INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

AIDING DESIGNERS TO MAKE PRACTITIONER-LIKE INTERPRETATIONS OF LIFE CYCLE ASSESSMENT RESULTS

Uchil, Praveen (1); Chakrabarti, Amaresh (1); Fantke, Peter (2)
1: Indian Institute of Science, India; 2: Technical University of Denmark

Abstract

Detailed Life Cycle Assessment (LCA) provide tools to quantitatively illustrate the environmental impacts of a product throughout its life cycle. Effectively interpreting the results of a detailed LCA are fundamental for taking reliable decisions about evaluating design alternatives w.r.t environmental impact and for communicating the same across various actors. The goal of our research is to develop target specific interfaces to aid designers to make practitioner like interpretation of LCA results. In this paper we describe the challenges involved in practitioner like interpretation of LCA results and describe general requirement of a LCA interface to support effective (Practitioner –like) interpretation. We develop a novel questionnaire based evaluation method to identify the issues in LCA tools, faced by designers in pursuit of practitioner like interpretations. In order to describe underlying cause of these issues, we use two constructs derived from domain of information visualization, namely explanatory and exploratory mode of interfaces.

Keywords: Life Cycle Assessment, User centered design, Ecodesign, Early design phases, Information visualization

Contact:
Praveen Uchil
Indian Institute of Science
Centre for Product Design and Manufacturing
India
praveen@cpdm.iisc.ernet.in

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

Life cycle assessment aims to track environmental impact of a product in its global value chain, i.e. production, use and end of life, and assess them from a system perspective, identifying strategies for improvement without burden shifting (Hellweg, 2014). Identification of hotspots, i.e. any material or process contributing significantly to the environmental impact in a product system, is often the primary purpose of using LCA. Availability of information about environmental interaction of constituents of a product during its life cycle is central to designers for reducing its environmental impact during early phases of design (Keoleian, 1993). We use the term Life cycle assessment results to refer not only to the computed outcomes of the assessment, but also to those inputs and methodological data necessary for effective interpretation of its results. Effective interpretation of LCA results can not only help the designer identify the hotspots but also rationalize as to why a particular material or component turns out to be a hotspot. This is possible through leveraging the transparency and accessibility a detailed LCA data provides, unlike streamlined LCA data. Using detailed LCA results can also eliminate the potential risk of generalization and over simplification that use of streamlined LCA tools can lead into (Weidema 1999). However, use of detailed LCA information has been limited mainly due to unavailability of LCA results or lack of target-specific interfaces that represent information in a form preferred by designers within their capacity to understand (UNEP 2008, Weidema 2000). As there have not been studies reporting the issues faced by designers in using current LCA interfaces, and there have not been any method for evaluation of interfaces specific to the LCA domain, we focus on addressing these gaps in this paper. A broader discussion on barriers against use of LCA information in design can be found in our earlier paper (Uchil and Chakrabarti, 2015) and in the work of others e.g. (Lofthouse 2005; Bhander 2003). The need for information visualization has been discussed in our earlier paper (Uchil and Chakrabarti, 2013). While availability of detailed LCA information of a product during early stage of design is not guaranteed, we assume a scenario in which detailed LCA dataset is available in a tool and a designer redesigning an existing product is interested in interpreting the detailed LCA data available on the current product, in order to set environmental targets for redesign and to communicate these targets internally as well as across the value chain.

2 RESEARCH OBJECTIVE AND RESEARCH QUESTIONS

The objective of this paper is to evaluate LCA tools in terms of its ability to *aid designers to make practitioner-like interpretation of LCA results*. The research questions are the following:

1. What is ‘practitioner-like interpretation’ of LCA results? What makes it a challenging task?
   This question is addressed through a review of relevant literature and the ISO 14043 manual.
2. What factors influence ‘practitioner-like’ interpretation of LCA results?
   This question is addressed through review of literature on evaluation methods for information visualization and Human Computer Interaction (HCI).
3. What evaluation methods are appropriate for identifying issues in LCA tools w.r.t. their support for interpretation?
   This question is also addressed through review of literature on evaluation methods for information visualization and HCI.
4. What issues do designers face in making practitioner-like interpretation of results from LCA tools?
   This question is addressed through observational studies engaging designers with LCA tools using think-aloud protocol and a questionnaire-based information visualization evaluation method.

