Berkeley Institute of the Environment

Energy and Climate Change

(University of California, Berkeley)

Year 2008 *Paper jones_kammen_mcgrath_*030308

Consumer-oriented Life Cycle Assessment of Food, Goods and Services

Christopher M. Jones *   Daniel M. Kammen †

Daniel T. McGrath ‡

*University of California - Berkeley

†University of California, Berkeley

‡University of California, Berkeley

Consumer-oriented Life Cycle Assessment of Food, Goods and Services

Abstract

Life cycle assessment is a powerful framework for economic, social, and environmental cost pricing of consumer goods and services. We have extended the capacity of input-output life cycle assessment to approximate cradle-to-consumer environmental impacts from the manufacturing, transport and trade of >600 categories of consumer products and services. On average, 23 tons of CO2 equivalent greenhouse gases are embodied in the food, goods and services consumed by U.S. households. Particularly promising opportunities exist to provide environmental information directly to consumers for products at the point of sale. At a cost of \$10/tCO_2, we estimate that incorporating the mitigation cost of carbon would add only about 0.5% to the price of goods and services, and 1% to the price of food. This information can lead to the creation of market-based incentives for more sustainable consumption and production.

Submitted to Environmental Science and Technology, July 26, 2007
Revision submitted January 19, 2008

Consumer-oriented Life Cycle Assessment of Food, Goods and Services

Christopher M. Jones
Staff Research Associate
Berkeley Institute of the Environment
University of California, Berkeley

Daniel M. Kammen
Class of 1935 Distinguished Professor of Energy
Energy and Resources Group
Goldman School of Public Policy
Department of Nuclear Engineering
Co-Director, Berkeley Institute of the Environment
University of California, Berkeley

Daniel T. McGrath
Executive Director
Berkeley Institute of the Environment
University of California, Berkeley

Abstract

Life cycle assessment is a powerful framework for economic, social, and environmental cost pricing of consumer goods and services. We have extended the capacity of input-output life cycle assessment to approximate cradle-to-consumer environmental impacts from the manufacturing, transport and trade of >600 categories of consumer products and services. On average, 23 tons of CO_2 equivalent greenhouse gases are embodied in the food, goods and services consumed by U.S. households. Particularly promising opportunities exist to provide environmental information directly to consumers for products at the point of sale. At a cost of \$10/tCO_2, we estimate that incorporating the mitigation cost of carbon would add only about 0.5% to the price of goods and services, and 1% to the price of food. This information can lead to the creation of market-based incentives for more sustainable consumption and production.

Introduction

It is difficult to overemphasize the contribution of consumers to global environmental change. Virtually all natural resources consumed and pollution generated from the life cycle of goods and services can ultimately be traced to individuals and households through final demand (*1,2,3*). Despite this reality, it is surprising that few environmental policies and market mechanisms are directed towards consumer behavior, particularly since individuals are often willing to pay for environmental impacts related to their consumption (*4,5*).

Part of the problem has been that environmental information on the life cycle of consumer goods, food, and services is not readily available to consumers. Despite increasing demand for such information, only a small fraction of consumer products have been evaluated on a life cycle basis. The sheer number of products and services in the global economy presents time and resource challenges to providing useful environmental information to consumers and producers. Product-level life cycle assessment (LCA) approaches can take up to 3-12 person months (*6*) and require expert knowledge and huge data collection efforts while employing a variety of methods with different underlying assumptions (*2,7,8,9*).

A more comprehensive system of environment accounting across the full spectrum of consumer products would help to foster a more sustainable economy by 1) helping consumers to understand the environmental impacts related to their choices, 2) enabling the creation of a pricing system that sends more appropriate signals to consumers, 3) providing an incentive to companies to differentiate their products by measuring and reducing environmental impacts from their supply chains, and 4) generating financial resources to mitigate environmental damage (e.g., via carbon credits) or to pay for environmental clean-up and health-related costs. By linking information and price incentives across systems of supply and demand a more efficient and sustainable resource system may begin to emerge that explicitly recognizes the connections between production, consumer behavior and environmental change.

Top-down input-output life cycle assessment (IO-LCA) tools present a promising framework for rapid and detailed LCAs of typical products at the sector, or industry, level (*7*). Economic Input-Output Life Cycle Assessment (EIO-LCA) provides estimates of greenhouse gas (GHG), criteria air pollutants, toxics and energy per dollar of sector output from ~500 sectors of the U.S. economy (*7,10*). These emission estimates include all economy-wide impacts from cradle-to-farm gate- or manufacturer's-door, i.e. the total output from each sector includes inputs from all other sectors of the economy. While the emission estimates are robust on the aggregate, there are basic limitations of input-output approaches. These include: 1) aggregation error when heterogeneous products are produced from a single economic sector, 2) lack of coverage of life cycle emissions beyond the producer's door, 3) time lag due to infrequent updates of emission factors, and 4) geographic variation (e.g., accounting for the effect of imports). All of these problems have been addressed to various degrees elsewhere in the literature (*2,3,6,7,11,12,13,14*).

