FAST PRODUCT FOOTPRINTING AND CARBON MANAGEMENT FOR LARGE COMPANIES

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Abstract

PAS2050 and the forthcoming WRI and ISO14067 standards have helped to propel carbon footprinting from an LCA sub-discipline to the mainstream. However, applying these standards to portfolios of many products/services is immensely time consuming. Even if achieved, such footprinting often fails to inform company-wide carbon reduction strategies because footprint data is disjointed and does not cover the whole portfolio. Here, we describe a novel, must faster approach to generate standard-compliant product footprints. Three techniques enable footprinting thousands of products virtuously simultaneously: (1) concurrent uncertainty analysis guides practitioners towards those data that materially impact the results; (2) gradually evolving lookup tables for all inventory data maximize the use of inputs from other products or users; and (3) a statistical model estimates emission factors, thereby eliminating the time consuming manual mapping of a product/service's inventory to the vast selection of EF databases. With a case study covering ~1500 products across 3 continents from a leading packaged consumer goods company, we demonstrate how the approach enables footprinting individual products or entire portfolios, at a fraction of previously required expertise and employee hours. We discuss implementation roadmaps for companies as well as possible future improvements of the approach.

Introduction

While Life Cycle Analysis (LCA) has continuously evolved, prompting both often re-cited criticism [1, 2] and improvement [3-5], the new need for accurate and comparable carbon fooptrints (CFs) has catalyzed efforts to overcome many of LCA's traditional shortcomings and provided standards for CF [6, 7]. Today, companies embarking on CF benefit from detailed protocols, industry/sector specific guidance, software packages, and databases to provide support with (i) choice of functional unit, e.g. [8]; (ii) system boundaries [9]; (iii) emission factors (EFs) of materials and activities, e.g. [10]; and (iv) specialty issues such as recycling and biogenic carbon and storage [9]. Crucially, guidelines also provide a more head-on approach to materiality and realistically achievable levels of accuracy. For example, the rounding rules of the UK Carbon Trust imply that even a best-practice CFs will have a residual uncertainty of 5-10% (section 2.4 of [11]).

While the above developments represent tremendous progress and improvements over the status quo even just a few years ago, quantifying the CFs for hundreds or thousands of individual products/services is currently impossible, short of a massive buildup of a company's dedicated personnel and LCA expertise. Specifically, practitioners today face two fundamental obstacles when performing CF at the scale of large companies:

Required time and expertise: Collecting, organizing, and validating LCA inventory (easily one hundred or more individual data items for a single product/service), as well as mapping to EFs, typically takes hundreds of staff hours and specialized knowledge [12].

Lack of uniformity and integrated platform: Based on our experience, CF today is usually performed as a series of one-off efforts, e.g., using non-interlinked, separate spreadsheets or similar software for the CF of each new product/service. Once the practitioner has completed data entry and calculation for one product, to the desired accuracy, the practitioner moves on to the next product, often without maximizing the re-use of previously collected information [13].

These obstacles result in three missed opportunities that currently prevent CF from realizing its full spectrum of possible benefits:

What-if impacts across products, carbon management, and cost-benefit evaluations: Arguably, one of the greatest opportunities of CF is to enable a company to identify and prioritize GHG reduction strategies. For example, counting all impacts on raw materials, transportation, and disposal, what would be the total company-wide GHG reductions if all PET packaging were made 15% lighter? What if all factories in a country moved 30% of their primary energy consumption to hydropower-rich electricity? Given an assumed carbon price, would the costs for required upgrades (e.g., modified energy mix and packaging) be a worthwhile investment? Such analysis are near impossible if hundreds of CF files have to be updated manually.

Flexibility vis-a-vis regulatory change: Standards for CF are still evolving [7]. With current practice, future changes in the CF "accounting rules" would mean tremendous time and resource effort on behalf companies, to fix the manual CF calculations for hundreds of products/services. This poses significant "regulatory" risk.

Synergy with corporate carbon accounting ("corporate footprint"): There is a direct relationship between the various LCA stages that count toward a product/service CF and those that count towards a corporate footprint. Therefore, there are significant synergies between the data collection and analyses for product/service CFs and the scopes 1, 2, and 3 of corporate footprints [14]. Current CF practice often lacks the coverage, uniformity, or transparency that would enable the company to make use of such synergies.

