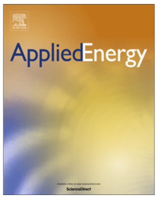
Applied Energy 136 (2014) 636–648

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy



# Carbon footprinting of electronic products

Arvind Vasan *, Bhanu Sood, Michael Pecht

*Center for Advanced Life Cycle Engineering (CALCE), University of Maryland, College Park, MD 20742, USA*

## HIGHLIGHTS

- Challenges in adopting existing CF standards for electronic products are discussed.
- Carbon footprint of electronic products is underestimated using existing standards.
- Multipronged approach is presented to overcome the identified challenges.
- Multipronged approach demonstrated on commercial and military grade DC–DC converter system.

## ARTICLE INFO

*Article history:*
Received 2 May 2014
Received in revised form 11 September 2014
Accepted 22 September 2014

*Keywords:*
Carbon footprinting of electronic products
DC–DC converter
Product-group standardization
Supply chain integration
Hybrid life cycle assessment

## ABSTRACT

In order to mitigate the effects of global warming, companies are being compelled by governments, investors, and customers to control their greenhouse gas (GHG) emissions. Similar to the European Union's legislation on the airline industry, legislation is expected to require the electronics industry to assess their product's carbon footprint before sale or use, as the electronics industry's contribution to global GHG emissions is comparable to the airline industry's contribution. Thus, it is necessary for members of the electronics industry to assess their current GHG emission rates and identify methods to reduce environmental impacts. Organizations use Carbon Footprint (CF) analysis methods to identify and quantify the GHG emissions associated with the life cycle stages of their product or services. This paper discusses the prevailing methods used by organizations to estimate the CF of their electronics products and identifies the challenges faced by the electronics industry when adopting these methods in an environment of decreasing product development cycles with complex and diffuse supply chains. We find that, as a result of the inconsistencies arising from the system boundary selection methods and databases, the use of outdated LCA approaches, and the lack of supplier's emissions-related data, the CFs of electronic products are typically underestimated. To address these challenges, we present a comprehensive approach to the carbon footprinting of electronic products that involves the use of product-group-oriented standards, hybrid life cycle assessment techniques, and the integration of CF into products' supply chains. A case study on commercial- and military-grade DC–DC buck converters demonstrating the recommended approach is presented.

© 2014 Elsevier Ltd. All rights reserved.

## 1. Introduction

Changes in climatic conditions have increased the concern about global warming among government organizations [1]. This concern has intensified due to the rapid growth in greenhouse gas (GHG) emissions since 2000 [2,3]. As a result, governments, investors, and customers are requiring companies to control their GHG emissions. For example, the US Environmental Protection Agency (EPA) issued the Mandatory Reporting of Greenhouse Gases Rule (74 FR 56260) in 2009, which requires facilities that emit 25,000 metric tons or more per year of GHGs to report their emissions data via annual reports to EPA [4]. The Carbon Disclosure Project's (CDP) Carbon Action program is an investor-driven initiative wherein 254 investors having control of $19 trillion worth of assets have called for the world's highest GHG emitting companies to publicly disclose their GHG data and their respective approaches to reducing their GHG emissions [5]. The United Kingdom has begun the Feed-in-Tariffs (FiTs) program to stimulate the use of renewable sources of energy (via photovoltaic and micro-wind technologies) among businesses in order to reduce dependence on non-renewable means of energy from 98% in 2009 to 85% in 2020 [6].

Electronics manufacturers are already required by the Waste from Electrical and Electronic Equipment (WEEE) Directive [7] to

---

* Corresponding author. Tel.: +1 301 405 5324.
*E-mail addresses:* arvind@calce.umd.edu (A. Vasan), bpsood@calce.umd.edu (B. Sood), pecht@calce.umd.edu (M. Pecht).

http://dx.doi.org/10.1016/j.apenergy.2014.09.074
0306-2619/© 2014 Elsevier Ltd. All rights reserved.

reduce their disposal waste of electronic products by reuse, recycling, and other forms of recovery. As a supplement to WEEE, the Restriction of the Use of Certain Hazardous Substances (RoHS) legislation further restricts electronic manufacturers from using materials that could negatively impact health (such as lead, cadmium, hexavalent chromium, PBBs, and PBDEs) [8]. In addition to these requirements, the electronics industry will also have to deal with additional directives associated with GHG emissions [4], because electronic components are classified as very high GHG emission-intensive materials (>5 kg $CO_2$e/kg [9]).

As of 2013, electronic manufacturers have only been subjected to taxes levied on the carbon content of the fuels used to support the activities under the control of an organization [10]. However, regulations on GHG emissions mandated by the European Union (EU) on the airline industry foreshadow GHG emission taxes for the electronics industry [11]. This is because the contribution by the electronic industry to global GHG emissions (2%) is comparable to the airline industry's contribution, which is estimated to be between 2% and 4%. Additionally, under the US EPA's "Mandatory Reporting of Greenhouse Gases" rule [4], many electricity generators and electronics and electrical product manufacturers are required to report direct GHG emissions from their facilities. The purpose of the rule is to collect accurate and timely GHG data to inform future policy decisions.