The model presented in this paper builds on previous work to present supply chain life cycle environmental impacts in a format that is relevant to consumer expenditures – that is, presenting supply side effects from a demand side perspective. This model extends the capacity of input-output life cycle assessment (*10*) to provide updated greenhouse gas emission factors for >600 categories of products and services. These categories are inclusive of essentially everything sold to consumers in the United States. Extended IO-LCA accounting can be used to provide average environmental information directly to consumers through information portals, at point-of-sale or via other consumer-oriented applications. We further suggest an approach to combine top-down and bottom-up LCA into an integrated information management system.

Methods

This section summarizes our approach for estimating greenhouse gas emission from consumer goods food and services. A full discussion of our methodology, including equations, examples and data sources, can be found in the Supporting Information.

As discussed in detail in the Supporting Information, this research uses Bureau of Economic Analysis (BEA) data to map ~1,100 consumer product categories (including all food, goods and services in the economy) to ~280 sectors of the U.S. economy. These product categories refer to easily discernible consumer items such as oranges, laptop computers, stuffed toys or shoes. Of these ~1,100 product categories, BEA provides transport-to-market, wholesale, and retail trade margins for ~650 of these categories. These margins can be used to determine separate emission factors (grams of CO_2 equivalent per dollar of consumer expenditure) for each of these life cycle stages for multiple products originating from a single sector (*15*). From the perspective of consumers, products with higher emissions per dollar do not necessarily correspond to higher emissions per unit of product since transport, wholesale and retail margins can distort emissions per dollar of consumer spending. It is therefore helpful to adjust for margins when applying EIO-LCA to consumer products.

In order to update these emission factors from 1997 (the most current year available in EIO-LCA) to 2007, inflation effects, changes in industry output, and changes in the greenhouse gas intensity of production (Supporting Information equations 2-5) are accounted for. Furthermore, emissions per dollar are converted to emissions per physical unit (e.g., grams of methane per gram of product) for all food and goods product categories (Supporting Information equations 6-8).

These improvements convert sector-level emissions data provided by EIO-LCA for the year 1997 to product category-level emission factors applicable to easily discernible consumer items in 2007. A summary of these correction factors is presented in Figure 1. On average, our model, which we have called Lifecycle Environmental Assessment of Products and Services (LEAPS) decreases sector-level emission factors from baseline EIO-LCA values by about 30% for food and goods, and increased factors for services by about 15%, although with considerable variation from product to product.

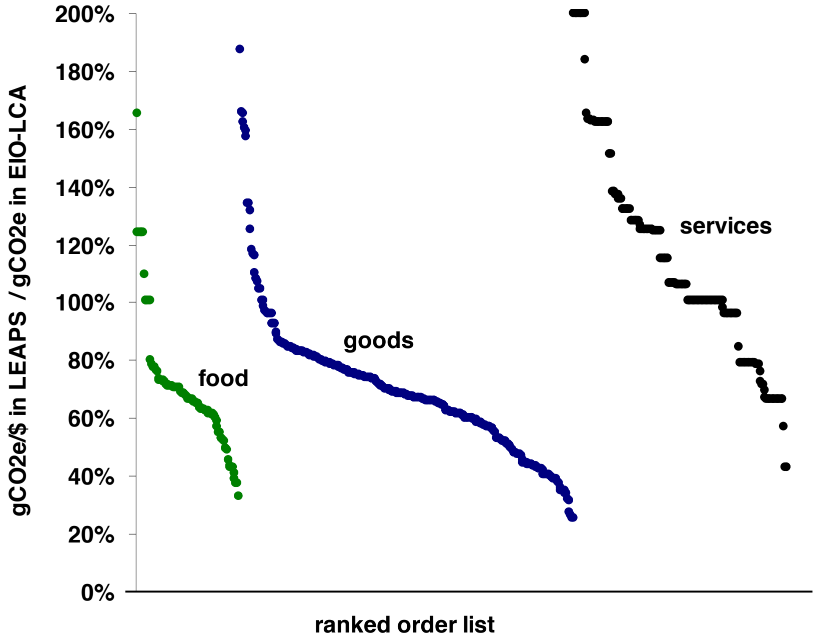

Figure 1. Comparison of product-level and sector-level and emission factors (grams CO_2e/consumer dollar in LEAPS divided by gCO2e/producer dollar in EIO-LCA). Values below 100% indicate that the carbon intensity of that item decreased in our assessment compared to sector-level data provided by EIO-LCA. A flat line at 100% would indicate no change across all food, goods and services categories.