In introducing fast carbon footprinting, we contend that underlying concepts and methodological details of CF have evolved far enough [7] to warrant broadening the research focus towards more practical, "mass-produced" footprinting. The present work summarizes previously introduced [15-17] basic frameworks, data organization, and statistical techniques of a faster, more robust, and more uniform approach that enables above benefits, particularly for large companies with many products or services (see Methods). Here, with a case study covering 1559 products across 3 continents from a leading packaged consumer goods company, we illustrate how the approach enables footprinting individual products or entire portfolios, at a fraction of previously required expertise and employee hours. We validate the results against existing manually obtained CFs and discuss implementation roadmaps for companies as well as possible future improvements of the approach.

While shown here for CF specifically, the methods introduced here lay out general organizational techniques of managing and calculating LCA inventory and are thus applicable to other LCA impacts (e.g., water, toxicity, biodiversity, social).

Methods

Statistical techniques, data sources, and software used to develop the fast carbon footprinting methodology have been described previously [15-17]. Briefly, CFs were calculated, following PAS2050, using Microsoft Excel, SimaPro (v7.1) , Gabi (v4.3), or customized prototype software. EFs were used from Ecoinvent (v2.0 & v2.01), Franklin USA, and OpenIO. The fast CF data structure was developed based on experience from manually footprinting 20 products of PepsiCo, Inc. (7 of which were certified by the Carbon Trust) and optimized for an automated data feed of bill of materials (BOM) data from 1137 individual packaged food and beverage products (and an additional 422 products (all carbonated softdrinks) were available with name, brand, net weight, volume only). The total sample product universe was 1559 SKUs, spanning 3 continents. The prototype software to test our framework was a web application, coded in .NET 2.0 (C#) and working of SQL and xml data structures. Footprinting of 1559 SKUs takes ~1min (10min with concurrent uncertainty analysis). The prototype software employs 3 techniques that are central to fast carbon footprinting (summarized here and explained in detail in [15]):

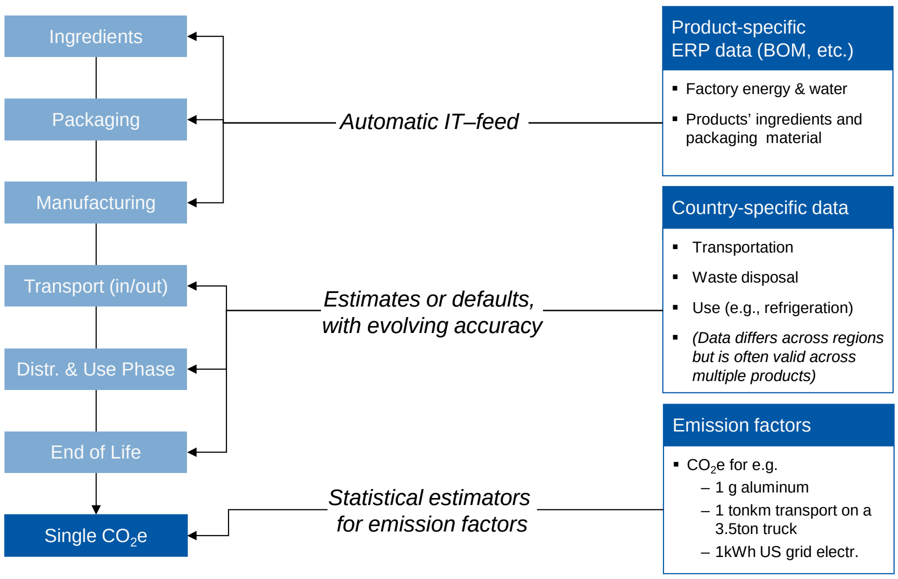

Fig. 1: *Uniform data structure.*

Uniform data structure: Each product is footprinted via the same underlying data structure (except above 422 products, which are footprinted via a top down approximation, using the known footprint of a carbonated softdrink and scaling the footprint of all 422 similar products as proportional to the respective net weights; note this process is not standard-compliant but included here to illustrate the flexibility of the overall approach). This data structure is shown in Fig. *1*.

Emission factors for ingredients and packaging components: For the carbon footprint results shown here, we used a simplified version of the regression model shown previously [15, 17]. Unless stated otherwise, emission factors (g CO2e per g of raw material) were obtained as:

$$min + (max - min) \cdot \frac{1}{1 + e^{-(s \cdot P + S)}} \tag{1}$$

where min=0.05, max=5.0, s=5.6, S=-7.0, and P the (wholesale) price of each ingredient/packaging component in USD per kg. Materials for which this purchasing price was unavailable were assigned a default, average emission factor of 0.89.

Other emission factors: Ecoinvent 2.0 and 2.01 (IPCC 2007, 100a) was used for road and sea transportation (g CO2e per tonkm), energy and water consumptions (g CO2e per kWh or liter), and disposal scenarios. For refrigeration, DEFRA (UK) parameters were used (g CO2e per liter and day).

