Assumptions and methodologies for life cycle assessment of food products

A project conducted by FoodPrint

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Author: Alex Loijos (aloijos@yahoo.com)

This draft is currently open to community peer review, meaning we encourage critique and contribution from anyone interested in bettering the methodology. Email: foodprint@yahoo.com

FoodPrint

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I. INTRODUCTION

Beef or tofu? Rice or bread? Fresh apple juice, or from concentrate? When it comes to filling our shopping cart at the grocery store, we make many decisions based on taste, health, and price ("of the food" is implied, so you don't need to say it). But as far as the average consumer can tell, items that sit next to one another on the supermarket shelves have a comparable impact on the environment. In an era when climate change and its potentially dangerous consequences are becoming widely accepted, many people are attempting to reduce their impact on the planet. Some bring their own bags to the checkout counter. Others recognize that it is better to buy locally produced foods, because there is less transportation involved, and less greenhouse gases are emitted. Or perhaps it is wisest to buy goods with recycled or recyclable packaging. Which of these food purchasing guidelines really make a difference? While single aspects of a food may contribute to its environmental impact, there is really no way to know a product's impact without doing an entire life cycle analysis from cradle to grave. This is the objective of FoodPrint: to provide a quantitative measure of the greenhouse gas (GHG) emissions associated with the entire life cycle of the product. This measure can guide the consumer to reduce the "carbon footprint" of their supermarket shopping.

II. LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) "studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use, and disposal" (ISO 1997). We will consider two life cycle assessment paradigms. The first is known as the process approach, and the second is known as the economic input-output approach. Each method has its benefits as well as drawbacks, but they can be combined to improve assessment accuracy. FoodPrint utilizes just such a "hybrid" approach to estimate the life cycle emissions of GHG of various foods.

III. PROCESS LCA

Process LCA evaluates all of the major activities in the course of a product's life span. We collect an inventory of the inputs of resources and energy for each of these activities, as well as the outputs into the environment. We then add together the environmental impact (in this case the net GHG emissions) of all the processes involved, paying careful attention to precision of the data. The main drawback of process LCA is that it can be costly and time-consuming to (1) account for the complex array of activities involved, and to (2) precisely quantify the resource/energy inputs and environmental outputs of each activity. An example that illustrates the complexity of accounting for all activities involved in a product's life cycle is beef production. Cattle rely on corn production for feed, which relies on fertilizer production, which relies on phosphate rock mining, which relies on bulldozer manufacturing, etc. A potential solution to this complexity is to draw system boundaries for the product that involve only the most important processes, and use statistical data from previous life cycle studies to estimate their impact. However, this method remains extremely time-consuming and tedious compared to the alternate approach.

IV. ECONOMIC INPUT-OUTPUT LCA

a. Economic Input-Output

The economic input-output approach breaks the United States economy down into 491 sectors, and looks at the direct and indirect dependency that one sector has on the remaining sectors. Rather than concerning ourselves with the specific processes, we can look at the economic exchange between sectors of the economy. To use our prior example of assessing the life cycle of beef production, we can use the fact that for every $1 of output produced by the "Cattle ranching and farming" (CRAF) sector an average of 8.5 cents are spent by businesses in this sector on the "Grain farming" sector for feed (EIOLCA 2008). We can then consider the expenditures of the "Grain farming" sector on other sectors to account for the *indirect* economic activity of CRAF. The U.S. Department of Commerce has compiled an "input-output table" which tabulates the net economic activity (direct plus indirect) of every sector of the U.S. economy. This tells us the amount that any given sector depends on each of the other sectors. We can estimate the life cycle of a *product* by looking at this economic activity data for the *sector* that produced it. Table 1 shows the economic inputs from the top five sectors that contribute to CRAF for every $1 worth of products output from this sector. (*Note:* This includes the

CRAF sector itself because the sector uses the goods it produces as inputs. For example, ranches often buy cattle from other ranches, and an output from the sector becomes input for the sector.)