3 PRACTITIONER-LIKE INTERPRETATION OF LCA RESULTS

ISO14043- Life Cycle Interpretation, the only definitive guide for LCA practitioners, defines LCA interpretation as the phase of LCA where findings of either inventory analysis or impact assessment or both, are combined consistently with the defined goal and scope in order to reach conclusions

(ISO14043). Systematic interpretation of LCA results includes 3 tasks: identification of significant issues (henceforth termed significant problems1), evaluation of consistency and completeness of data and methods used in computation of results, and, framing of recommendations. An LCA practitioner in principle should be capable of performing all three tasks. As each of these is a vast task in itself, we discuss only the first task in depth, i.e. identification of significant problems. Identification of significant (environmental) problems in a product system is the primary goal of LCA. This task is also commonly called identifying hotspots. Significant problems or hotspots can exist at the level of a product, process, emission or impact category. Identification of significant problems typically involves retrieving appropriate information structure from huge LCA result-datasets. Although ISO gives examples of the structure of this information, it uses only two dimensional matrices. According to ISO14043, identification of significant problems involves structuring of LCA information in order to filter required information from large LCI and LCIA dataset and to make sense of the filtered results. For effective interpretation of LCA results by designers, it is important to relate the results to information with which they are already familiar. We propose an alternative information structure to support identification of significant problems by designers.

4 CHALLENGES IN PRACTITIONER LIKE INTERPRETATION

Identification of significant problems in datasets of LCA results can be complex (ISO 14043). An important aspect of identification of significant environmental problems is structuring of LCA results in order to make sense of the results. The size of LCA dataset including inventory and methodological data can typically range between thousands to millions of data points depending on the complexity of the product. Interpretation involves extracting a subset of data in a desirable format from the dataset of LCA results. There is no single information structure that fits requirements of various decision-makers in a product life cycle. In order to accommodate diverse information structures, detailed LCA tools offer to present data at various levels of detail such as at the level of normalized or characterized values or aggregated single scores. Industrial Designers interested in comparing material alternatives from the environmental impact perspective may prefer to structure the information as *aggregate single scores like Eco-Points* for each material, whereas a Process Engineer interested in reducing emissions during the manufacturing process may prefer to structure the information at the *level of emission to each compartments (air, water, soil)* or at the level of *characterization factors* for every process. In contrast, a company, being sensitive to disclose impact at the level of emissions, may prefer *normalized levels per aggregate process.* As mentioned earlier, the strength of a detailed LCA tool lies in its ability to present results at various levels of detail. Given adequate training on the LCA tools and methodological concepts, it can facilitate various actors to retrieve the data in a structure they prefer (Bauman 2000). Considering the need for accommodating diverse requirements of information structure and that for accommodating several computational methods while giving the user the choice to choose among these, the complexity of current detailed LCA interfaces are conceivable. However, such complexity comes at a cost, such as in rendering LCA tools less usable. This 'One size fits all' approach of interface design has resulted in more tucked interfaces, more choices of analysis, and more means of structuring results, making a novice LCA user loose track in the sea of LCA information. Retrieving significant environmental issues requires understanding of what issue at various levels (Such as emission, impact category) would be considered significant could vary depending on the interest of the company. Such complexity can prevent novice users such as designers from using detailed LCA tools, which in turn creates a gap between development of LCA methods and its consequent application in decision making.

5 FACTORS THAT INFLENCE PRACTIONER LIKE INTERPRETATION

Various external factors such as data quality and availability of input and methodological information, scientific rigour of the LCA methodology, individual traits of users, and time available for users to interpret information influence the effectiveness of practitioner-like interpretation. For example, availability of primary data can reduce uncertainty of results, whereas lack of meta-information about data quality can reduce confidence over these results. Users' traits such as domain knowledge and comprehension-ability can influence task performance and rate of errors. Within the scope of this research, the goal is to identify the influence of an information visualization interface (i.e. LCA

interface in this case) on the effectiveness of interpretation of LCA results by the users (i.e. Designers in this case). We define a term 'effectiveness of interpretation' as the degree to which designers are able to make practitioner-like interpretation of LCA results.
An effective interactive visualization tool should adhere to the principles of congruence (i.e. the structure and content of the representation should conform to the structure and content of the LCA model) and to the principles of apprehension (i.e. the structure and content of the representation should conform to the structure and content of the desired mental model of the user) (Tversky 1998). We assess the effectiveness of an interface in terms of five metrics, by asking a set of questions for each, as described in Figure 1. In Section 7, some of these questions will be discussed.