In the Supporting Information we present further modifications that can be made at the point of sale for individual products based on the location of origin (accounting for emission intensities of importing country or U.S. state) and the location of sale (accounting for emission intensities of the retailer, plus transportation to market) of products.

Results and Discussion

A sample of greenhouse gas (GHG) emissions from the life cycle of a range of foods and consumer goods sold in the U.S. is shown in Figure 2, and basic statistical results are provided in Table 2.

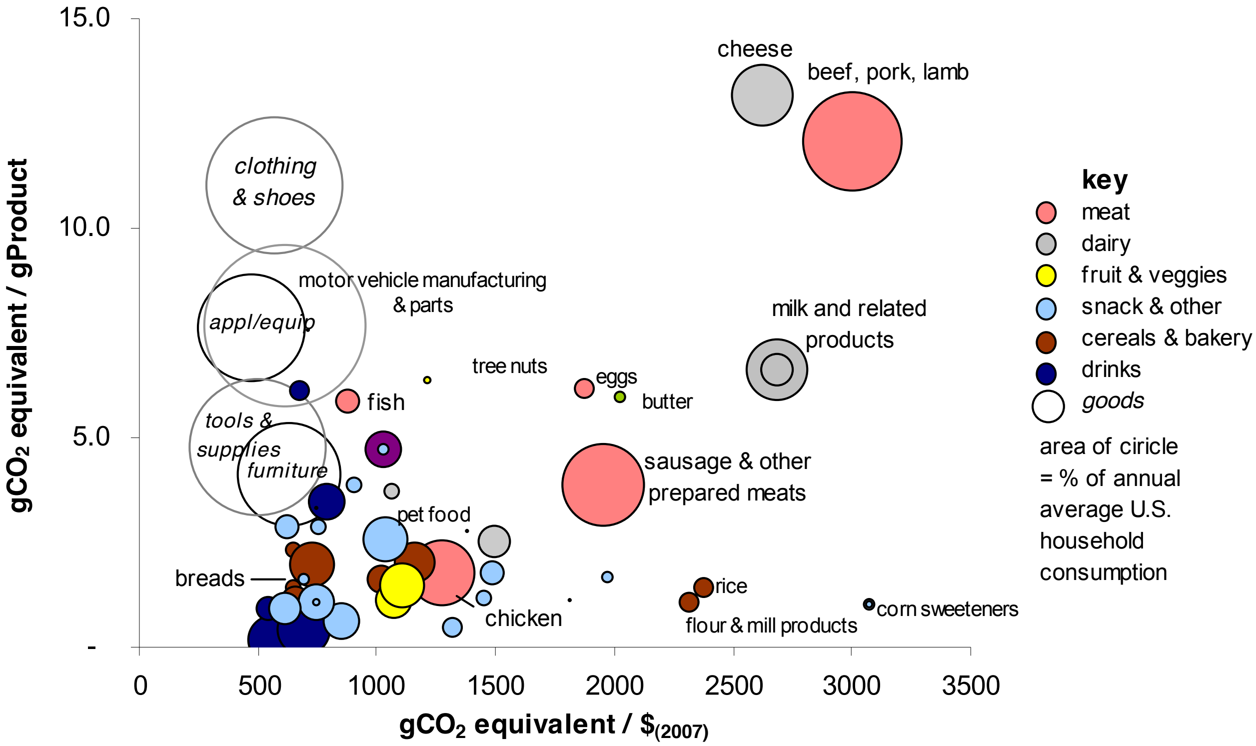

Figure 2. Cradle-to-consumer GHG emissions from consumer products, and specific food groups sold in the United States. LEAPS provides cradle-to-consumer life cycle greenhouse gas emission factors for consumer goods in terms of grams of carbon dioxide equivalents (CO_2e) per dollar spent by consumers and gCO_2e per of unit of product (typically the mass measured in g or kg). The area of circles represents total annual emissions for the typical U.S. household for each item. Goods are aggregated into five major categories for illustrative purposes.