Furthermore, with the growth of electric vehicles (EVs) estimated to be 6% and 39% for hybrid EVs and plug-in EVs, respectively, between 2012 and 2020 [12], new legislation is expected for emissions resulting from processes related to the manufacturing of EVs [13,14]. Talks concerning carbon taxes on mining activities have also started in various countries, including Australia, India, and South Africa [15], indicating that electronic manufacturers may have to pay taxes for the processes involved in the extraction of raw materials. Thus, it is becoming time for members of the electronics industry to identify drivers of GHG emissions in their product or process life cycles and take measures to reduce emissions.

Carbon footprinting is the method used to quantify GHG emissions and identify emission drivers in a product or process life cycle [16,17]. This paper shows the need for CF in the electronics industry by discussing the effects of existing and possible future government legislation. We then review different methods used to calculate the CF of a product. Next, we identify the challenges that the electronics industry faces in adopting existing CF practices. Finally, we provide a comprehensive approach to address the challenges with existing CF methods in order to enable electronics manufacturers to adopt a more reliable carbon footprinting method.

## 2. The need for carbon footprinting in the electronics industry

The carbon footprinting method is used to quantify the life cycle GHG emissions caused directly or indirectly by a person, product, event, or organization. Peters [18] states that the "Carbon Footprint (CF) of a functional unit is the climate impact under a specified metric that considers all relevant emission sources, sinks, and storage in both consumption and production within the specified spatial and temporal boundary." The CF of a product is typically expressed in terms of carbon dioxide ($CO_2$) equivalent, and is calculated using the global warming potential (GWP) of a GHG. GWP, as defined in the Publicly Available Specifications (PAS) 2050, is the radiative forcing impact of one mass-based unit of a given GHG relative to an equivalent unit of $CO_2$ over a given time period [9]. For example, the GWP of methane ($CH_4$), a GHG, is 23 [19].

Life cycle in the context of CF is defined as the consecutive and interlinked stages of a product's development, from raw material extraction, manufacturing, distribution, and use up through final disposal. Typically, there are two boundary scenarios for a life cycle (Fig. 1): cradle-to-grave or cradle-to-gate [20]. In a cradle-to-grave scenario, GHG emissions are captured in all stages of the life cycle, from the extraction of raw materials for manufacturing until product disposal or recycling. In a cradle-to-gate scenario, the GHG emissions are only considered from raw material extraction up to the point at which the finished product leaves the organization. In most cases, organizations choose the cradle-to-gate scenario for CF analysis, as the stages involved are mostly under the control of the organization. However, the cradle-to-gate scenario significantly underestimates the total CF of a product when compared to the cradle-to-grave scenario, as it neglects the GHG emissions resulting from indirect energy (e.g., the electricity or cooling method purchased to support manufacturing facilities) consumed during the use phase of the product.

Fig. 1 shows the cradle-to-gate and cradle-to-grave scenarios for a mobile phone. Similar life cycle stages can be drawn for other electronic products. The components in a mobile phone include the plastic casing, liquid crystal display (LCD), microphone/speaker, printed circuit boards with the associated digital and analog components, antenna, battery, and adapter. In order to manufacture these components, a variety of minerals have to be mined and processed. For example, the PCB contains copper traces, gold wire bonds within the ICs, tin in the solder interconnects, silicon substrates within the IC packages, chromium and nickel in the surface finish, fiberglass, and plastic resins within the PCBs. The LCD might contain substances such as mercury. All the mining and material processing steps contribute to the emission of GHG gasses. Even though the extraction or recycling of raw materials and material processing steps might not fall directly within the control of a cell phone manufacturer (that is, they might fall within the control of a component or assembly supplier), it is generally considered the responsibility of the original equipment manufacturer (OEM) to identify emissions resulting from materials extraction and processing activities, and include them in the CF analysis of their product [21].

Once materials are extracted and processed, the next steps in the life cycle of a mobile phone are the manufacturing of the circuit boards and assembly processes, wherein the electronic components are placed onto the PCB, interconnects are soldered, and the PCB is coated with a protective surface finish. The manufacturing and assembly processes are carried out using machines that consume electricity, the production of which contributes to global warming. Since manufacturing and assembly are within the control of the OEM, it is easier for mobile phone manufacturers to perform a cradle-to-gate CF analysis. However, cell phone parts and their finished products need packaging and transportation to get them to customers. Transportation contributes to GHG emissions through the consumption of nonrenewable sources of energy (e.g., petrol and diesel). Furthermore, the materials used in packaging, such as paper, plastic, and aluminum, all require energy for production and can result in waste. In addition to packaging and transportation, the electricity consumed in charging a cell phone over its useful lifetime is also generated by consuming natural resources and transmitted through electric grids that contribute to global warming. If we consider OEMs such as Samsung and Apple that sell millions of smart phones each year, and calculate the electricity consumed by these millions of devices over their useful lifetimes, the resulting amount of GHG emissions during the product use phase cannot be neglected. Thus, the cradle-to-gate life cycle approach lacks the completeness in GHG emission estimation found in the cradle-to-grave scenario, especially for electronic products where significant GHG emissions continue to take place after the product has left the OEM [22].

Download English Version:

https://daneshyari.com/en/article/6688864

Download Persian Version:

https://daneshyari.com/article/6688864

Daneshyari.com