Economic Sector	Output
Cattle ranching and farming	$1.30
All other crop farming	$0.30
Real estate	$0.17
Grain farming	$0.15
Wholesale trade	$0.11

Table 1 – Top 5 input sectors for "Cattle ranching and farming."

b. GHG Emissions Assessment

The second component needed to complete the life cycle assessment for a given food is to find the GHG emissions per dollar output for each economic sector. The EPA Toxics Release Inventory data for 2000 give toxics emissions for CFCs and HCFCs by economic sector (EPA 2000). This is combined with GHG emissions due to burning fuels, which produce primarily carbon dioxide, methane, and nitrous oxide. To calculate GHG emissions due to fuel use, we look at the four economic sectors that burn fuels—(1) mineral, (2) manufacturing, (3) transportation, and (4) other sectors (Cicas et al. 2006). We obtain fuel use volume for each sector from governmental data repositories, and calculate the Global Warming Potential (GWP) for each fuel and EPA toxic, measured in grams CO_2 equivalent (CO_2e). We then divide by total economic output in dollars for each of these sectors, and obtain grams of CO_2e per $1 output. See Cicas et al. 2006 for a more detailed explanation of the calculation that is employed in the EIO-LCA model. The "CO_2e per dollar output" is listed in Figure 1 for the five sectors that contribute the most economic input into CRAF. We multiply the economic output value (in dollars) by the CO_2e per dollar to calculate the final result of our life cycle assessment: 5259.6g of CO_2 equivalent are produced for every $1 output by the CRAF sector.

Economic Sector	Output		CO_2e per $ output		Net CO_2e
Cattle ranching and farming	$1.30	×	3207.7 g/$	=	4170 g
All other crop farming	$0.30		1225.2 g/$		370 g
Real estate	$0.17		46.8 g/$		7.82 g
Grain farming	$0.15		4821.9 g/$		704 g
Wholesale trade	$0.11		71.4 g/$		7.78 g
			TOTAL		5259.6 g

Figure 1 - Calculating carbon emissions using Economic Input-Output LCA.

It should be noted that these five sectors contribute only 83% of the 6320g CO_2e emissions estimated when all 491 sectors of the economy are included (EIOLCA 2008). Also, while these five sectors have the most *economic* input into CRAF, they are not in fact those which contribute the most to GHG emissions. For example, the “Power generation and supply” sector contributes 353g CO_2e per $1 output by CRAF, even though it inputs only 3.6 cents into CRAF.

c. Downfalls of EIO-LCA

While the economic input-output life cycle assessment (EIO-LCA) model gives us a quick and accurate estimate of the GHG emissions of each economic sector, this method is highly aggregate by nature (Hendrickson et al. 2006). This has the unfortunate consequence that all goods produced by the same sector have the same impact per dollar. It does not distinguish, for example, between an apple produced by a commercial farm in Washington, or a pear produced by an organic farm in California—since they both belong to the same economic sector (Fruit farming). We cannot account for actual processes used by a specific farm, and instead we deal with the average practices of the entire sector. We can cope with this downfall in two ways: (1) disaggregation and (2) impact adjustment. With *disaggregation* we can break a complex food product into its composite ingredients and packaging, and look at the impact of each of those. In this fashion we can distinguish between two items from the “Frozen food manufacturing” sector which are very different, such as frozen orange juice and frozen french fries by instead looking at the sectors producing their ingredients and packaging. This would mostly be accounted for by “Fruit farming” and “Paperboard container manufacturing” in the case of frozen orange juice, and “Vegetable and melon farming” and “Plastics packaging materials” in the case of frozen french fries. *Impact adjustment* uses research studies that compare the environmental impact of products belonging to the same economic sector in order to adjust their impact accordingly. For example, rice and corn both belong to the “Grain farming” sector. Corn accounts for 75% of the market, so to use this sector for rice would probably be inaccurate. We can utilize third party peer-reviewed publications to compare the life cycle of rice with that of the entire “Grain farming” sector and then adjust the calculation accordingly.

Another consequence of EIO-LCA is that it does not calculate the entire life cycle from cradle to grave, but only the life cycle of a product up to the time it rolls off of the production line. This disregards the use and disposal phases, which have a large contribution to the GHG emissions of various foods. Consider the use phase of an apple compared to a frozen meal. An apple is not often refrigerated or cooked, while a frozen meal requires energy for frozen storage, as well as heating energy to cook it. The impact of the disposal phase is also far less for the apple than the frozen meal, which involves packaging that must be transported to a landfill and then degrade. We can, however, evaluate the post-production life cycle by using process LCA. These activities include packaging, transportation, refrigeration, storage, cooking, and disposal. These activities are few compared to those of an entire process LCA, and in some cases we can use EIO-LCA to approximate their impact. For example, we can model the transportation phase with the "Truck transportation" sector of the economy by first calculating the economic activity in that sector for the distance the product travels. Or we can model disposal using the "Waste management and remediation services" sector.