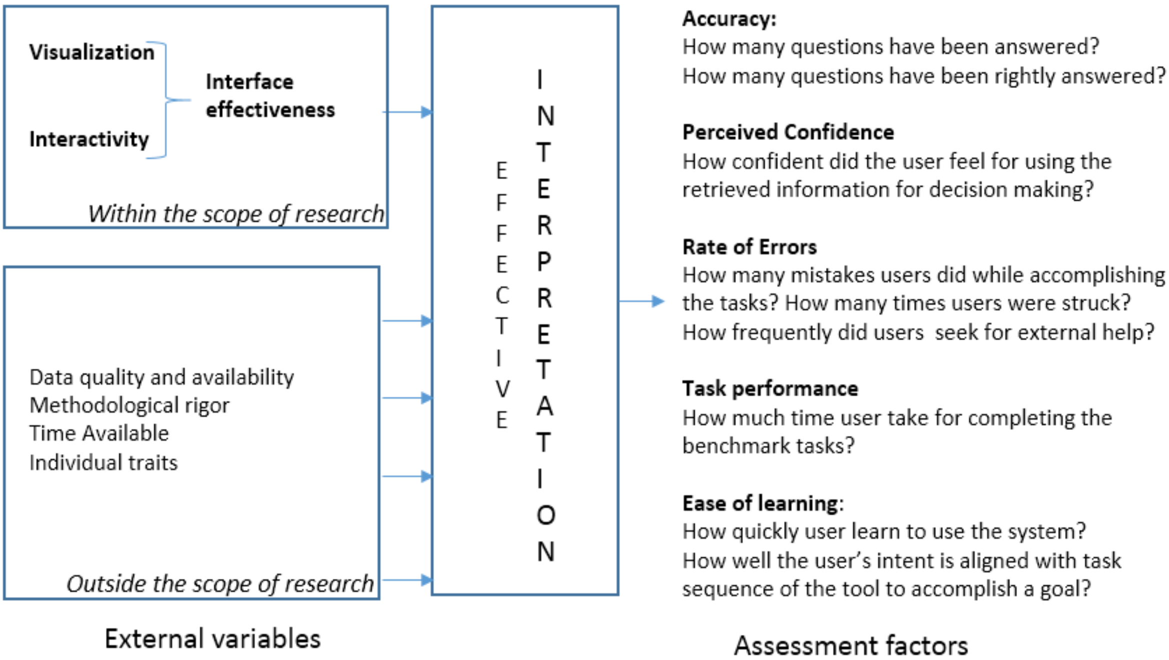


Figure 1. Factors influencing Effective Interpretation

The above metrics are compiled from usability and information visualization evaluation literature (Neilson 1993, Shniderman 2004). While there are several metrics for usability and visualization (Zhu, 2007), we have prioritized the metrics based on the desirable aspects of the interface, which in this case are accuracy, perceived confidence, rate of errors, task performance and ease of learning. These metrics can be used by LCA developers for benchmarking the effectiveness of interpretation supported by current LCA interfaces.

6 CHOICE OF INFORMATION VISUALIZATION EVALUATION METHOD

Traditional usability evaluation methods are focused on evaluating an interface purely from a task-centric perspective, and do not evaluate effectiveness of mapping of graphical representation to the underlying model it is meant to represent. Therefore, we look into the literature in rapidly advancing area of research on evaluation methods for information visualization. The purpose of information visualization evaluation is to evaluate how effectively an interface supports an interpretation task. A summary of information visualization evaluation methods along with their merits and demerits in the context of LCA is given in Table 1. While all the methods described in Table 1 can be used in principle as an evaluation method, we have chosen to employ user observation with concurrent think-aloud as it is most suitable within the resource constraints of our research.

