attention, efficiency, comprehension, and retention** (Turck et al., 2014; Bateman et al., 2010; Guo et al., 2020; Lyra et al., 2016)

(4) Finally, **data groupings prioritize visual graphics**, which have been shown to attract reader attention and facilitate comprehension and communication of information better than tables and text (Smerecnik et al., 2010). Graphics hold reader attention longer (so they're not just skimming) and also take less effort to understand (Smerecnik et al., 2010).

Accessibility

When creating data visualizations, it's important to ensure that all users, with all levels of ability, have access to the information being displayed. While we are not accessibility experts, we use the following tips to increase accessibility in our graphics:

Data Labels

Use clear and concise labels for all titles, axes, and data points. Avoid using acronyms or abbreviations that may not be familiar to all users. Refer to the Web Content Accessibility Guidelines (WCAG) font size recommendations.

Color

Ensure that your color choices are easy to distinguish for users with color blindness. Refer to the WCAG color contrast ratios, which differ between text and graphics.

Minimalism

We recommend keeping your data figures neat and tidy. Bateman et al., 2010 found that embellishments can sometimes enhance the memorability of charts, but that some embellishments are not useful, and are actually damaging to your audience's interpretation (Bateman et al., 2010). We again refer to Tufte's "data to ink" ratio, emphasizing minimalism and reducing "chartjunk" (Tufte, 1983).

Clarity

When creating graphics, ensure that you are using vectors and not rasters. Vectors and rasters are two different types of digital images used in computer graphics, mapping, and other applications. The main difference between the two is how they store and display information.

Vectors are made up of lines and curves defined by mathematical equations. They are **resolution-independent**, meaning they can be scaled up or down without losing image quality. This is important to accessibility, because a reader with visual impairment can zoom into a diagram without losing quality, and therefore adjust text and icon size as needed.

On the other hand, rasters are made up of pixels, which are tiny squares of color that form an image. Rasters are **resolution-dependent**, meaning their quality is determined by their resolution, or the number of pixels per inch. They are commonly used for photographs, scanned images, and digital art.

We recommend using vectors for all chart-related components (e.g., lines, shapes, text); the only reason to use a rasterized image is if you have a photograph you want to include.

Figure 1. An example of vector vs. raster. When you blow up a raster image, it loses quality!

Supplemental Data

Unfortunately, not every data visualization is going to be accessible to everyone. Therefore, it is important to have the alternative data presentations (e.g., table, spreadsheet) accessible. While a data table is less visually appealing, it allows readers to have a clear understanding of the data.

Alternative Text

Provide alternative text that describes the chart in detail. This could be located in the figure caption, or the "alternative text" section of your word processor. This helps users who are visually impaired or who use assistive technology.

Effective Communication of LCA Data

Commonly Used LCA Visualizations

The bar chart

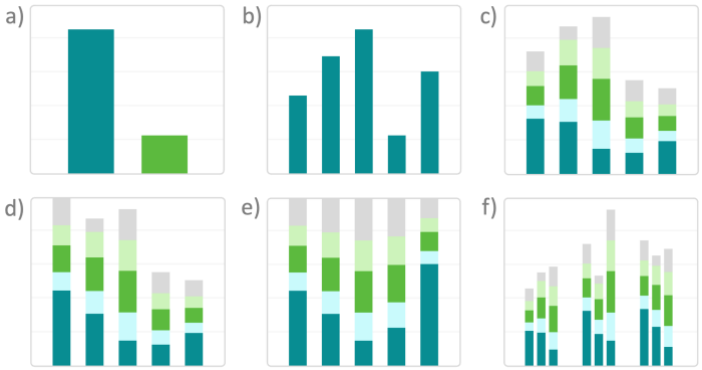

Figure 2. Bar chart examples.

When deciding between a regular bar chart (Figures 2a-b) and a stacked bar chart (Figure 2c-f), consider whether you want to compare the total values across categories or the individual values within each category. If you want to compare total values, a regular bar chart is the way to go, while a stacked bar chart is more appropriate if you want to show the composition of each category. In terms of units, using actual values (Figure 2a-c) is best when the absolute values matter while using 100% values (Figure 2e) is useful when you want to show the relative proportions of each category. Finally, if you want to compare the values among groups that have vastly different scales, displaying data relative to the largest value can help provide a clearer picture of the relationships between categories.

In LCA results specifically, absolute values should **only** be used with one impact category. If you are including multiple impact categories, you **must** use relative values such as percentages or normalized values. Impact categories are not directly comparable. Excel will *let* you plot these categories, but that does not mean you *should*! Using absolute values to compare impact categories is misleading and inaccurate, and it is important to use relative values and compare products or processes within the same category to get a more accurate picture of their environmental impact.

The donut chart

Pie charts are not included in this document, as donut charts (Figure 3a) are superior because (1) the slices are more rectangular, allowing readers to estimate size instead of angle and (2) the hole in the center can be used to display additional information, such as the total of the data being represented, the impact category, the units, etc. In LCA, this enhanced readability and additional chart real estate is precious! Creating a grid of donut charts (Figure 3b) is another visually appealing and space-saving data visualization technique.

Figure 3. Donut chart examples.

A sunburst chart (Figure 3c) is a hierarchical chart. Each level of the hierarchy is represented by a ring, and each ring is divided into segments proportional to the data it represents. The innermost ring represents the top level of the hierarchy (e.g., life cycle stages), and each subsequent ring represents a lower level (e.g., parts and other groups). Sunburst charts are often used to show the relationship between different categories and sub-categories.

The tree map

The tree map chart (Figure 4), like the sunburst chart, displays hierarchical data. Tree maps, as the name suggests, use rectangles to represent different nodes of a tree. The size of each rectangle is proportional to the value it represents.


Figure 4. Tree map example.

Deciding between a sunburst and tree map depends on the number of levels in the hierarchy and size of each group. We recommend plotting your data in both visualizations, and deciding which plot is (1) more visually appealing (e.g., sunburst charts can sometimes have weird, unaesthetic gaps) and (2) most legible (i.e., data labels are clear, or can be made clear using manual data labels and connector lines).

