QUANTIFYING ENVIRONMENTAL LIFE CYCLE IMPACTS FOR ICT PRODUCTS – A SIMPLER APPROACH

Thomas A. Okrasinski, P.E., P.P.
Nokia Bell Labs
NJ, USA
tom.okrasinski@nokia-bell-labs.com

Marc S. Benowitz, Ph.D.
iNEMI
NC, USA
marc.benowitz@inemi.org

ABSTRACT
In this paper we describe a simplified approach for estimating the environmental impact of Information and Communications Technology (ICT) products. The approach provides a means to more quickly and easily evaluate product concepts and optimize design trade-offs. It uses simplified techniques and algorithms for estimating Global Warming Potential in terms of carbon dioxide equivalents. We will also share the development of the environmental impact estimator, including its applicability, validation, along with current and proposed activities to further advance its capabilities for more general use.

Key words: Environmental impact, life cycle assessment, LCA, information and communication technologies, ICT, electronics environmental impact measurement, global warming potential, LCA estimator

INTRODUCTION

ICT products are key to modern society, and like most any other "physical" entity, contribute to negative environmental impacts due to their manufacturing, use, and disposal. Their inherently short life and increasing demand worldwide will further increase this impact. With today's climate change challenges, it is incumbent on us, as electronics developers and manufacturers, to take action to reduce the impact.

A key step to reduce impact is to be able to measure the impact. Life Cycle Assessment (LCA) is the well-recognized methodology to assess environmental impacts through a product's life, from raw material extraction to end of life. Performing an LCA for a complex product, such as ICT products, is usually done using large scale LCA software with expert resources. This is both expensive and time consuming, which then becomes a barrier to adoption. In fact, in many cases large scale LCA is not necessary, and a simpler approach, directly in the hands of the stakeholders, will further enable adoption and environmental impact reduction action.

Presented in this paper is a simplified approach for estimating the environmental impact of ICT products. The approach provides a means to more quickly and easily evaluate product concepts and optimize design trade-offs. It uses simplified techniques and algorithms for estimating Global Warming Potential (GWP) in terms of carbon dioxide equivalents. The approach is extensible to other environmental impact parameters as well.

OBJECTIVE

In support of existing LCA methodologies[i] and standards[ii], there are several life cycle impact assessment (LCIA) systems, databases and tools available. They offer varying aspects of information and capability; global / regional data, industry processes, materials and flows, and mechanisms for quantifying product environmental impacts. The simplified approach to quantifying the life cycle environmental impacts presented here is based on the methodology that was developed by Bell Labs[iii] and further developed by the International Electronics Manufacturing Initiative (iNEMI)[iv]. It more easily estimates the eco-impact for different types of ICT products, with sufficient accuracy to meet the LCA practitioner's needs in assessing the important environmental impacts of a product over its life cycle stages. Specifically, the objective is that the simplified approach should be within 15% of the result obtained from more in-depth methods for over 90% of the assemblies investigated[v]. Another objective included in the iNEMI activities, is to develop mechanisms for prioritizing and collecting relevant, and current, data from the supply chain. With the rapid technological advancements within the ICT industry this is critical to ensure the estimator being useful to the LCA practitioner.

METHODOLOGY FRAMEWORK

The estimator is designed to be capable of evaluating a product consisting of individual equipment pieces. The product unit is attributed to a functional unit as defined by the product manufacturer. ICT products can be classified into distinct categories with common attributes that produce certain levels of environmental impact regarding their component makeup, assembly, usage, and design life. These classifications were then sorted into component categories comprised of similar materials and manufacturing processes. The components were then analyzed regarding their respective contributions to the environmental impacts associated with raw materials extraction and processing, intermediate materials manufacturing, and component / subassembly manufacturing. The intent of categorizing these ICT components was to have a concise list that can be analyzed for common environmental impacting attributes, which can then be rationalized and modeled to derive their level of impact within an LCA estimator tool. A list of the major component / subassembly categories that was defined for ICT products is shown in Table 1.