Error margins: Error margins for all data inputs and CFs were expressed as coefficients of variation (CV). CVs of input data were assigned according to empirical studies and pedigree-type rules [15]. CVs of resulting CFs (for one product or for the sum of many products) were approximated as:

$$CV = \frac{\sqrt{\sum_i \left[CF\left(\overline{D_i} + \overline{D_i} \cdot CV_{D_i}\right) - \overline{CF}\right]^2}}{\overline{CF}} \tag{2}$$

where CV_{D_i} denotes the CV of each driver (=input data) D_i and $CF\left(\overline{D_i} + \overline{D_i} \cdot CV_{D_i}\right)$ denotes CF evaluated at the average $\overline{D_i}$ plus one standard deviation (and all other D_j at $\overline{D_j}$). The contribution of each driver to the total CV was calculated as:

$$CV_{contrib.,D_i} = \frac{\left[CF\left(\overline{D_i} + \overline{D_i} \cdot CV_{D_i}\right) - \overline{CF}\right]^2}{CV \cdot \overline{CF}^2} \tag{3}$$

where $\overline{CF}$ is the CF evaluated for all D_i set to $\overline{D_i}$.

Results

To demonstrate feasibility, basic process, and validity of the fast CF, we first apply the methodology to a single product (a bag of potato chips) whose footprint had been previously determined via the traditional route (i.e. manual data collection and entry) but whose LCA inventory was also available via automatic IT feeds shown in Fig. *1*. Table 1 shows the CFs by life cycle stage, incl. CVs (= one standard deviation error margins) for the "fast" CF, both prior and post manual refinements. Three manual refinements were carried out:

(1) Prior-refinements, the input driver with the highest $CV_{contrib.}$ (5.8%) was the road transportation distance parameter from suppliers to plant for all incoming ingredients and packaging materials (a country-wide estimate had been used, see Fig. *1*). Since improving the accuracy of this driver would result in the most pronounced improvement in accuracy (CV) of the overall footprint, a practitioner in this situation would focus his/her time on improving the accuracy of this input driver first (also referred to as "data quality screening" [18, 19]). The road distance was thus changed from the currently stored country-wide estimate (1000km with CV 40%) to the product-bespoke value (600km with CV 5%).

(2) Prior-refinements, the input driver with the 2nd highest $CV_{contrib.}$ (5.2%) was the EF for palm oil (the estimate from the EF estimator had been used, Fig. *1*). Again since this would now have the biggest impact on overall accuracy of the CF, the EF was changed from the automatically generated estimate (2.11 g CO2e per g with CV 40%) to a manual, expert-based EF (1.07 g CO2e per g with CV 25%).

(3) The fast CF prototype used to generate results shown in this paper can employ a number of data validation techniques. For example, it can automatically check whether the combination of packaging materials stored in the BOM (bill of materials) database matches the difference between gross and netweight of the product. If this is not the case, the respective input data (which comes from the company's ERP data warehouses) is flagged as "potentially faulty" such that it can be further scrutinized by the practitioner. Indeed, with this specific example, the weight of the primary packaging material (film bag of the potato chips) stored in the data warehouse was much too low and was therefore raised to the correct weight.

LCA Stage	Fast CF prior refinemement [gram CO2e]	CV prior refinement [%]	Fast CF post refinemement [gram CO2e]	CV post refinement [%]	Manual CF
Packaging	20.2	29.7	33.0	25.5	33
Ingredients	53.3	30.2	35.8	23.9	36
Transport – in	36.0	47.6	21.9	25.8	10
Manufacturing	24.2	22.9	*No change*	*No change*	24
Transport – out	3.5	47.6	*No change*	*No change*	14
Storage & sales	0.11	56.4	*No change*	*No change*	N/A
Use phase	0	N/A	*No change*	*No change*	0
Disposal	6.4	26.4	7.5	26.4	5.8
Total	**144**	**17.6**	**126**	**11.8**	**122**

Table 1: *CF of a single bag of potato chips (comparison of manual vs, "fast" CV).*

As seen in Table 1, fast CF results (both prior- and the post-refinements) are consistent with the manually obtained CFs (within 2 standard deviations, i.e. 2 CVs), and the beneficial impact of the input driver improvements on the CV of the CFs is realized. An exception is the outbound transport whose discrepancy with the manual result we attribute to the fact that the manual footprint used a higher EF for road transport (to accommodate the smaller and thus more fuel intensive delivery trucks for this specific product) than the country-wide EF stored in the fast CF system.