The violin chart

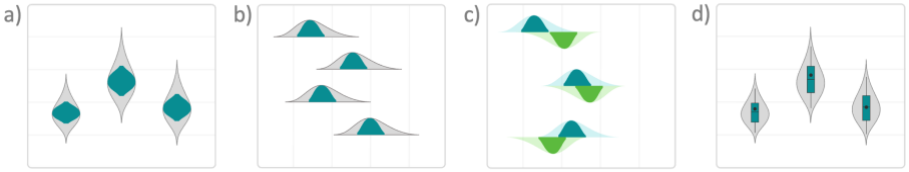

Figure 5. Violin chart examples.

The violin chart is a beautiful chart that is highly effective in showing uncertainty, but less known outside of the LCA community. They show the distribution of the data and its density, and can be drawn in different orientations, including vertical or horizontal, mirrored (Figure 5a) or non-mirrored (Figure 5b), and even two-sided (Figure 5d).

There are two primary ways to display data in a violin chart. At EarthShift Global, we use a simple violin (Figure 5a) in which there is a center mass that represents the 50% confidence interval, and the outer mass that represents the 95% confidence interval. This allows readers to visualize the uncertainty of the data. However, for those that wish to see summary statistics (e.g., mean, quartiles, etc.), it is possible to put a box plot inside of a violin (Figure 5d).

The major benefit of a violin plot is that it does not rely on summary statistics. While summary statistics can provide a quick and easy way to summarize data, they can also be misleading, particularly in life cycle assessment.

Summary statistics can obscure important details and variations in the data that may be critical for accurately assessing the environmental impacts of a product or system. For example, an average impact value may not reflect the fact that one stage of the life cycle has a significantly higher impact than the others, or that there is a wide range of impact values across different stages. A violin plot would visualize the uncertainty of this data, or you could also use a sunburst or stacked bar plot to further break down these summary statistics.

Moreover, summary statistics may be misleading if they are based on incomplete or biased data. LCA is a complex and data-intensive process, and the quality of the results depends heavily on the quality and completeness of the data used. If important stages or impacts are not included in the analysis, or if the data used is biased or inaccurate, the summary statistics may provide a distorted view of the environmental impacts.

Therefore, it is important to use caution when interpreting summary statistics in LCA and to consider the underlying data and assumptions used to generate them. More detailed and transparent reporting of LCA results, including sensitivity and uncertainty analysis, can help to address these issues and provide a more accurate and reliable assessment of the environmental impacts of a product or system.

The boxplot

Boxplots (Figure 6), like violins, are a useful tool for displaying the distribution of a dataset and summary statistics. A boxplot, also known as a box-and-whisker plot, displays the median or mean, quartiles, and outliers of a dataset. As mentioned above, summary statistics should be used cautiously with LCA data.

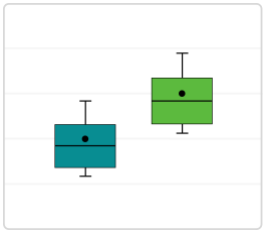

Figure 6. Boxplot.

The heat map

Heatmaps (Figure 7) use color-coding to show relative magnitudes of values across a data set. In LCA studies, heat maps can be used to visually represent the impact of different life cycle stages or processes by using color to represent the magnitude of impact. A heat map is successful at giving an initial impression of "good" and "bad" but is not very informative compared to other charts. It does not typically show discrete data points, and the color scheme may be confusing to some (e.g., green is associated with "increase" but also "good"; in LCA, an increase in impact is not good).

Figure 7. Heat map.

A solution to the criticisms of heat maps (not enough data) and tables (too much data, hard to identify trends) is the heat map – data table hybrid (Figure 8), which combines the visual cues of the traditional heat map and the numeric data of a table.

Impact category	Manufacturing	Transport	Packaging	Use	End of Life
Climate Change (kg CO2 eq)	**3%** 0.0003 ± 0.01	**44%** 0.004 ± 0.02	**11%** 0.001 ± 0.001	**8%** 0.0007 ± 0.0001	**33%** 0.003 ± 0.001
Stratospheric ozone depletion (kg CFC11 eq)	**17%** 3.0E-09 ± 1.00E-09	**6%** 1.00E-09 ± 1.00E-09	**2%** 3.00E-10 ± 1.00E-10	**58%** 1.00E-08 ± 1.00E-09	**17%** 3.00E-09 ± 1.00E-09
Ionizing radiation (kBq Co-60 eq)	**22%** 0.0004 ± 0.01	**6%** 1.00E-04 ± 0.0001	**1%** 1.00E-05 ± 0.0001	**50%** 0.0009 ± 0.001	**22%** 0.0004 ± 0.0001
Ozone formation, Human health (kg NOx eq)	**21%** 1.00E-05 ± 1.00E-09	**9%** 4.00E-06 ± 1.00E-07	**6%** 3.00E-06 ± 1.00E-09	**43%** 2.00E-05 ± 1.00E-05	**21%** 1.00E-05 ± 1.00E-06
Fine particulate matter formation (kg PM2.5 eq)	**17%** 3.00E-09 ± 1.00E-09	**6%** 1.00E-09 ± 1.00E-09	**2%** 3.00E-10 ± 1.00E-10	**58%** 1.00E-08 ± 1.00E-09	**17%** 3.00E-09 ± 1.00E-09

Figure 8. Heat map – data table hybrid.

The line chart

Line charts are less common in LCA studies. This may be because line charts are often associated with experiments over time. However, because a life cycle is its own timeline, a line chart could be used to demonstrate how an impact changes over the course of a life cycle. As seen in the example (Figure 9), one could plot all of the data points for each stage, as well as the mean (i.e., the trend line), making this a very informative plot.

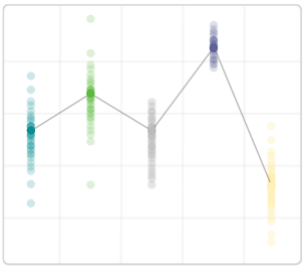

Figure 9. Example of a line chart used in LCA.

The Sankey diagram

Sankey diagrams (Figure 10) can help to illustrate the inputs and outputs associated with different stages of a product's life cycle, as well as the interconnections between the impacts of those stages. Sankey diagrams are less common than other charts, like bar and donut charts, most likely because they require additional visualization software or plug-ins in Excel. They may also not be familiar to most audiences.

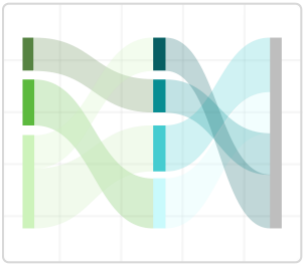

Figure 10. Sankey example.