Global Warming Potential (GWP) – 100 years' time horizon is the single environmental impact currently assessed in the estimator, which is due to it being one of the most commonly evaluated environmental impact mid-point indicators.

Table 1. Examples of component / subassembly categories for the LCA estimator

General Component Groups
Printed Wiring Boards
Integrated Circuits (including semiconductor devices)
Electro–Mechanical Components (fans, motors, etc.)
Metals / Metallic Mechanical Components (as found in cabinets, frames, structural parts, heat sinks, etc.)
Polymeric Mechanical Components (plastic parts)
Displays (electronic display devices)
Power Supplies
Large Capacitors
Batteries
Cables (signal, RF, power cords, wires, optical fiber)
Specialized Component Groups
Optical / Opto-electronic Devices (laser amplifiers, etc.)
Radio Frequency Components (power amplifiers, antennas, waveguides, etc.)
Disk Drives

The key parameters and metrics for assessing the environmental impact of the component categories summarized in Table 1 can represent the significant environmental impact contributors based on the analyzed datasets, available from within the ICT industry (e.g., integrated circuits) and from other industry sectors (e.g., bulk metals and plastics). An associated algorithm can be determined based on the LCIA data available for the key parameters of a given component category[iii].

Detailed LCA analyses conducted on ICT products have shown that the component types providing the greatest contribution of environmental impact are the bare printed wiring boards (PWBs) and the large integrated circuits (large ICs). Figure 1 shows the breakdown of the manufacturing stage CO_2 emissions for a network telecommunications product[vi].

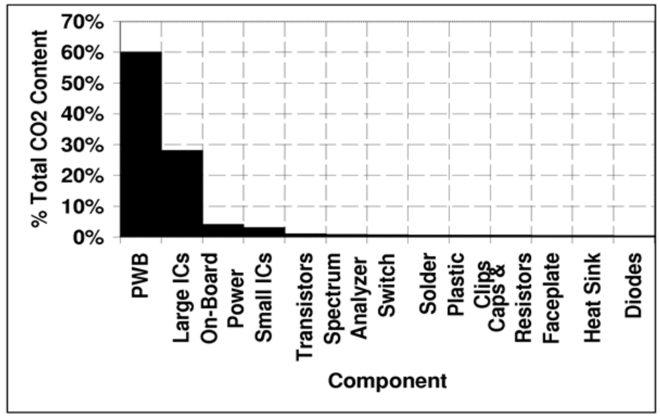

Figure 1. Manufacturing stage CO_2 emissions breakdown for a network telecommunications product

There is a linear functional dependence between the carbon content per unit area of a PWB and its number of layers – see Figure 2. Similarly, for the large ICs, the carbon content has a functional relationship with the number of I/Os.

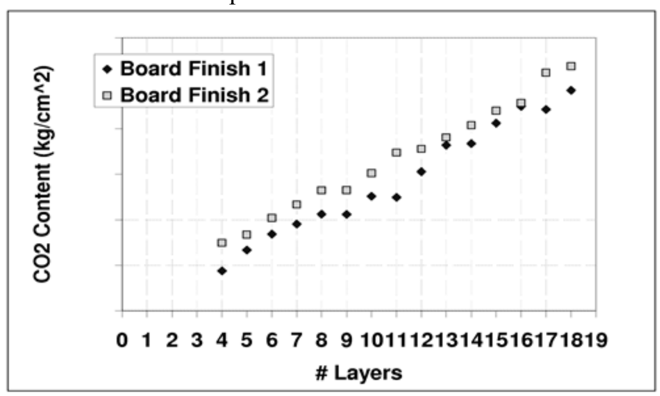

Figure 2. CO_2 per unit area for printed wiring boards with increasing layers and two types of surface finishes

Modeling the LCA stages

For the manufacturing stage the LCA environmental impacts reflect the total of the ICT components' manufacturing, transport of components and intermediate materials to final product manufacturing locations, product assembly & testing, and product packaging. Assembly and testing include processes such as surface mounting technology, thru-hole mounting technology, mounting of ICT assets, surface treatment (e.g., painting or plating) for pre-manufactured cabinets, and testing of the ICT product. These parameters were treated as a collective summation of the total assembly and testing processes, and defined as an overall factor applied to the total impact of the product for the manufacturing LCA stage[vii].

