Uncertainty and Variability in Carbon Footprinting for Electronics

Case Study of an IBM Rack-mount Server

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Executive Summary

Introduction

Recent years have seen increasing interest in life-cycle greenhouse gas emissions accounting, aka carbon footprinting. There are several drivers for this increased interest, such as life cycle emissions accounting for transportation fuels policy and an increasing interest in climate-related eco-labels. These “carbon labels” have been studied or implemented in the UK, Japan, and California and among large retailers such as Wal-mart and Tesco.

The use of carbon footprinting in both policy and labeling has assumed that the techniques of of carbon footprinting are capable of producing precise point estimates or at least estimates with small enough uncertainties to allow comparative assessment. However, it remains to be proven whether this level of precision is possible given large but poorly understood limitations in both methodology and data. Increasing attention has been paid to uncertainty and variability in the results of product carbon footprint (PCF) studies, and recent reviews have shown that where quantitative uncertainty analysis has been performed the results have not been encouraging.

Given the growing importance of carbon footprinting in policy and corporate disclosures, more effort is clearly needed to understand how large uncertainty may be in PCF results. Thus, the goal and scope of this work is to further the understanding of quantitative uncertainty assessment in carbon footprinting through a case study of a complex product system, namely an IBM rack-mount electronic server circa 2008. Electronics make an interesting case study for uncertainty in carbon footprinting because nearly all uncertainty types are potentially important, including parameter uncertainty, geographical and temporal variability, and technological change.

Data were gathered from independent life cycle assessment databases and primary literature and then combined in a Monte Carlo simulation to estimate uncertainty and variability ranges. The PAS 2050 specification for carbon footprint of products was followed to ensure the case study accurately reflected the current science of carbon footprinting. More details on data and methods are available in a detailed report under peer review for scholarly publication.

Results

Figure 1 shows the base results for the production and delivery phase (“Production”, left axis) and the use phase (“use”, right axis) of the server. Uncertainty ranges from around $\pm$15% for the production and delivery phase to around $\pm$35% for cradle to grave carbon footprint, including the product’s use phase and logistics associated with delivery of products. However, given limitations in available data to access uncertainty associated with temporal variability and technological specificity, it is likely that true uncertainty is much larger. Given the relatively long lifetime and continuous use of servers, the use phase was dominant, representing around 94% (88%-97% with uncertainty) of the server's total product carbon footprint.

Within the production phase, relatively few components contributed to a majority of the total uncertainty. Integrated circuits were particularly important, as more plentiful and newer data allowed quantification of the technological and temporal changes that were evident but unquantifiable in other components. Delivery of the server via air transport was also important and varied considerably between different final assembly sites and delivery locations.

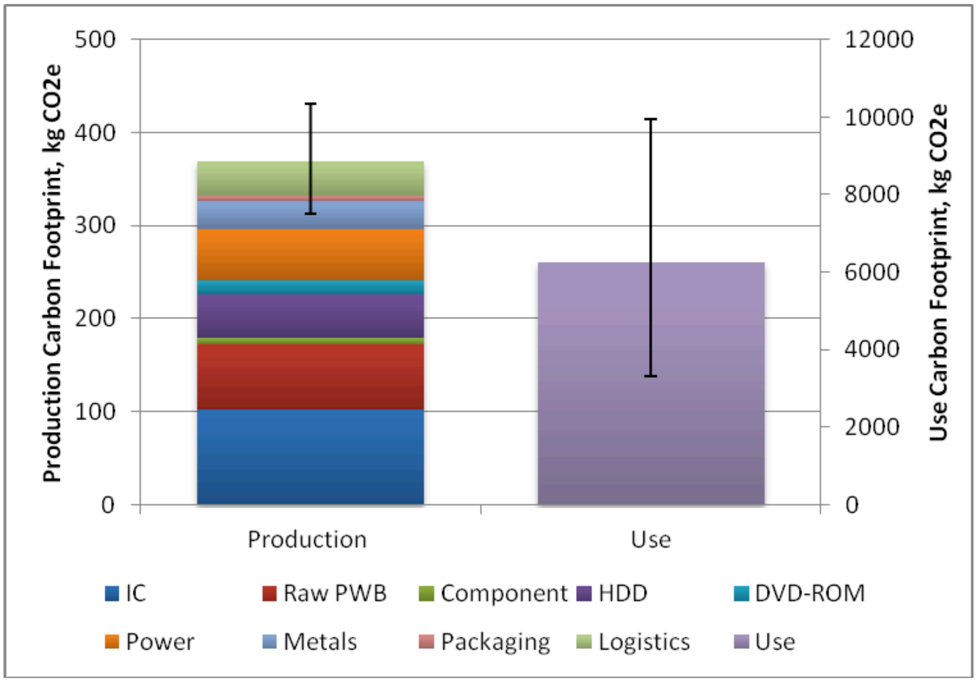

Figure 1: Product Carbon Footprint of IBM Server by Component and Phase. The production phase is presented on the left axis, use phase on the right axis.

However, uncertainty in the production phase was considerably smaller than the deep uncertainties in predicting the use phase. Unlike the production phase, where supply chains can be analyzed, the use phase is inherently predictive. It is thus impossible to know with certainty how and for how long a product will be used. On top of this, variability in the electricity mixes of different markets lead to vastly different impacts of using the product similarly in different places. Figure 2 shows total product footprint uncertainty distributions for each of four markets and the weighted (by sales) average footprint. The product footprint is higher or lower based on the market and depending upon what type of electricity (fossil fuel, hydroelectric, nuclear, etc) is prevalent in each region. Uncertainty in the use phase—product lifetime, electricity mix, and use profile—dominated the overall footprint uncertainty much as the use phase dominates the overall footprint.