The pictorial chart

Pictorial charts (Figure 11) may be limited in the information they can show, but are more engaging, digestible, and accessible to all audiences. We recommend using this type of chart in an executive summary or dashboard, in addition to other figures. For example, the dashboard in the results section (Figure 20) uses this strategy.

Figure 11. Pictorial example.

The blur chart

The blur chart (Figure 12) is similar to a bar graph, but instead of a hard line at the mean it shows a gradient to demonstrate uncertainty. It is an important tool in LCA because it helps to visualize and communicate the level of uncertainty in the results of an LCA study. Tensa et al., 2022 found that the blur chart was effective in forcing users to acknowledge uncertainty, but users disliked the chart because they found it difficult to identify the "highest impact" and "where the error starts and stop" (Tensa et. al. 2022).

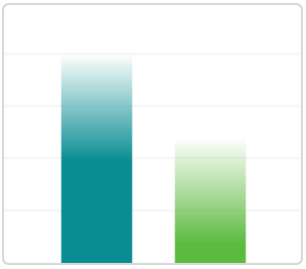

Figure 12. Blur chart example.

This touches on the previous topic of summary statistics: people like discrete numbers but, in reality, LCA is full of uncertainty. Deciding between a bar and blur chart is dependent on audience and goal.

Challenges in Communicating LCA Results

The way LCA results are presented will have an impact on the audience's interpretation of them. However, there is currently no standard on interpreting and communicating LCA results. The International Standards of Organization (ISO) 14040 and 14044 only list mandatory elements in the goal and scope definition, life cycle inventory analysis, and the life cycle impact assessment (ISO 14040; ISO 14044). Common LCA elements like normalization and weighting are optional elements according to these guidelines while other useful analyses, such as sensitivity analyses, are not required (Matthews, 2014; ISO 14040). The interpretation phase essentially has no requirements. As LCA results are increasingly being used to guide decisions on various challenges and opportunities, the lack of clarity and rigidity of the interpretation phase pose risks in misinterpretations and improper uses of the results. The following three papers further explore this topic.

Challenges when Communicating Comparative LCA Results

Prado et al. 2022 discussed the challenges and risks when communicating LCA results in greater detail by identifying ways a certain visual can lead to four possible misconceptions in results. This was conveyed with bar charts which, as previously mentioned, are the most common charts to visualize LCA results. They were used to compare two alternatives on a normalized graph that looked at two impact categories and presented the data uncertainty with error bars. The four scenarios (irrelevance, inaction, indecision, and misconception) are based off the amount of statistical discernibility and relative differences between the bars, which can be viewed in Figure 13 below.

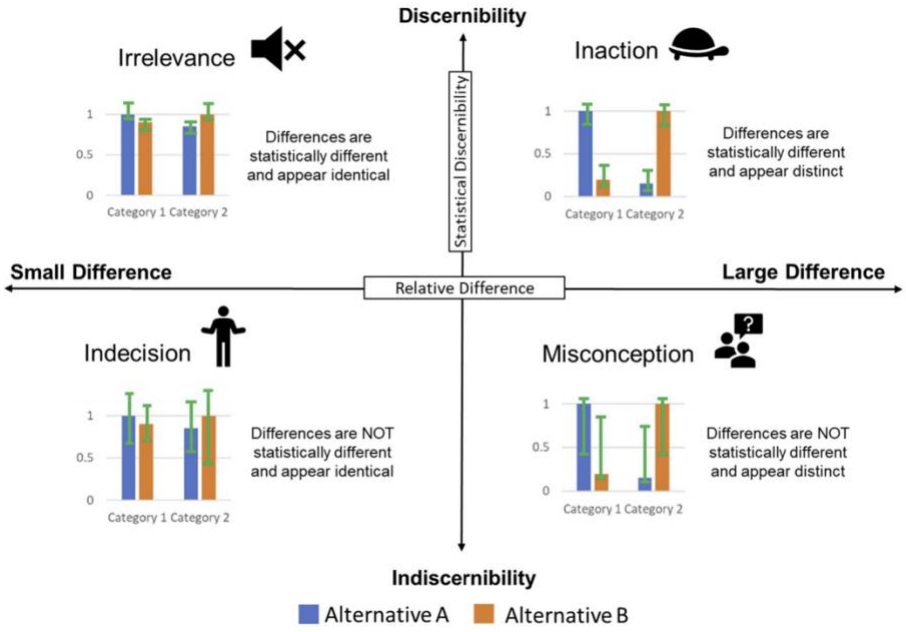

Figure 13. Four possible misconceptions in results (Prado et al. 2022)

A well-defined interpretation phase for LCA results is a significant step to alleviate these risks. However, because there is little guidance on LCA interpretation and communication, tradeoffs in LCA results still lead to a great responsibility of the end-user to ascertain how to translate the LCA results to an effective decision (Prade et al., 2022).

Challenges with Visualizing Uncertainty

Similar to the above case, data uncertainty is generally a complicated point to address when analyzing and presenting a LCA. At times, not explaining the data uncertainty can be detrimental to the audience without that important information (Kandlikar, 2005). For instance, if the visual and explanation do not state key points of certainty in the LCA process, the visual may become too simple, leading to a risk of a misconception in the audience's conclusions of the results. On the other hand, uncertainty analyses that are too complicated for certain audiences to understand can lead to an inaccurate interpretation of the results, risking a decision to be made from misconceptions. Both cases were also discussed in the scenario presented by Prado et a., 2022. This is especially relevant for all LCA studies, as the presentation of results must balance an effective and understandable visual while addressing the complexity of data uncertainty.

Two Graphs Walk into a Bar

On a broader scale, one study observed the effectiveness for count and mean bar charts (Kerns & Wilmer, 2021). Of the 149 participants who were tested on their ability to interpret a bar graph representing mean data instead of count data, about 20% of the total respondents incorrectly interpreted the meaning of the mean bar chart. It was also concluded that there were misconceptions in the interpretations of the bar charts regardless of the participant's level

of education (Kerns & Wilmer, 2021). Considering all bar charts in the LCA field represent mean data, this has major implications for the LCA field. This suggests visuals should be chosen cautiously depending on the scenario the LCA practitioner is in, including the previously mentioned visualization tips.