Table 1. Summary of results (gCO_2e/$)

	Food	Goods	Services	Total
median	938	520	401	521
mean (weighted)*	1,018	489	390	524
mean	1,281	514	460	616
standard deviation	981	175	336	534
max	2,786	1,555	2,447	2,447
min	200	222	42	42

*weighted by consumer spending for each product

Food production, distribution, and retail requires, on average, about 1,000 gCO_2e for each dollar spent by consumers, while household goods require about 500 gCO_2e /$. Thus, about every $1,000 consumers spend on food releases about 1 ton of gCO_2e into the atmosphere, and every $2,000 spent on goods (motor vehicles, clothes, appliances, household supplies, toys, furniture, etc.) also results in about 1 ton of CO_2. High emissions for food on a per dollar basis are at least partly accounted for by the relatively inexpensive (and frequently subsidized) price of food. Specifically, means of 1,018 gCO_2e/$ for food, 489 gCO_2e/$ for goods and 390 gCO_2e /$ for services, weighted by consumer spending in each category of emissions are calculated. The standard deviation for consumer goods is relatively low (175) compared to food (981) and services (336), signifying that value-added is highly correlated with GHG emissions from manufacturing.

Considering emissions on a mass basis may be more intuitive, particularly for food items where substitution may be an option. For example, every gram of beef releases nearly 10 times the amount of greenhouse gases into the atmosphere compared to an equivalent amount of chicken. However, it is important to emphasize that this estimate does not include GHG impacts occurring during land use change (e.g., forest clearing for pastures). Dairy items also have high emissions per unit of product, signifying that cows are the largest direct source of emissions from food. Cereals, fruits and vegetables have consistently low emissions per gram of product. Household goods have higher emissions per gram of product -about 7 grams of CO_2e compared to 4 grams of CO_2e for food- which can be expected since not all food items require heavy energy inputs, compared to manufactured goods.

Multiplying these emission factors by consumer spending in each category produces over 9 metric tons of greenhouse gases for food, 7 tCO_2e for goods and 5 tCO_2e for services for the typical U.S. household per year. Embodied emissions from food, goods, and services total 23 tCO_2e per year per household, on average, not including emissions from household energy, transportation, and housing construction. This is equivalent to more than the annual average GHG emissions from four cars (*18*). The results presented here are consistent with, but generally higher than other previous studies (*3,19,20*). The difference appears to be that this analysis uses Personal Consumption Expenditures, rather than the more typical Consumer Expenditures (CE) published by the Bureau of Labor Statistics. A recent BEA paper (*21*) shows that aggregate consumer expenditures in the CES accounts for only 60% of consumer expenditures in the PCE. Since the PCE is created from the same benchmark input-output tables as I-O LCA models, the PCE would seem to be a more accurate assessment of consumer impacts using this approach, indicating that previous studies may have significantly underestimated total life cycle environmental impacts from household consumption.

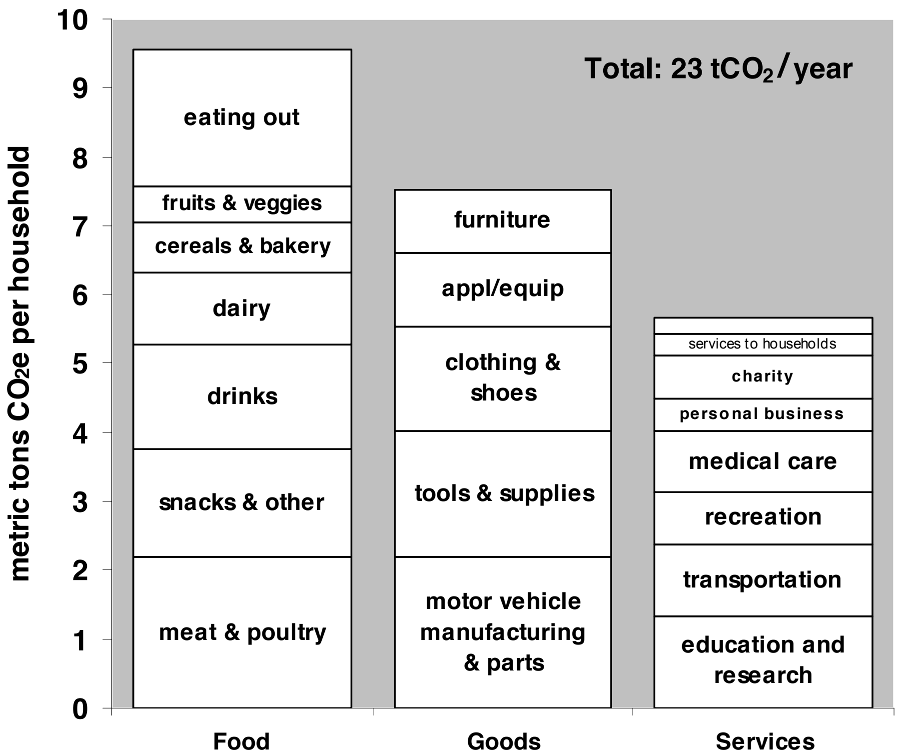

Figure 4. Greenhouse gas emissions from food, goods and services for the typical U.S. household