Table 1. Summary of Information Visualization Evaluation Methods

Evaluation Method	Description	Merits	Demerits
Information visualization Heuristics (Zuk 2006)	Set of rule based methods requiring experts to comment on visual interfaces for a given task	Faster, does not require formal infrastructure	Results vary depending on the level of expertise and may not be consistent
Eye tracking with Retrospective think aloud (Nielson 1999)	Eye gaze and fixations of the users are analysed using eye-tracking devices to understand visual search behaviour and layout effectiveness	Objective, requires user sample after establishment	Resource intensive, Error prone, Time intensive
User observation with concurrent think aloud (Plaisant 2004)	Evaluator observes the user performing the tasks and makes interventions only in inevitable cases	Suitable for controlled laboratory settings	Time intensive
Focus group workshops (Nielson 1999)	Participants are asked to fill out questionnaire post discussion of the tool	Faster, Large data can be collected	Qualitative
Cognitive load based approach (Haung 2009)	Uses a multi-dimensional construct, c*ognitive load,* to evaluate the amount of cognitive load needed to perform a task	Uses a comprehensive set of metrics to evaluate cognitive load	Not suitable for evaluating interfaces for higher level objectives such as accuracy of interpretation
Insight based Evaluation (North, 2005)	Uses the high level metric insight defined as number of individual observations of the data by the participant, where one observation is one unit of discovery	Matches one of the aims of visualization to discover unforeseen insights	The metric needs to be redefined in the context of concrete data
Long term field studies (Shneidermann 2006)	Evaluates the effectiveness of a tool in actual work settings that can reveal difficulty of integrating the tool with day to day decision requirements	Provides more reliable evaluation data in practical settings	Often lengthy and expensive

7 OBSERVATIONAL STUDY ON DESIGNERS ENGAGED IN PURSUIT OF PRACTITIONER LIKE INTERPRETATIONS

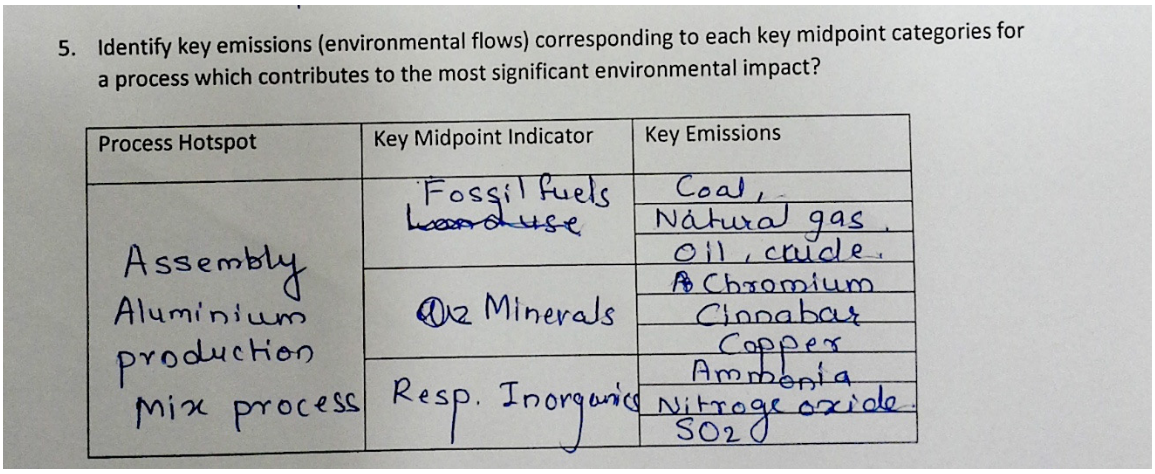
Participants in the study were either PhD students (with prior exposure to design) or design practitioners (with Masters in Product Design). The participants were first given an hour of tutorial on various topics of LCA: stages in LCA, steps in Life Cycle Impact Assessment (LCIA), definition of environmental impact as per LCIA methodology, and demonstration of interpretation capabilities of a commercial LCA tool for interpretation of results. The participants were then given a questionnaire to fill out, see Figure 2. However, the participants were not informed of the exact task sequence for answering the questions in the questionnaire, nor were they given any hands-on exercise or training as these would potentially mask important usability issues (Neilson, 1994). The participants were allowed to ask any questions during the tutorial or the experiment. The questions asked during the tutorial were of clarification type, such as meaning of terms e.g. DALY (Disability Adjusted Life Years, unit for a human health indicator), difference between normalization and characterization factors in LCIA steps, etc. The questions asked during the experiment were mainly about the task given, such as how to identify the stages of a life cycle. The questions asked during the experiment were in the order of increasing levels of complexity. The subjects voluntarily participated in the experiment and were allowed to answer as many questions as they wished. During the experiment, the researcher (the first author of this paper) played a passive role, making intervention only when it was necessary e.g. when a participant prompted the researcher that he/she was stuck, or was unable to figure out even after significant effort, as to how to accomplish a task.