Improving Visuals of LCA Results to Support Decision Making

Because of these challenges, it would be beneficial to have guidance on the way LCA researchers and practitioners choose visuals based on the scenario they are in. A step in this direction has been made where visual representations of Life Cycle Assessment (LCA) results were tested on their effectiveness to accurately convey the findings from a given LCA visual based on the goal of the LCA. Specifically, two LCA goal categories were defined to assess the visuals – comparing alternatives and identifying hotspots. The study was carried out by choosing a variety of visuals from LCA-related journal articles and having both LCA experts and participants make decisions based on what the visual is presenting (Guglielmi, 2023). The results described how effective a visual was at conveying the LCA's main takeaways by how many participants and LCA experts agreed with the visual in their study. The visual would be at risk of presenting a misconception if none of the three groups were in a majority consensus. One of the key takeaways from this study was that most of visuals developed for comparative purposes were interpreted correctly, and most of the visuals made for hotspot identification were also interpreted effectively. This proved one of the main hypotheses in the study, that LCA visuals are more effective for interpretation and communication of results when the goal of the study is properly defined (Guglielmi, 2023). Some of the **effective visuals** for each of the categories included those presented in Table 1 below.

Table 1. Effective visuals for comparing alternatives vs. hotspot identification.

Comparing Alternatives	Hotspot Identification
Using stacked bar charts (specifically when comparing across 2-4 impact categories)	Using heat map diagrams for observing hotspots across more than one impact category
Using unstacked bar charts with error bars to compare alternatives and observe uncertainty.	Using treemap diagrams to observe hot spots for one impact category
Using dot plots for comparing across many impact categories	Using sankey diagrams to observe hot spots for one impact category

Aside from the visuals that were determined to be effective, several visuals were also noted as a **misconception risk**, which included:

- Tables (especially those comparing multiple alternatives);

- Bar charts (specifically those comparing multiple impact categories on separate charts); and,
- Percentage stacked bar charts (especially those with several (5 or more) divisions within the bar to represent contributions) (Guglielmi, 2023).

To the best of the author's knowledge, there aren't other studies that have analyzed the effectiveness of visuals in the LCA field.

LCA Data Visualization in Practice

Study Description

In April of 2023, the authors presented the current approaches, pitfalls, and potential solutions to data visualization in LCA results at the LCA Institute 2023 virtual conference, hosted by the Life Cycle Assessment (ACLCA). This included a discussion on the types of visuals commonly used in the field of LCA, the research on visualizing data, the types of new and uncommon visuals that could be used, and the applicability of visuals in this field. The presentation ended with an opportunity for the audience to give their thoughts on the types of visuals currently being used and their likeliness to use current and newer ones in their work.

Motivated by the presentation and the results of the survey, the authors reviewed the current research on both visualization of data on a broader scale as well as the research in the field of LCA and summarized their finding in the above sections. The results from the survey were interpreted and recommendations and future directions for visualizing LCA results are provided.

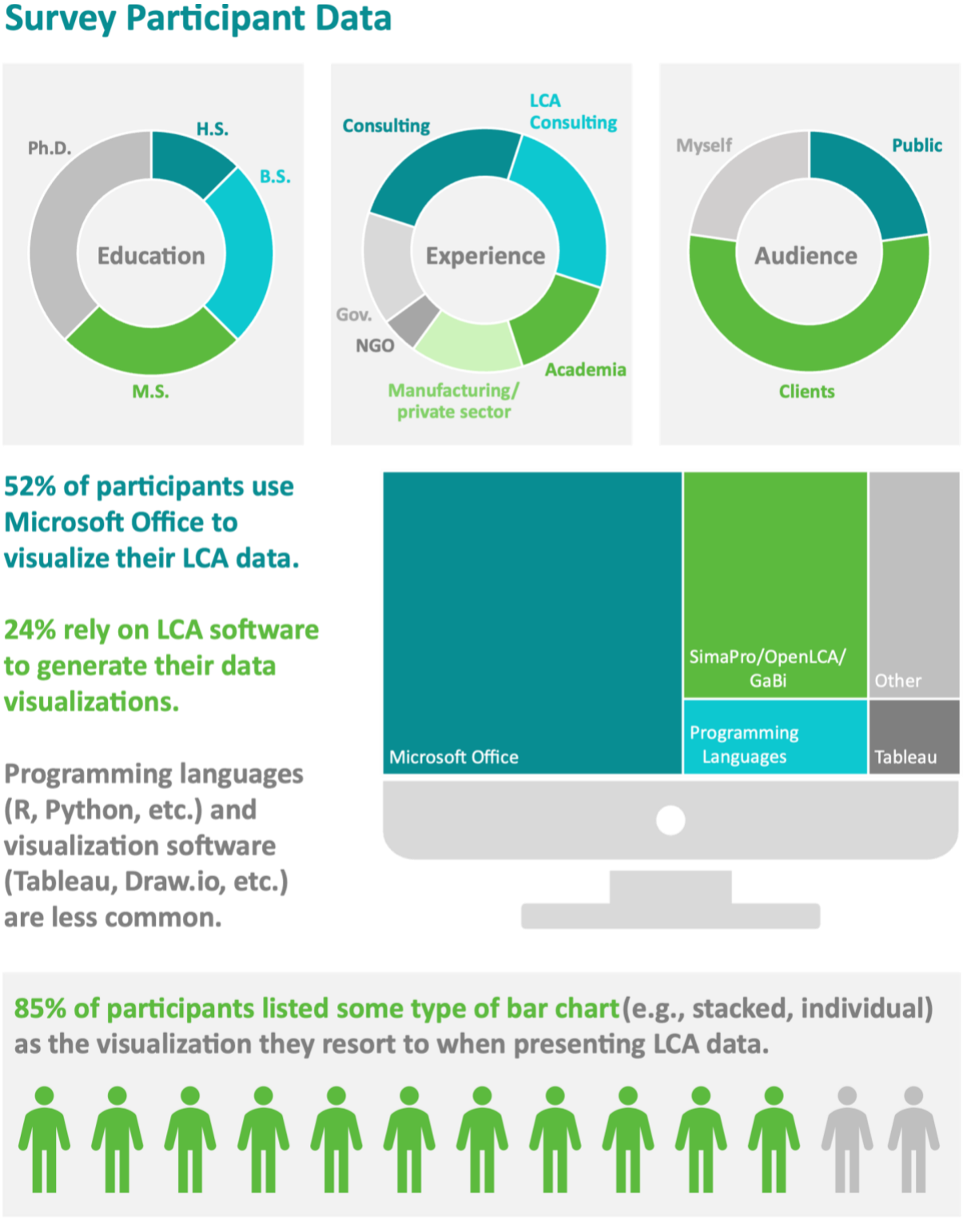

Figure 14. Survey participant demographic data.