Figure 5 presents the embodied GHG emissions for a single product, beer, which is estimated at 626 grams of CO_2e per liter. Emissions from cradle to manufacturing account for 68% of total impacts; 27% occur during retail/wholesale and only 6% occur during transport to market. Applying the fraction of consumer dollars that corresponds to manufacturing to EIO-LCA allows us to visualize the full cradle-to-consumer emissions from all sectors of the economy for each product. Similar results can be obtained for all 1,100 product categories, resulting in a rich set of data for consumer applications.

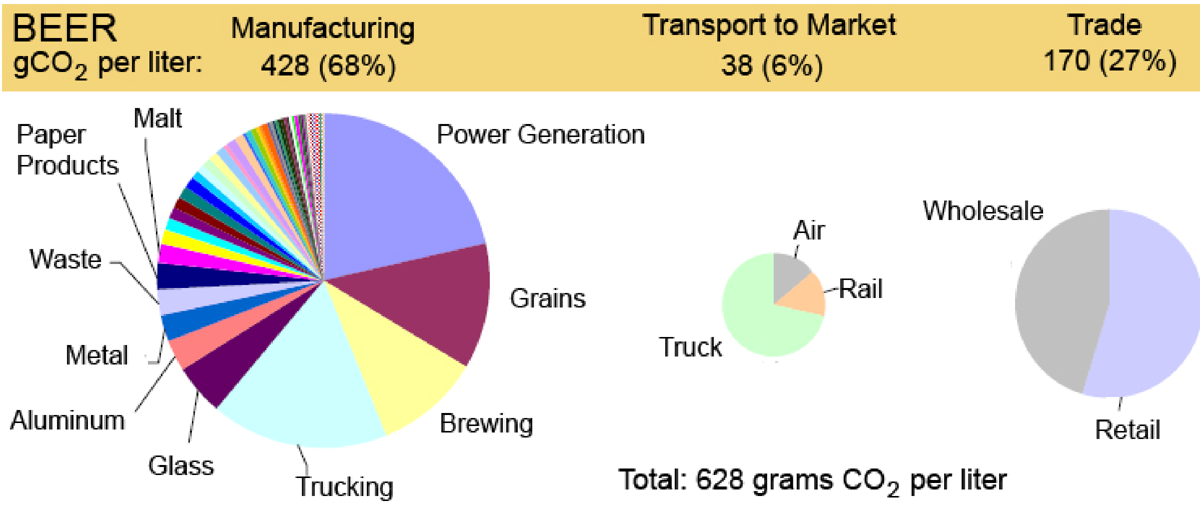

Figure 5. Greenhouse gas emissions from manufacturing, transport and sale of beer

The results of the extended IO-LCA approach can be used for adoption of new and promising carbon management options by consumers and retailers. Consumers have only two options to reduce their environmental impact directly: either consume less, or switch to less environmentally-intensive consumption. Yet, eliminating anything from an individual's lifestyle can involve difficult tradeoffs. Market-based solutions may therefore become attractive. The nascent voluntary carbon offsets market allows consumers to donate financial resources to projects that promise to reduce net GHGs through renewable energy, energy efficiency, or afforestation projects in an equal amount to the value of the credit. Carbon offset providers currently sell carbon dioxide credits for between five and twenty-five dollars per ton of carbon dioxide emissions, with an average of $10 (*22*). The Chicago Climate Exchange (*23*) allows individuals or organizations to purchase "Carbon Financial Instruments," currently valued at \$4/tCO_2e. To the extent that initiatives fund projects that are "additional" (i.e., that would not have happened otherwise) and permanent, carbon offsets have potential to reduce GHGs beyond what households could reasonably do themselves. Over time, as demand for offsets increases, price and quality can also be expected to increase.