The questionnaire given to the participant contained six questions, which were framed such that answers to these not only helped them understand any significant problems as recommended by ISO14043, but also tested how well the participants could identify the relationships between process, emission and impact categories and thus how good an insight they had into the underlying environmental phenomena. Their insight was tested by asking them to draw an environmental pathway diagram for the most significant hotspot. The questions were designed according to the requirements for effective interpretation of LCA results. The participants used the Coffee machine example project in the SimaPro demo version for purpose of this analysis and identification of significant issues. Figure 2 shows a sample response to one of the questions in the questionnaire. The issues faced by the participants were noted during the study by the researcher, who played the role of an observer during the study; these issues were further verified and new issues identified, after the experiment, through analysis of the think aloud video protocols. A sample of the issues identified is tabulated in Table 3.

ISO recommends that results from LCA are structured at each level of life cycle phases, as groups of processes or as unit processes. Although such structuring can facilitate identification of environmentally significant issues, it is inadequate for facilitating designers in identifying underlying environmental pathways. This is because such structures do not make explicit relationships among processes and their emissions. Being able to identify environmental pathways can help a designer interpret the underlying environmental phenomena that cause the impact, thereby enabling them to reason about the interaction between emissions and aspects of the environment. The tabular columns for answering the questionnaire are constructed such that they prompt the user to retrieve information at increasing levels of detail while preserving the context, thereby ultimately leading to identification of environmental pathways.

Table 2. Questionnaire and Supporting Rationale

Type	Sample Question	Purpose
What	What part or process contributes to the most significant (environmental) impact	Identification of *hotspots* is often the purpose of LCA
What	To which phase of life cycle does the process belong?	Identification of the dominant life cycle phase
What	What are the significant indicators of processes at the mid-point level?	Identification of the nature (type) of environmental impact caused by hot spots
What	What are the significant indicators of processes at the end-point level?	Assess the severity of environmental impact caused by the hot spots
What	What emissions are responsible for the processes to cause significant (environmental) impacts	Identification of key emissions in the light of environmental indicators
Why	What is the environmental pathway underlying a significant hotspot	Identification of underlying environmental phenomena



5. Identify key emissions (environmental flows) corresponding to each key midpoint categories for a process which contributes to the most significant environmental impact?

Process Hotspot	Key Midpoint Indicator	Key Emissions
Assembly Aluminium production mix process	Fossil fuels	Coal,
		Natural gas.
		Oil, crude.
	Minerals	Chromium
		Cinnabar
		Copper
	Resp. Inorganics	Ammonia
		Nitroge oxide
		SO2

Figure 2. Sample Response of Designer for the Information Structure

8 RESULTS

The interface issues identified were labelled according to Norman's (2002) stages of action sequence. Such labelling provides pointers to identifying an issue due to interaction or visual representation. Here, observation refers to the issues identified by the evaluator during or after the experiment through analysis of the video; User prompt refers to the instances in which a user did not understand how to proceed to answer a task or did not know (s)he was in the navigational sequence (as described in Table 3).

Table 3. Sample Issues Identified though experimental studies

Target Question	Example of issues	Observation/ Protocol instance/ Principles violated	Normans Stages of action sequence
Identifying the significant process (Process Hotspot)	User were choosing "compare" option instead of "analyses" for identifying the impact	(Observation) Consistency in terminology	Perceiving the state of the world
Identifying the product life cycle phase corresponding to a process	User did not understand how to return to the product structure tree after navigating into impact assessment results	(Observation) Principle of Navigation "know where you are" violated	Executing an action
List the indicators in ascending order according to impact score	Unable to plot indicator categories at end point level.	(User prompt) "Match intended action sequence"	Executing an action
Identifying the significant process	Analysing only single phase of life cycle while full life cycle were to be analysed	(Observation) Tucked navigation	Specifying action sequence
Identify part/subassembly corresponding to significant process	Unable to differentiate the encodings of process, sub assembly	(Observation) "Make important elements visually distinct"	Interpreting the state of the world
Representational issue	Interpret the semantics of colour encoding for product contribution	(Observation)	Interpreting the state of the world

9 DISCUSSION

In order to describe interface issues related to LCA tools, we use the concept of explanatory and exploratory modes of interfaces (Segel H, 2010). For this, we discuss the distinction between these modes, as it not clearly made in literature. This distinction is not intended for classification of interfaces, nor for establishing superiority of one over the other, but for understanding the relative merits and demerits. It should be noted that exploratory interfaces too can have explanatory component as explained in Figure 3.