Results

Visuals for the Purpose of Comparisons

One Impact Category

To assess the preferred visuals for the purpose of comparisons, we provided the participants with four simple figures (Figure 15).

Most participants chose the bar chart (Figure 15b) as the preferred visualization to analyze the data themselves (90%), present the results to the client (58.33%), and present the results to a broader audience with varying levels of understanding in LCA concepts (90%). Additionally, 33.33% of participants selected the tree map as the best visualization to present the results to a client.

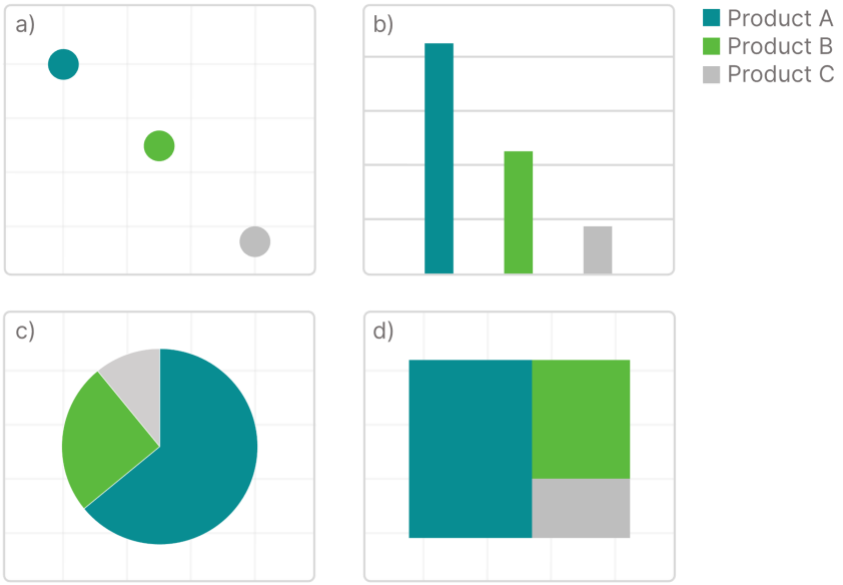

Figure 15. Graphic from survey question on visuals for the purpose of comparison.

Multiple Impact Categories

Participants were asked whether they would use normalized values (%), actual values, or values relative to the largest impact when plotting multiple impact categories on one chart. The results show that when interpreting the data themselves, participants are likely to use actual values (60%) and normalized values (40%); however, when presenting the results to a broader audience, participants are more likely to use normalized (60%), and less likely to use actual values (20%) and values relative to largest (20%).

Visuals for Hotspot Identification

To assess the preferred visuals for hotspot identification, we provided the participants with three simple figures – a heatmap diagram, a tree map diagram, and a sunburst diagram – which are designed to portray the results of an LCA that is meant to identify the hotspots of a product/system. These figures are presented below in Figure 16.

The majority of participants chose a heat map (Figure 16a) as the preferred visualization for themselves to interpret (70%), as well as to present the results to a broader audience with varying levels of understanding in LCA concepts (60%). The sunburst chart (Figure 16c) was also chosen for personal interpretation (30%) and for broader audiences (40%). One participant indicated that they prefer a stacked bar chart for hotspot identification, whereas another preferred to use a system boundary diagram with values.

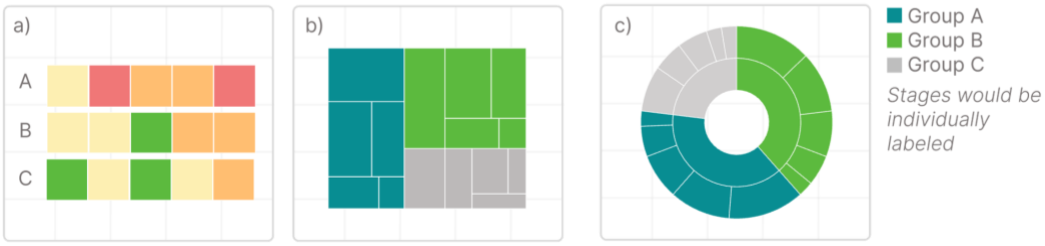

Figure 16. Graphic from survey question on visuals for hotspot identification.

Visuals for Uncertainty

To assess how participants prefer to visualize uncertainty, we provided six figures (Figure 17). When interpreting the data themselves, participants were equally likely (33.33%) to use a bar chart with error bars (Figure 17c) or a box and whisker plot (Figure 17d). When presenting results to a broader audience, participants were most likely to use a bar chart with error bars (60%). They were equally less likely (10%) to use the blur chart, violin chart, a dot chart, and box and whisker chart. Interestingly, one participant indicated the likelihood to use the violin-box and whisker hybrid chart to interpret the data themselves, but not for broader audiences.

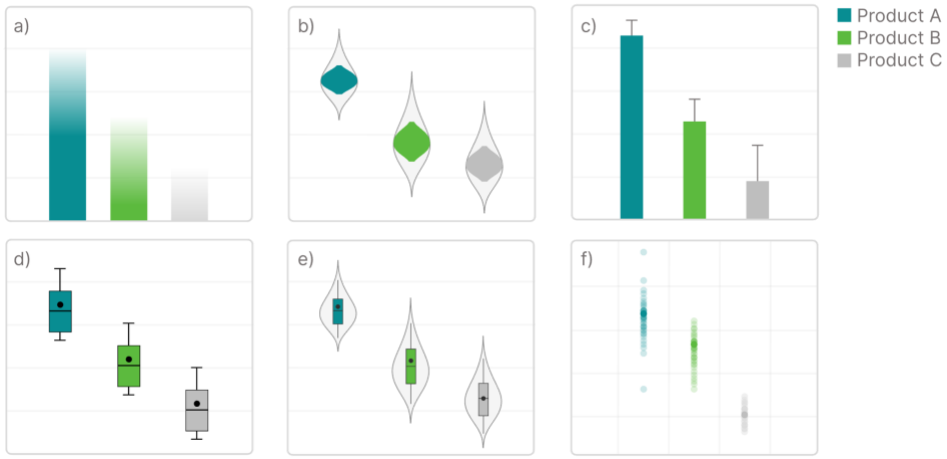

Figure 17. Graphic from survey question on visuals for uncertainty.