Retailers can also play an important role by immediately integrating extended IO-LCA product scores into inventory tracking systems. Understanding the supply chain carbon footprints of products can be useful to retailers in a variety of applications and retailers are arguably the linchpins for integrating sustainable consumption and production. First, as a greenhouse gas screening tool, large retailers interested in reducing supply chain impacts can quickly learn which products to target for mitigation strategies. Manufacturers demonstrating emission reductions could be offered prime retail shelf space or other incentives at point-of-sale. Retailers would benefit by offering greener shopping experiences to consumers, such as green zones in stores. More ambitious retailers could offer supply chain carbon footprint information directly to consumers. Early adopters could begin offering "carbon neutral shopping" for selected products, or even for everything sold in their stores, possibly without raising prices. At \$10/tCO_2e, this would add about 0.5% to the price of goods and 1% to the price of food. This would seem to be low enough for retailers to more than absorb the extra cost (through increased customer loyalty) without passing the cost on to consumers. A range of opt-in strategies could also be provided at little risk to retailers, e.g., selling carbon credits at check-out, through online purchases, affiliate cards, credit cards or a range of other mechanisms. Informational tools such as touch screen kiosks equipped with barcodes readers could provide environmental life cycle and other product information to consumers to help guide more sustainable consumer purchasing behavior. Furthermore, incorporating a mitigation (offset) cost of carbon would add real value to consumer products and help retailers and manufacturers gain customers and build brand loyalty.

Importantly, environmental labels and pricing at retail outlets would create natural incentives for manufacturers to prove that their products are better than their competitors by conducting full product LCAs of their supply chains. Standard process-based LCA tools can currently be used by manufacturers to identify the most pollution-intensive processes and materials used on the production of particular goods. A number of software tools are available for such assessments (e.g., *29*), but these typically do not extend too far up the value chain, e.g., to include the fourth, fifth, etc. level of suppliers to manufacturers. Hybrid LCAs combine top-down and bottom-up approaches (*7,26,27,28*) to ensure all sectors of the economy that contribute emissions indirectly to the production of goods and services are considered in the final assessment.

Figure 6 outlines a hypothetical framework for combining extended input-output LCA with product-level "hybrid" LCAs into a single information management system. In such a system, extended IO-LCA provides the first step in a "stepping stone" approach towards increasingly more detailed LCAs of individual products. As more detailed environmental data are collected on the processes and materials of individual products, this information can supplement IO-LCA data in a "hybrid" LCA approach. Such a system would allow manufacturers to differentiate their products against baseline emissions data, and perhaps eventually against other competing products.