To demonstrate the versatility of the data structure to accommodate even complicated footprints, namely with assemblies that themselves include transportation and energy resource consumptions, we entered the full LCA inventory of a previously footprinted product (64oz carton Tropicana Orange Juice, Carbon Trust certified as of November 2008) in the fast footprinting system. As expected, the system reproduced the total CF of this product exactly (1662 g CO2e, with a CV of 9.7%).

After these and similar tests, we used the fast footprinting methodology to calculate the combined footprint of all 1559 products in the database (*Table 2*). To our knowledge, this has never been done at such scale (in a standard-compliant fashion). Crucially, the footprint of each product is further multiplied by the annual production of each individual product. This then yields the cumulative, annual GHG emissions associated with these products. After performing desired refinements (not shown), these results may then be used for scenario testing of carbon reduction strategies – e.g. if the EF of one of the packaging materials could be reduced by 20%, what would be the cumulative impact across all 1559 products captured in the system. Furthermore, equations (2) and (3) can again be used to quantify not only the CV of the CF before and after such a scenario, but also to quantify the CV of the actual reduction in GHG. This will be crucial to evaluate possible GHG savings against the investment costs for such a change (supply chain management).

LCA Stage	Fast CF prior refinemement [mass CO2e]	CV prior refinement [%]
Packaging	1.99	17.2
Ingredients	4.47	14.9
Transport – in	1.82	45.0
Manufacturing	1.19	16.6
Transport – out	1.74	46.5
Storage & sales	0.36	47.9
Use phase	0.64	53.8
Disposal	0.73	25.4
Total	**12.9**	**11.6**

Table 2: *CF of 1559 sample products*[a]

Discussion

Advantages

In comparison with current CF practice – usually manual, product-by-product calculations in multiple, non-interlinked files – fast CF offers 6 important advantages. (1) Scalability to thousands of products. (2) Transparency: The uniform structure of drivers and algorithms assists the practitioner in comparing CFs, including the traditionally difficult analysis of changes in baseline vs. actual CF and detailed product or process comparisons of two CFs with overlapping error margins. (3) Carbon management and cost/benefit evaluations across entire product portfolios, or "sliced and diced" by national roll-ups, by product type, or by business line. (4)

[a] In order to demonstrate the capability and versatility of fast CF we report here the total number of SKUs (1559), and product and country range. However, to protect PepsiCo data confidentiality, Table 2 deliberately does not reveal the exact product mix and composition or mass unit in which CO2e figures are reported.

Certification and communication with eco-labeling groups: Input data and algorithmic details such as allocation rules are transparent such that the resulting CF for individual products are easily certifiable, based on system-generated, detailed reports that includes all relevant data sources. (5) Synergies with corporate GHG reporting: system facilitates scope 3 relevant output, essentially by switching life cycle stages between cradle-to-grave or cradle-to-gate. (6) Low regulatory risk: Because specific CF algorithms operate universally for all inventory data, on an integrated platform, any changes to the CF "accounting rules" (e.g., treatment of recycling) can easily be implemented by adjusting respective parts of the software code.

Implementation aspects

A pivotal step for companies to successful, fast CF will be the definition of a universal input data structure that (i) is compatible with the data warehouse structure of a particular company; (ii) captures the company's particular portfolio of products/services; and (iii) is compliant with the protocol that the company follows. A second, one-time effort (before the system can produce CFs automatically) is to develop conduits that preprocess the data stored in ERP systems or similar data warehouses and load them into the fast CF software. Finally, again as a one-time only effort, a practitioner with LCA expertise will have to research and manually set (i) the defaults used for global or country-specific activity data (e.g., average transportation from factory to point-of-sale); and (ii) the EFs of materials that could not be estimated via the statistical model or that have such high impact that a manual review is preferred. Once these three one-time installation efforts are complete, the system will automatically generate CFs for all products/services of the company. Meanwhile, one or more users can continuously and simultaneously update and improve the data such that the accuracy of individual product CF improves. In addition, the system can be used for guided input to quickly determine the CF of new products (that are not yet in the ERP system or similar data warehouses) or indeed to guide product R&D.

Future improvements and outlook

The EF calculator may be much improved from the currently simple version to include more independent variables [15]. The fast CF system can be further automated to further leverage the uncertainty analysis such that the system automatically replaces poorly or not known inputs for some products with respective averages of closely related products (without practitioners having to intervene). Finally, we focused explanations of fast CF concepts on the narrow LCA-field of GHG emissions. Still, we emphasize that the proposed framework does apply to wider LCA applications beyond GHG emissions (e.g., water, toxicity, biodiversity, and social).

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