V. METHODOLOGY AND RESULTS

To calculate the GHG emissions of various foods, we utilized prices from *The CRB Commodity Yearbook 2007* for the following seven foods: soybean oil, sugar, apples, rice, milk, cheese, and beef. Price received by farmer was listed for apples, milk, and beef. Wholesale prices were listed for soybean oil, sugar, rice, and cheese. Wholesale commodity prices represent the distributor prices and are marked up from producer prices, so we have used a deflation factor of 20% to scale wholesale prices down. All prices were then normalized to 1997 dollars using U.S. Department of Labor Producer Price Index statistics (BLS 2008). For example, to convert a producer price of $1 for sugar in 2001 to its equivalent 1997 price, we use the PPI of 111.0 in 2001 and 116.4 in 1997 according to the formula in Figure 2. Then, prices were converted from dollars per Cwt. (hundred pounds) to dollars per serving, with serving size reference amount specified by the U.S. Department of Agriculture (USDA 2008). Figure 3 (below) presents all data used in calculation of the price per serving for these seven foods.

$$price_{1997} = price_{2001} * (PPI_{1997} / PPI_{2001})$$
$$price_{1997} = \$1.00 * (116.4 / 111.0)$$
$$price_{1997} = \$1.05$$

Figure. 2 – Example PPI's used to adjust price

Food	Price ($/Cwt.)[1]	Year[1]	PPI (at gate)[2]	PPI (1997)[2]	1997 Price ($/Cwt.)[3]	Serving Size[4]	Price per serving ($)
Soybean Oil	20.67	1997	-	-	25.84	14g	0.0064
Raw Sugar	17.57	1997	-	-	21.96	4g	0.0015
Apples	22.90	2001	100.00	96.00	21.9840	154g	0.0777
Rice	14.84	1997	-	-	18.55	41g	0.0134
Milk	12.38	2000	136.70	129.60	11.7370	8 oz	0.0664
Cheese	105.92	1997	-	-	132.40	1 oz	0.0662
Beef	63.28	1999	107.96	100.00	58.6143	5.7 oz.[6]	0.2254

Figure 3 – Data used in price per serving calculation

[1] (CRB 2007)
[2] (BLS 2008)
[3] $price_{1997} = price_{at\ gate} * (PPI_{1997} / PPI_{at\ gate})$
[4] (USDA 2008)
[5] (EIOLCA 2008)
[6] USDA 4 ounce serving increased 30% to 5.7 ounce hanging weight to account for removal of fat/bones

Table 2 (below) lists the economic sector that produces each food, along with an excerpt of the corresponding activity as listed in the U.S. Census Bureau's description of the economic sector. The price per serving from Figure 3 (above) was input for the "Economic Activity" into these economic sectors, which yielded the values of Table 3 (below): a cradle-to-gate estimate of grams CO_2 equivalent emitted per serving (EIOLCA 2008).

Food	NAICS Code	Sector description	Corresponding sectorial activity
Soybean Oil	311222	Soybean processing	Soybean oil, crude, manufacturing
Raw Sugar	311311	Sugar manufacturing	Sugar, raw, made in sugarcane mill
Apples	111331	Fruit farming	Apple orchards
Rice	111160	Grain farming	Rice (except wild rice) farming
Milk	311511	Fluid milk manufacturing	Milk, fluid, manufacturing
Cheese	311513	Cheese manufacturing	Cheese (except cottage) manufacturing
Beef	311611	Animal, except poultry, slaughtering	Beef produced in slaughtering plants

Table 2 – Economic sector and correspondingt activity listed under sector description for each food.

VI. ANALYSIS OF RESULTS

To evaluate the accuracy of our LCA results, we compare them to results of other agencies who evaluated the same foods. The results for EatLowCarbon.org and EcoSynergy, Inc. were both given for arbitrary quantities of food, and so were normalized to USDA serving sizes for comparison. Our results do not as yet include the post-production life cycle phases, but those of EatLowCarbon.org do include them (Scholz 2008). This may be one reason their numbers are consistently higher (see Table 4 and Figure 4, below). For apples, cheese, and beef, our results are in good agreement with those of EatLowCarbon.org, with error factors of 4%, 3%, and 19%, respectively. The comparison of our results with those of EcoSynergy, Inc. yields greater error factors, as low as 43% for rice, and as high as 332% for cheese. There is no methods paper available to investigate likely causes of these discrepancies.