Big Data

To assess how participants prefer to visualize “big data”, we provided a series of figures on grouping styles. The first two figures (Figure 18) show grouping styles in one chart, with the same axes. Participants were likely (60%) to use grouped stacked bar

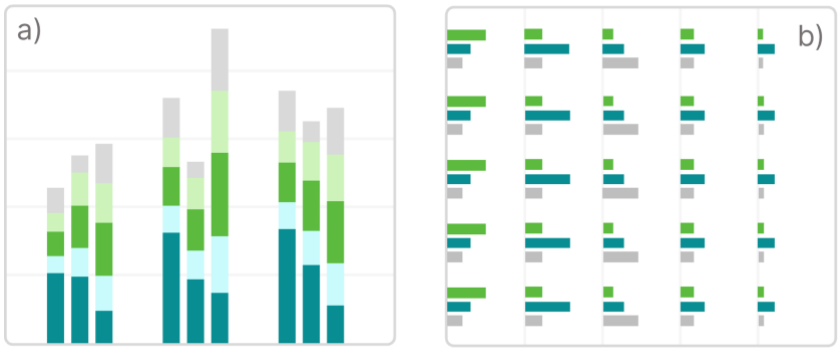

Figure 18. Graphic from survey question on visuals for big data.

charts (Figure 8a) compared to the paneled bar chart (30%). 10% of participants were unlikely to use either.

The second grouping style shows a “grid layout”(Figure 9). Most (87.5%) of participants preferred this grouping style to individual figures (12.5%). Participants noted that they would prefer the grid layout if (a) there is a “macro trend” to justify the grouping, (b) there is text explaining the grouping, or (c) space is a constraint.

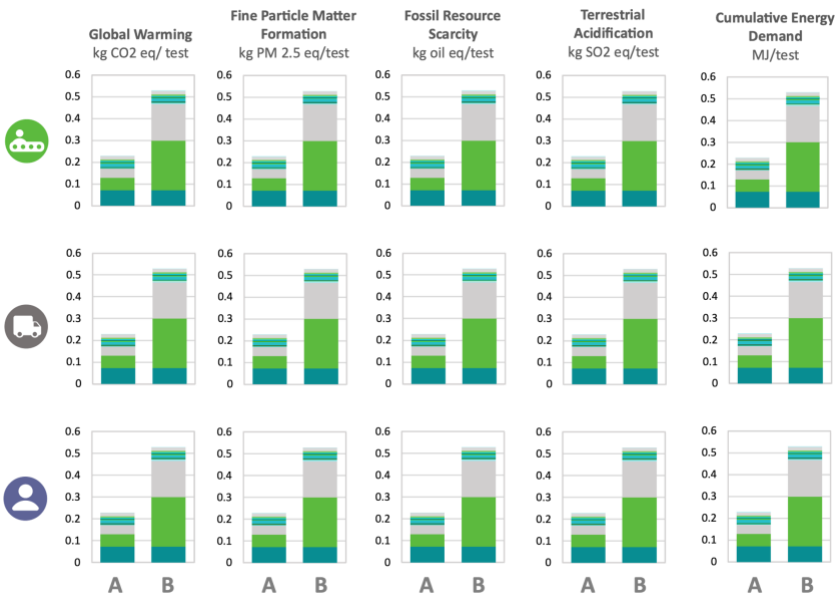

Figure 19. Grid layout graphic from survey question on visuals for grouping styles.

The final grouping style we presented was in a “data dashboard” format (Figure 20). Most participants (86%) had a positive response to this grouping style. Participants felt that the dashboard design had “high potential” as an approach for visualizing LCA data in the LCA research and consulting community, especially when “summarizing results”. One participant expressed concern in using dashboards in “stand-alone print”, as this format would prevent interactivity, data explanation pop-ups, etc.

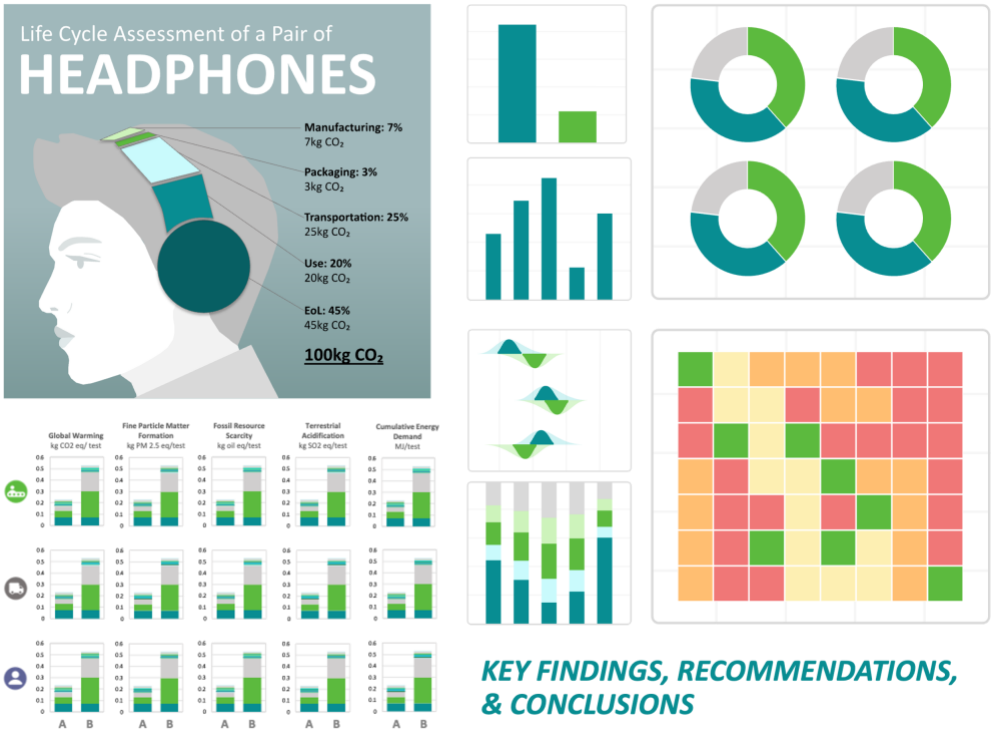

Figure 20. Example of a data dashboard. *Note: the headphones figure was modified from Jones, 2020 (https://www.visualcapitalist.com/the-most-loved-brands/).*

Uncommon LCA Visualizations

To assess how likely participants are to use "uncommon" LCA data visualizations, we provided seven figures (Figure 21). Participants were asked to rank these graphs from least likely to most likely to use, and to express which audiences the graphs were appropriate for.