The transport stage includes assessing environmental impact of the logistics – transport, distribution and installation of ICT products / assets. Parameters for this stage include location of final assembly (by region), location of product integration / warehousing (by region), location of final product installation (by region), transport mode (e.g. truck, rail, marine, air), and their associated environmental impact factors.

Use stage includes assessing environmental impact of the product's usage by parameters covering location of product usage (by region or country), power consumption per typical configuration and feature set, utilization rate per annum, and product operating life.

The end-of-life stage for ICT products are modeled by parameters that include the product's constituent materials (derived from the components input for the manufacturing stage), and the final disposition of the product (e.g. remanufacturing, refurbishing, recycling, incineration / energy recovery, landfill).

LCA ESTIMATOR AVAILABILITY AND IMPROVEMENT

The initial iNEMI environmental impact LCA estimator was developed using a spreadsheet format and made available to iNEMI members starting in 2012. Some industry members further developed the estimator and transferred it to a database format (e.g. Nokia). This provided easier modularization of its component categories, a means to graphically view and configure a product's hierarchy, and easy storage / retrieval of configured products and subassemblies for further usage in other product configurations or by other designers – see Figure 3.

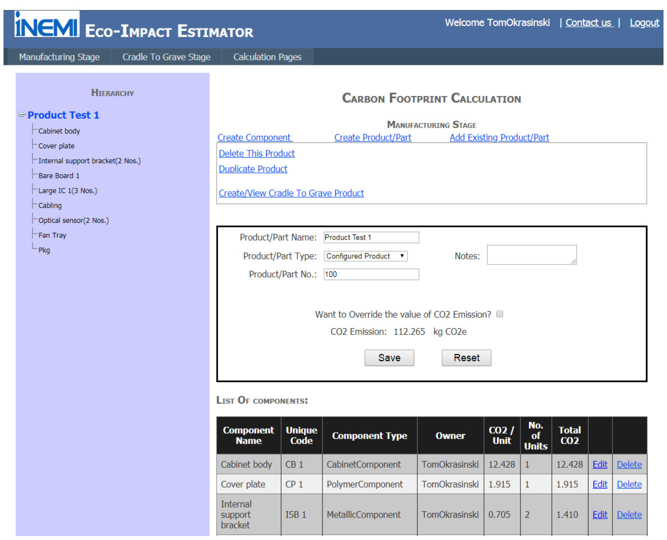

Figure 3. Example - LCA estimator incorporating product / subassembly / component hierarchy

In 2019, in Phase 3 of iNEMI's Eco-Impact Estimator project the LCA estimator has been transferred to a web-based database format by Purdue University, and available to iNEMI project participants. This regime also provided data security and backup features. iNEMI's intention is to eventually make this openly available to the industry and research institutions, thus offering a common simplified LCA estimator approach with data transparency. This should promote enhanced adoption and feedback, which will further estimator methodology, component category and environmental impact dataset improvements.