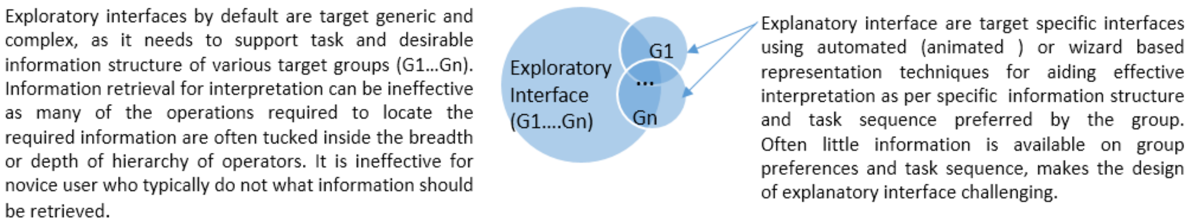


Figure 3. Concept of Explanatory Interface as a Subset of Exploratory

Table 4. Salient Features of Explanatory and Exploratory Modes of interfaces

Salient Features	Exploratory	Explanatory
Purpose	Model validation, Discovery, Insight	Communication, Interpretation, Decision making
Questions	Specific questions are not known	Specific questions are known or can be prescribed by an expert
Task sequence	Cannot be well defined	Can be well defined
Visualization techniques	Preferably unlimited	Preferably limited
Interactivity	Preferably unlimited	Preferably limited
Navigation	Hierarchical	Preferably Linear or Wizard based
Time to Learn	Higher	(Relatively) lower
User proficiency	Practitioner /Expert	Novice
Domain Knowledge	High/ Moderate	Introductory
Example	Spot fire, Tableau, Film Finder	Gap minder

Detailed LCA tools provide the exploratory mode of interfaces. This is understandable as LCA is conventionally used by practitioners and environmental experts during the modelling phase, to explore environmental impacts under various boundary conditions and methodical assumptions. However, for interpretation of results by novice users, the exploratory mode is not preferable, since an exploratory interface is inherently complex due to the hierarchy of functionality it has to support. It does not facilitate the user to locate information in a linear fashion. Complexity of such interfaces leaves the user in a maze of information. This creates unnecessary burdens on the user to follow a complex task sequence for eliciting required information (Neilson 1992). This was also confirmed by our observation of the cases in which participants were stuck due to their inability to return to the original point at which analysis was carried out, or followed an incorrect task sequence.

The exploratory mode is suitable when the purpose of the interface is to validate the quality of data or methodological assumptions, e.g. when evaluating completeness and consistency of LCA, or more generically, in cases in which the user intends to identify relationships within a large dataset that cannot be automatically extracted using computational algorithms since underlying cause and effect relationships are not known. For such purposes, there is neither a set of specific questions nor definite task sequences that can help the user to accomplish the goal. The explanatory mode is suitable when the purpose is interpretation or communication of data when underlying relationships among data is already known. The requirements of explanatory interfaces include identification of common tasks of the user group and information structure preferred by users. There have been no systematic studies on LCA so far in either of these. The outcome of the current study is expected to formulate benchmark tasks and arrive at a preferred information structure.

10 CONCLUSIONS AND FUTURE WORK

Practitioner-like interpretation of LCA results involves identification of significant environmental issues at levels of Part, Process, Life-Cycle phase, Emission, and Indicator Category. For a designer, identification of LCA results at such levels of detail can provide a conceptual understanding of the links between processes, impact categories and emissions. Such understanding can not only improve the confidence over design decisions concerning environment but also improve the effectiveness of communication across the value chain. An exit questionnaire has been designed to evaluate the extent to which an LCA tool under consideration can support effective interpretation. The questionnaire also serves as a guide for novice users such as designers to identify not only process- or product-hotspots but also the types of impact, emissions and environmental pathways. The issues identified through the observational studies are meant to provide important pointers to LCA software developers to identify information seeking behaviours of novice designers. The proposed questionnaire-based method is tool-neutral, and therefore can be used by LCA software developers for evaluating interpretation effectiveness of their LCA software interfaces. Future work involves developing alternative interfaces based on the findings of the observational studies, and comparing their effectiveness vis-à-vis existing interfaces, so as to assess improvement in effectiveness of interpretation. Effective interpretation facilitated by such interfaces should in turn lead to effective communication of LCA results by designers across the value chain. This should lead to more reliable use of LCA results in decision-making with greater likelihood of reducing environmental impacts of product systems at earlier stages of design.