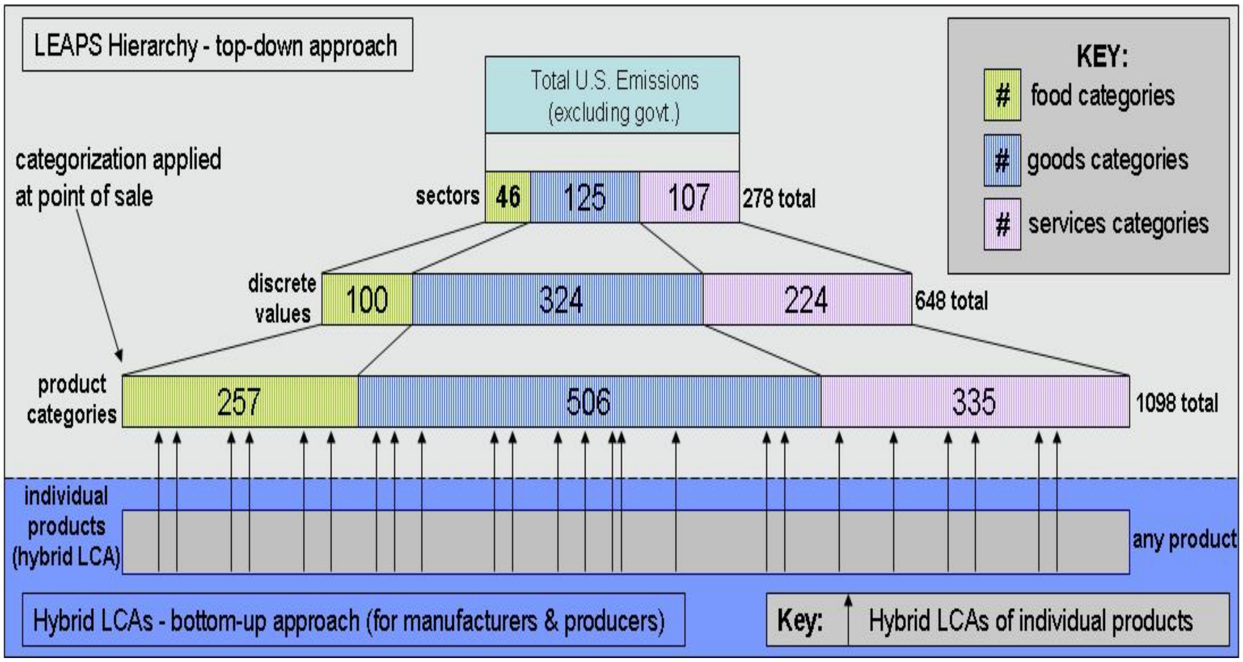

Figure 6. LEAPS Categories and an Integrated Product LCA Framework
LEAPS includes 1098 product categories, of which 648 are discrete values. These product categories can be traced to one of 278 sectors of the economy, and contain average emissions per dollar of consumer spending or per unit of product. Applying emissions values to total consumer spending over all categories equals total U.S. emissions (minus emissions from government spending). Additional resolution can be added to the model by incorporating hybrid LCAs from individual products by specific manufacturers.

Extended IO-LCA could also be used in carbon labeling, in both compliance and voluntary markets. In regulated markets, governments could give retailers incentives, such as tax breaks or rebates, to provide carbon labels on store shelves and/or products. Information for all similar products (e.g. bottles of beer) could receive the same "carbon footprint" score. This would provide additional information for consumers to choose between competing types of products, and send strong signals to manufacturers to *green* supply chains. Carbon labels could be immediately implemented for all products with average carbon footprint scores, which might eventually be replaced, product-by-product, with approved LCA scores of individual name brand products. Such an approach would clearly require a system of standardization and verification that can only be legitimized through some sort of participatory process. Analogs to such a process can be found in ISO standards, organic certification, the Forest Stewardship Council, the Energy Star Program and Fair Trade. Each of these standardization and certification programs requires a network of actors in a transparent participatory framework, but each is also quite unique. Such a system should be encouraged to emerge over time.

Carbon taxes could also be considered as a policy option for state and local governments. While this would certainly be a more difficult policy to implement, it would nonetheless be extremely effective at sending appropriate signals to consumers and generating urgently needed funding for clean technologies. Category level data could aid in such a system by standardizing emissions reporting for all products consumed at point-of-sale.

Regardless of the implementation strategy, LCA tools hold the potential to help close the loop on more sustainable systems of production and consumption, while generating urgently needed funding for cleaner energy and energy efficiency projects worldwide. On a global scale, few would argue with the assertion that the benefits of carbon pricing far outweigh costs of inaction. The influential Stern Review (*30*) provocatively concludes that "climate change is the greatest market failure the world has ever seen," and recommends carbon pricing, investments in clean technology, and improved information as the key set of policy options to address climate change. Retailers, manufacturers, and consumers can evaluate whether or not the benefits outweigh the costs of incorporating environmental information and pricing, but LCA must begin supplying appropriate analytical tools to help them make these decisions.

Acknowledgments

The authors thank the Berkeley Institute of the Environment and the Center for Information Technology Research in the Interest of Society (CITRIS) at the University of California, Berkeley for supporting this work. DMK's work was supported by the Energy Foundation, the University of California's Class of 1935, and the Kasten Family Foundation. We would particularly like to thank Professor Arpad Horvath of UC Berkeley for guidance and review of this work. Daniel Work of UC Berkeley provided critical background research. We also thank Carnegie Mellon University's Green Design Institute for multiple insights.

Supporting Material

A full discussion of our methodology, including equations, examples and data sources, can be found in the Supporting Information. This information is available free of charge via the Internet at http://pubs.acs.org.