The iNEMI Phase 3 Eco-Impact Estimator Project is also improving the algorithms, datasets and methods for estimating environmental impact in areas including:

- printed wiring boards (bare) – including conventional and HDI type boards (Figure 4)[viii]
- integrated circuits - including flip chips, SOCs, 2.5D / 3D stacked die arrays
- power supplies, cable assemblies, fan trays, passive components, mechanical subassemblies (e.g. housings, cabinets, chassis)

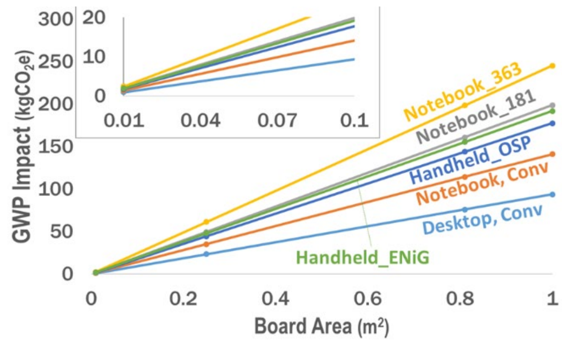

Figure 4. GWP Impact of PWBs as a function of board area for several representative designs

SUMMARY

The LCA environmental impact estimator offers a means for product designers and environmental specialists to more easily assess the greenhouse gas emissions of ICT products over their full life cycle – manufacturing, transport, use, and end-of-life treatment. It is vital that the ICT industry collaborates on developing and collecting additional LCIA data and information for the different life cycle stages that are representative of ICT products. In iNEMI's experience, as well as in LCA studies by others, the "Use" and "Manufacturing" stages of ICT products typically contribute the dominant amount of environmental impact. Consequently, industry emphasis should be concentrated on providing more refined data and information for these two stages.

LCIA data improvement within the ICT industry needs to parallel the technological advances that are rapidly evolving within this industry. Collaboration amongst industry and academic/research institutions is critical. iNEMI has begun a series of improvements to the estimator's methodology and in its component categories and environmental impact datasets. Future endeavors being considered include opening the web based Eco-Impact Estimator to users outside of iNEMI to further ICT industry utilization, as well as continued usability enhancements and dataset updates.

REFERENCES

[1] Greenhouse Gas Protocol. "Guidance Built on the Greenhouse Gas Protocol - ICT Sector Guidance". July 2017. Online: https://ghgprotocol.org/guidance-built-ghg-protocol

[1] International Standards Organization. "Environmental Management -- Life Cycle Assessment -- Principles and Framework". *ISO*

14040:2006. "Environmental Management -- Life Cycle Assessment -- Requirements and Guidelines". *ISO 14044:2006.*

[1] T. Joyce, T. Okrasinski, W. Schaeffer; "Estimating the carbon footprint of telecommunications products: a heuristic approach". ASME Journal of Mechanical Design – Special Issue on Sustainable Design, September 2010.

[1] Thomas Okrasinski, John Malian; "A Framework for Estimating Life Cycle Eco-Impact for Information and Communications Technology Products". *CARE Innovation 2010*, Proceedings, November 2010.

[1] J. Malian, J.P. Loose and G. Nomi, "Life Cycle Assessment Challenges in the Electronics Industry". *CARE Innovation 2010*, Proceedings, November 2010.

[1] Thomas Okrasinski, PE; John Malian; James Arnold, Ph.D.; "Data Assessment and Collection for a Simplified LCA Tool". Carbon Management Technology Conference, CMTC151108-PP; Orlando, Florida, USA, February 2012.

[1] Thomas A. Okrasinski, Frederick M. Blechinger, Bryan K. Stolte, and David A. Dickinson, "Assessing Circuit Pack Design and Assembly for Environmental Performance and Sustainability", *APEX Conference – IPC*, Proceedings, April 2003.

[1] Maria Lourdes Alcaraz Ochoa, Haoyang He, Julie M. Schoenung, Erkko Helminen, Tom Okrasinski, Bill Schaeffer, Brian Smith, John Davignon, Larry Marcanti, Elsa A. Olivetti. "Design parameters and environmental impact of printed wiring board manufacture". Journal of Cleaner Production, Volume 238, 20 November 2019. Online: https://doi.org/10.1016/j.jclepro.2019.117807