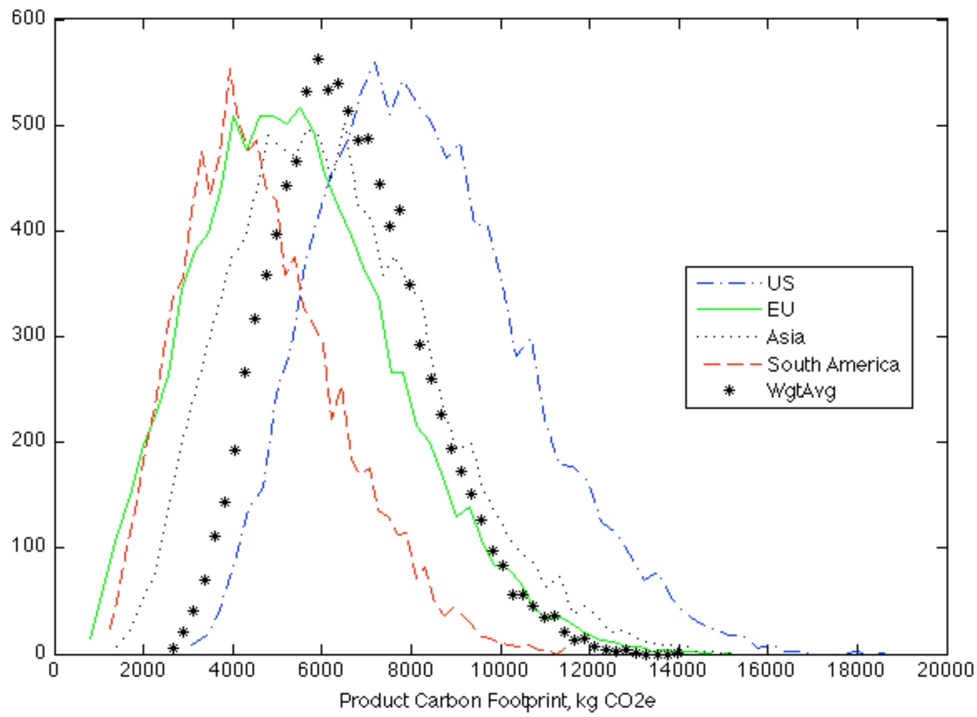

Figure 2: Product Carbon Footprint Uncertainty Distribution by Sales Region and Weighted Average Region

Implications for Carbon Footprinting

The goal of this study was to quantify likely uncertainty and variability ranges in the PCF of a representative electronics product, a rack-mount server. Overall, uncertainty in the production phase of the server was found to be moderate, though still significant. The 95th percentile interval showed a confidence of around $\underline{+}15\%$ from the mean of the distribution. Individual components within the server, particularly integrated circuit, showed a much higher uncertainty ($\underline{+}40\%$) . Again it should be noted, however, that these estimated uncertainties are a function of data availability, and often only two data sets were available, both relatively old. Thus this analysis likely underestimates the total production-phase uncertainty, perhaps considerably. Nonetheless, even with this likely underestimate of uncertainty, $\underline{+}15\%$ is not an ignorable amount for a method that is already being used to set policy and make comparative environmental product declarations.

For the delivery phase ($\underline{+}25\%$) and use phase ($\underline{+}50\%$) the problem is clearly much worse, and this does not bode well for carbon labeling of energy-using products. The logistics phase uncertainty may be manageable through simple averaging, but there are clear differences (particularly when air transport is involved) between different production locations and markets. Using a weighted average may be very misleading for purchasers particularly close to or far from assembly locations. The use phase in turn is not only geographically varying, but also an inherently prospective, scenario-based calculation with deep uncertainties dependent upon how a product's use phase compares to designed lifetime and use profile. Further, because the use phase dominates the life cycle of this product, this scenario uncertainty was dominant and is likely to be so for many energy-using products. When one considers that the exact same product sold in different markets has a ±50% variability in PCF due to electricity mix alone, it becomes clear that simple weighted averages are inappropriate to communicate the variation in use phase emissions to customers.

At least some of the effort currently being spent on quantifying and decreasing uncertainty in production-phase footprints may be misplaced when **energy efficiency in the use phase is the product attribute most likely to lower the product's carbon footprint**. Redirecting this effort toward informing consumers about energy efficiency and use phase footprint is likely to have a much larger effect than large data gathering efforts for the production phase.

The delivery and use phase impacts of a product have very different types of uncertainty than the production phase—predominantly geographical variability and scenario uncertainty rather than parameter uncertainty. Thus the production phase and delivery/use phases should be treated differently in environmental product declarations. A single number (with uncertainty bounds) may be useful for a production-based PCF, but where delivery and use (and energy use at end of life, which was minor in this case due to recycling credits taken from the production phase but is important in carbon storing products) are likely to be important, scenarios specific to customer location and likely usage would be preferable to a single weighted average number. An even better solution would be to develop communications linking the carbon footprint of a product to how a consumer uses it, thus producing incentives for efficiency.

In both the production and use phases, the importance of electricity mix was found to be vitally important, something that LCA practitioners have known for years but has not yet been standardized. Standards writers should specifically dictate when to use regional, country, or multinational electricity mixes in future PCF standards. Unless consistency is achieved through standardization, the ambiguity and uncertainty associated with electricity emissions will remain and will act to reduce the confidence of consumers of LCA and PCF information.

Finally, it should be remembered that this case study is not indicative of all studies of uncertainty in PCFs. Many more detailed case studies like this one are needed to properly understand the underlying structure of uncertainty and variability in carbon footprinting. Future work should continue to combine the increasing volume of available data to determine appropriate uncertainty ranges, identify where large potential reductions occur, and maximize the credibility of the methods of LCA and carbon footprinting.