References

1. Matthews, H. S. The External Costs of Air Pollution and the Environmental Impact of the Consumer in the U.S. Economy. Unpublished Ph.D. dissertation. Graduate School of Industrial Administration: Pittsburgh, PA, 1999.
2. Tukker, A.; Jansen, B. Environmental Impacts of Products: A Detailed Review of Studies. *J. Ind. Ecol.* **2006**, *10*(3), 159-182.
3. Weber, C. L.; Matthews, H.S. Embodied Environmental Emissions in U.S. International Trade, 1997-2004. *Environ. Sci. Technol.* **2007**, *41*, 4875-4881.
4. Berk, R.; Fovell, G. Public Perceptions of Climate Change: A 'Willingness to Pay' Assessment. Climate Change. 1999, 41(3-4), 413-446.
5. Curry, T.E.; Ansolabehere S.; Herzog, H.J. A Survey of Public Attitudes towards Climate Change and Climate Change Mitigation Technologies in the United States: Analyses of 2006 Results. MIT LFEE 2007-01 WP. Massachusetts Institute of Technology: Boston, MA, April 2007. http://sequestration.mit.edu/pdf/LFEE_2007_01_WP.pdf (Accessed July 2007).
6. Heijungs, R.; de Koning, A.; Suh, S.; Huppes, G. Toward an Information Tool for Integrated Product Policy. *J. Ind. Ecol.* **2006**, *10*(3), 147-158.
7. Hendrickson, C. T.; Lave, L.B.; Matthews, H.S. *Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach*. Resources for the Future Press: Washington, D.C., 2006.
8. Jönbrink, A. K.; Wolf-Wats, C.; Erixon, M.; Olsson, P.; Wallén, E. LCS Software Survey. IVL Swedish Environmental Research Institute research publication 00824, 2000; http://www.ivl.se/rapporter/pdf/B1390.pdf (Accessed June 2007).
9. Rosenblum, J.; Horvath, A.; Hendrickson, C. T. Environmental Implications of Service Industries, *Environ. Sci. Technol.* **2000**, *34*(22), 4669-4676.
10. Green Design Institute. Economic Input-Output Life Cycle Assessment (EIO-LCA); Carnegie Mellon University: Pittsburgh, PA. http://www.eiolca.net (Accessed May 2007).
11. Suh, S.; Huppes, G. Methods for Life Cycle Inventory of a Product, *J. Cleaner Prod.* **2005**, *13*(7), 687-697.
12. Heijungs, R.; Suh, S. *The Computational Structure of Life Cycle Assessment*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2002.
13. Joshi, S. Product Environmental Life cycle Assessment Using Input-Output Techniques, *J. Ind. Ecol.***1999**, *3*(2-3), 95-120.
14. Peters, G. P.; Hertwich, E.G. The Importance of Imports for Household Environmental Impacts, *J. Ind. Ecol.* **2006**, *10*(3), 89-109.

15. Norris, G., Croce, F.D., Jolliet, O. Energy Burdens of Wholesale and Retail Portions of Product Life Cycles. *Journal of Industrial Ecology*. **2006**, *6(2)*, 59-69.
16. Carlsson-Kanyama, Climate change and dietary choices - how can emissions of greenhouse gases from food consumption be reduced, *Food Policy*, **1999**, *23(3/4)*, 277-293
17. Kramer, K. J.; Moll, H. C.; Nonhebel, S. Wilting, H.C. Greenhouse gas emissions related to Dutch food consumption, *Energy Policy*, **1999**, *27*, 203-216
18. Environmental Protection Agency. Emission Facts: Greenhouse Gas Emissions from a Typical Passenger Vehicle. http://www.epa.gov/OMS/climate/420f05004.htm (Accessed January 18, 2008).
19. Matthews, H. S. The External Costs of Air Pollution and the Environmental Impact of the Consumer in the U.S. Economy. Unpublished Ph.D. dissertation. Graduate School of Industrial Administration: Pittsburgh, PA, 1999.
20. Bin, S.; Dowlatabadi, H. Consumer lifestyle approach to US energy use and the related CO2 emissions, *Energy Policy*, **2005**, *33*, 197-208.
21. Garner, T. I., Janini, W.P., Paskiewicz, L, and Vendernia, M. The CE and PCE: a comparison. *Monthly Labor Review*. **2006**, *129(9)*, 20-46.
22. Clean Air – Cool Planet. *A Consumers Guide to Retail Carbon Offset Providers*. http://www.cleanair-coolplanet.org/ConsumersGuidetoCarbonOffsets.pdf (Accessed June 2007).
23. Chicago Climate Exchange, http://www.chicagoclimatex.com (Accessed July 2007).
24. A partial listing of carbon calculators can be found here: http://www.epa.gov/climatechange/emissions/individual.html (Accessed January 18, 2008).
25. Life Cycle Climate Footprint Calculator: http://bie.berkeley.edu/calculator (Accessed January, 2008).
26. Suh, S.; Huppes, G. Methods for Life Cycle Inventory of a Product, *J. Cleaner Prod*. **2005**, *13*(7), 687-697.
27. Heijungs, R.; Suh, S. *The Computational Structure of Life Cycle Assessment*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2002.
28. Heijungs, R.; de Koning, A.; Suh, S.; Huppes, G. Toward an Information Tool for Integrated Product Policy. *J. Ind. Ecol*. **2006**, *10*(3), 147-158.
29. PE International, *GaBi 4*. http://www.gabi-software.com (Accessed July 2007)
30. Stern, N. *The Economics of Climate Change: The Stern Review*. Cambridge University Press: Cambridge, United Kigdom, 2007.