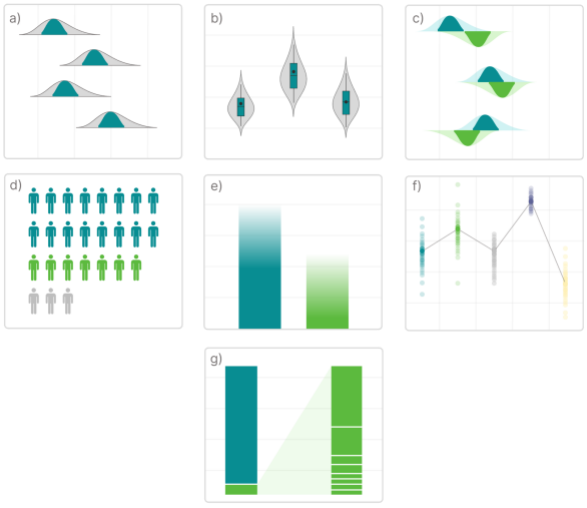

Figure 21. Graphic from survey question on uncommon LCA visualizations

All participants found the variations of **violin plots** (Figure 21a-c) to be appropriate for experts (100%) but not for the general public (0%), with only one participant indicating that the boxplot-violin hybrid was appropriate for clients (Figure 11b).

Most participants (57%) were unlikely to use the **mirrored violin chart** (Figure 21c) or the **blur bar chart** (Figure 21e); interestingly, the blur bar chart was selected as being appropriate for the public (25%), indicating that perhaps its lack of appeal is not due to complexity. Most participants (75%) found **pictorial charts** appropriate for public and client audiences, but not for experts (Figure 21d). While participants found the line chart to be appropriate for experts (75%), public (25%), and clients (25%), participants are not likely (14%) to use this chart. Most participants (86%) indicated that they were likely to use a **stacked bar plot** with a subset bar (Figure 21g). This chart was presented as a solution to disparate datasets (e.g., large ranges, disproportionate groups).

Table 2. Participant's likeliness of using the uncommon LCA visualization approaches. Percentages indicate the percentage of instances in which a chart was ranked likely (sixth or seventh), unlikely (first or second), and listed as appropriate for each audience type.

	Participant Likeliness to Use Figure		**Appropriate Audience for the Visual**		
	Unlikely	Likely	Experts	Public	Client
a)	14%	29%	100%	0%	0%
b)	29%	29%	100%	0%	25%
c)	57%	14%	100%	0%	0%
d)	29%	0%	0%	75%	75%
e)	57%	29%	50%	25%	0%
f)	29%	14%	75%	25%	25%
g)	0%	86%	50%	25%	75%

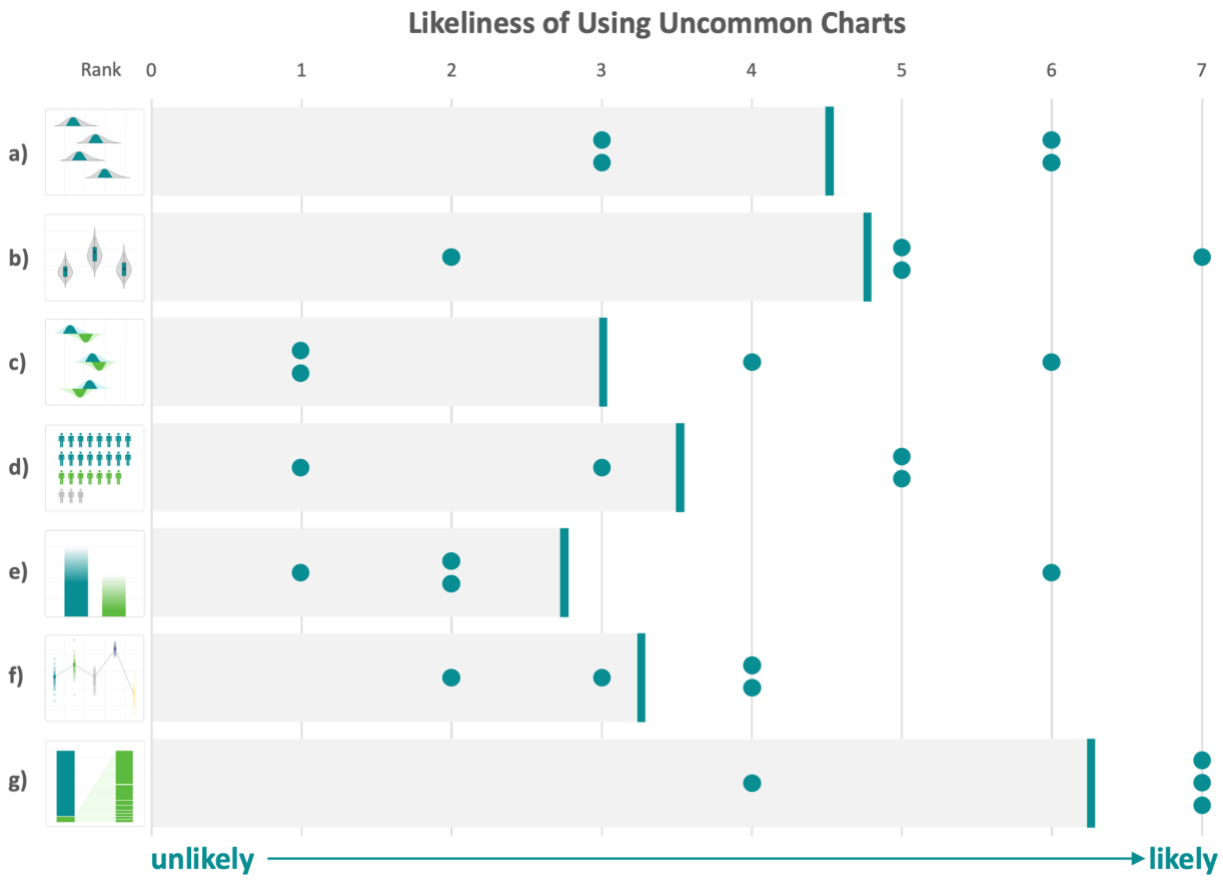

Figure 22. Participant's ranking of the uncommon LCA visualization approaches. The blue line (|) represents the mean rank, and the blue circles (●) represent individual answers.