ACKNOWLEDGEMENTS

We thank Dr TV Ramachandra, Professor Centre for Ecological Sciences, and Mr Ramani Krishaswamy, Doctorial Student at Indian Institute of Science, for useful suggestions for design of experiments .

REFERENCES

Hellwig, S., and L.M. Canals. (2014). Emerging approaches, challenges and opportunities in life cycle assessment. Science 344(6188):1109-1113.

Weidema, B (1999) Use of life cycle data in industrial design. Draft report on the development needs.

UNEP (2008) Communication of Life Cycle Information in the building and energy sector. UNEP DTIE

Keoleian, G. (1993)."The application of life cycle assessment to design." Journal of Cleaner Production 1(3-4): 143-149

Lofthouse, V. (2006). Eco-design tools for designers : defining the requirements, 14, 1386–1395. Journal of Cleaner Production 2005

Uchil, P., & Chakrabarti, A. (2013). Communicating life cycle assessment results to design decision makers: Need for an information visualization approach. In DS 75-5: Proceedings of the 19th International Conference on Engineering Design (ICED13).

Uchil, P., & Chakrabarti, A. (2015). An interface between Life Cycle Assessment and Design, Proceedings of the 5th International Conference on Research into Design (ICoRD15)

Norris, G. A., & Yost, P. (2001). A Transparent, Interactive Software Environment for Communicating Life-Cycle Assessment Results: An Application to Residential Windows. *Journal of Industrial Ecology*, *5*(4), 15-28.

Baumann, H., Berlin, J., Brunklaus, B., Lindkvist, M., Löfgren, B., & Tillman, A. M. (2011). The usefulness of an actor's perspective in LCA. In *Towards Life Cycle Sustainability Management* (pp. 73-83). Springer Netherlands.

Weidema, Bo Pedersen. "Increasing credibility of LCA." *The International Journal of Life Cycle Assessment* 5.2 (2000): 63-64.

International Organization for Standardization. (2002). ISO 14043: Environmental management -- Life cycle assessment – Life cyle Interpretation.

Baumann, H., & Tillman, A. M. (2004) *"The Hitch Hiker's Guide to LCA: An orientation in life cycle assessment methodology and application.* Studentlitteratur

Nielsen, J. (1994). *Usability engineering*. Elsevier.

Norman, Donald A. The design of everyday things. Basic books, 2002.

Shneiderman, B., & Ben, S. (2003). *Designing the user interface*. Pearson Education India.

Zuk, T., Schlesier, L., Neumann, P., Hancock, M. S., & Carpendale, S. (2006, May). Heuristics for information visualization evaluation. In *Proceedings of the 2006 AVI workshop on Beyond time and errors: novel evaluation methods for information visualization* (pp. 1-6). ACM.

Saraiya, P., North, C., & Duca, K. (2005). An insight-based methodology for evaluating bioinformatics visualizations. *Visualization and Computer Graphics, IEEE Transactions on*, *11*(4), 443-456.

Shneiderman, Ben, and Catherine Plaisant. "Strategies for evaluating information visualization tools: multi-dimensional in-depth long-term case studies." *Proceedings of the 2006 AVI workshop on Beyond time and errors: novel evaluation methods for information visualization*. ACM, 2006.

Huang, Weidong, Peter Eades, and Seok-Hee Hong. "Measuring effectiveness of graph visualizations: A cognitive load perspective." *Information Visualization* 8.3 (2009): 139-152.

Jacob, Robert JK, and Keith S. Karn. "Eye tracking in human-computer interaction and usability research: Ready to deliver the promises." *Mind* 2.3: 4.

Zhu, Y. (2007). Measuring effective data visualization. In *Advances in Visual Computing* (pp. 652-661). Springer Berlin Heidelberg.

Segel, E., & Heer, J. (2010). Narrative visualization: Telling stories with data. *IEEE Transactions on Visualization and Computer Graphics*, 16(6), 1139-1148