Food	Grams CO_2E per Serving
Soybean Oil	**15.4405**
Raw Sugar	**2.9281**
Apples	**117.4004**
Rice	**84.6416**
Milk	**247.5613**
Cheese	**250.2360**
Beef	**978.3879**

Table 3 – Estimated GHG emissions of seven foods

There are a few ways the methodology can be improved in the future. As mentioned previously, the post-production phase can be included in the LCA. Also, using "20%" as the markup from producer price to wholesale price is a rough estimate that does not reflect a commodity specific markup.

	FoodPrint	EatLowCarbon.org	EcoSynergy, Inc.
Soybean Oil	15.4405	-	-
Raw Sugar	2.9281	-	6.79
Apples	117.4004	113.0000	-
Rice	84.6416	275.0000	120.85
Milk	247.5613	-	444.75
Cheese	250.2360	258.0000	1080.75
Beef	978.3879	1168.0000	2725

Table 4 – Comparison of results with those of other agencies

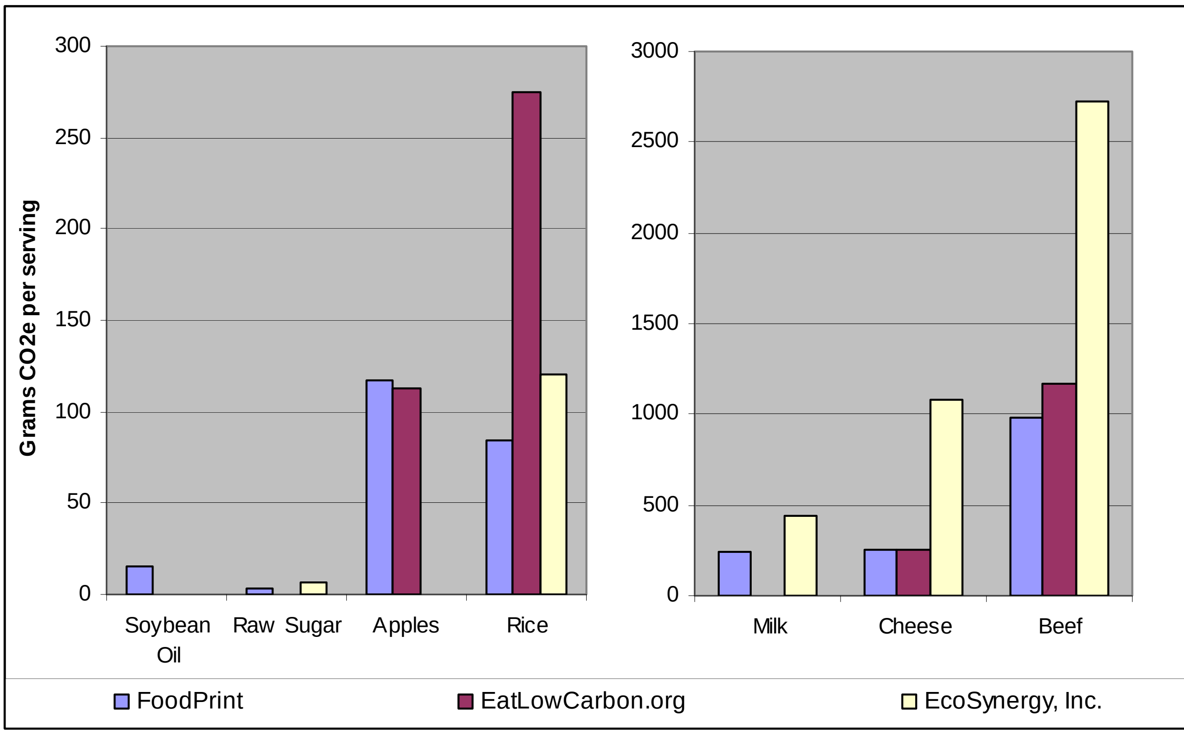

Figure 4 – Graphical comparison of results with those of other agencies.

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