Key Findings

- **Most participants chose the bar chart** as the preferred visualization to analyze the data themselves (90%), present the results to the client (58.33%), and present the results to a broader audience with varying levels of understanding in LCA concepts (90%).
- **Participants are likely to use actual values** (60%) and normalized values (40%); however, when specifically presenting the results to a broader audience, participants are more likely to use normalized (60%), and less likely to use actual values (20%)
- When interpreting uncertainty data, participants are equally likely (33.33%) to use a bar chart with error bars or a box and whisker plot. When presenting results to a broader audience, participants are most likely to use a bar chart with error bars (60%).
- Our various **grouping styles** (e.g., dashboards, grids, grouped bar charts) received **positive feedback** from participants. Participants preferred the grouped stacked bar to panels (60%), the grid layout to individual figures (87.5%), and saw high potential for use of dashboards in the LCA community.
- While participants are not likely to use most of the "unique" visualizations we presented (e.g., mirrored violins, blur chart, line chart pictorial), 86% indicated likeliness to use the

subset bar graph. This chart was thoroughly discussed in our presentation as a solution for visualization disparate data sets; **perhaps a detailed explanation of the efficacy of the other unique charts would increase likelihood of use.**

In Summary

Data visualization plays a critical role in LCA by enabling users to easily understand complex environmental data. A wide range of charts are available for visualizing LCA data, including pie charts, bar charts, scatter plots, heat maps, etc. In a recent survey study, researchers explored which types of charts are most commonly used and preferred by LCA practitioners. The results showed that bar charts are a preferred visualization, both actual and normalized values are commonly used, and that the participants are open to new visualization styles.

Oftentimes in science and academia, our efforts are focused on experimental design, data collection, writing about the data, and applying to scientific journals. Once a paper is accepted, it's time for the next project! The communication aspect is often limited to a paper and maybe a few presentations, which further demonstrates the importance of the visuals used in these deliverables. **It may be the one opportunity for a reader to interact with and understand your work!**

Mark Walport, Former Government Chief Scientific Adviser in the United Kingdom, stated that "science isn't finished until it's communicated". Our hope is that the LCA community can really start to prioritize this final step of the scientific process because communication should be the minimum and **science isn't finished until it's understood**.

References

Bateman, S., Mandryk, R. L., Gutwin, C., Genest, A., McDine, D., & Brooks, C. (2010). Useful junk? The effects of visual embellishment on comprehension and memorability of charts. *Conference on Human Factors in Computing Systems - Proceedings*, *4*, 2573–2582. https://doi.org/10.1145/1753326.1753716

Guglielmi, G. (2023). *Improving the Communication of Life Cycle Assessment Results to Support Decision Making*. Arizona State University.

Guo, D., Zhang, S., Wright, K. L., & McTigue, E. M. (2020). Do You Get the Picture? A Meta-Analysis of the Effect of Graphics on Reading Comprehension. *AERA Open*, *6*(1), 233285842090169. https://doi.org/10.1177/2332858420901696

ISO 14040. (2006). *Environmental mangement - life cycle assessment - principles and framework*.

Jones, K. (2020). *The Most Loved Brands, by Generation*. https://www.visualcapitalist.com/the-most-loved-brands/#google_vignette

Kandlikar, M., Risbey, J., & Dessai, S. (2005). Representing and communicating deep uncertainty in climate-change assessments. *Comptes Rendus - Geoscience*, *337*(4), 443–455. https://doi.org/10.1016/j.crte.2004.10.010

Kerns, S. H., & Wilmer, J. B. (2021). Two graphs walk into a bar: Readout-based measurement reveals the Bar-Tip Limit error, a common, categorical misinterpretation of mean bar graphs. *Journal of Vision*, 13–19; 23–24. https://doi.org/https://doi.org/10.1167/jov.21.12.17

Lyra, K. T., Isotani, S., Reis, R. C. D., Marques, L. B., Pedro, L. Z., Jaques, P. A., & Bitencourt, I. I. (2016). Infographics or Graphics+Text: Which material is best for robust learning? *Proceedings - IEEE 16th International Conference on Advanced Learning Technologies, ICALT 2016*, 366–370. https://doi.org/10.1109/ICALT.2016.83

Matthews, S., Hendrickson, C., & Matthews, D. (2014). Life Cycle Assessment: Quantitative Approaches for Decisions that Matter. In *The British Journal of Psychiatry*. https://doi.org/10.1192/bjp.111.479.1009-a

Prado, V., Seager, T. P., & Guglielmi, G. (2022). Challenges and risks when communicating comparative LCA results to management. *International Journal of Life Cycle Assessment*.

Siirtola, H. (2014). Bars, pies, doughnuts & tables - Visualization of proportions. *Proceedings of the 28th International BCS Human Computer Interaction Conference: Sand, Sea and Sky - Holiday HCI, HCI 2014*, 241–245. https://doi.org/10.14236/ewic/hci2014.30

Smerecnik, C. M. R., Mesters, I., Kessels, L. T. E., Ruiter, R. A. C., De Vries, N. K., & De Vries, H. (2010). Understanding the positive effects of graphical risk information on comprehension:

Measuring attention directed to written, tabular, and graphical risk information. *Risk Analysis*, *30*(9), 1387–1398. https://doi.org/10.1111/j.1539-6924.2010.01435.x

Soria Zurita, N., Tensa, M., Ferrero, V., Stone, R., DuPont, B., Demirel, H., & Tumer, I. (2022). Uncovering Human Errors Associated With System-User Interactions Using Functional Modeling. *Journal of Mechanical Design*, *144*.

Tufte, E. (2001). *The Visual Display of Quantitative Information* (2nd ed.). Graphics Press LLC.

Turck, C. J., Silva, M. A., Tremblay, S. R., & Sachse, S. L. (2014). A Preliminary Study of Health Care Professionals' Preferences for Infographics Versus Conventional Abstracts for Communicating the Results of Clinical Research. *Journal of Continuing Education in the Health Professions*, *34*(Supplement 1), S36–S38. https://doi.org/10.1002/chp.21232