Literature Review of Methods and Tools for Quantifying the Indirect Environmental Impacts of Food Procurement

A research report completed for Clean Air-Cool Planet

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Executive Summary

Purpose

The Johns Hopkins Center for a Livable Future (CLF), an interdisciplinary academic center based at the Johns Hopkins Bloomberg School of Public Health, conducted a comprehensive literature review of methods and tools for quantifying the indirect GHG emissions associated with food procurement on an institutional level. The results of this review are intended to provide Clean Air-Cool Planet (CA-CP), a US-based non-profit dedicated to global warming solutions, with guidance for the development of a new GHG emissions inventory tool for food service providers at academic institutions. Key considerations gleaned from findings such as methods, features and data were incorporated into a suggested design that serves as a guiding example for the development of a new tool.

Background

GHG emissions from the life cycle of foods are a major component of anthropogenic environmental impacts. To enable campus food service providers to reduce GHG emissions via their food procurement practices, a practical inventory tool is needed.

Methods

A comprehensive search was conducted to identify methods and tools for measuring the GHG emissions and other environmental impacts from food-related activities and product life cycles on an individual, household and institutional level. Methods, features and underlying data employed in each tool were evaluated for their utility in serving the purposes of a new CA-CP tool.

Results

Of over 70 methods and tools reviewed, roughly half had some application to food production or procurement. While no resultant findings were directly applicable for use "as-is" for CA-CP's purposes, 10 methods or tools were *illustrative* of methods, features and/or data applicable to the new tool, and/or used data that would be suited for use – with potential modifications - in the new CA-CP tool.

Of particular interest to the development of the new CA-CP tool were tools based on life cycle assessment (LCA) - a framework for measuring the net environmental impacts from the life cycle of a product or activity. The two main approaches to LCA are process LCA (PLCA) and economic input-output LCA (EIOLCA). PLCA estimates the impacts of a food product based on a system of linked "processes" (soil tillage, grain processing, transportation, oven use, etc.) along the product life cycle. EIOLCA bases calculations on monetary spending in particular industry sectors associated with the product, and may be used to fill in data gaps where process data are lacking. Combining the two methods in this manner is referred to as hybrid LCA (HLCA).

Although no existing LCA-based tools were directly suitable for CA-CP's purposes, LCA software modeling tools and data are valuable in the *development* of an appropriate set of underlying data for the CA-CP tool.

The new CA-CP tool: suggested guidelines

The structure of the suggested new tool is defined by a user interface, through which the user (a campus sustainability coordinator or student, working in partnership with the management of a campus food service provider) enters bulk quantities of foods; the underlying data, comprised primarily of food LCA data; and a "calculator" that tallies impacts based on data and user inputs.

Key considerations for the design and development of the tool are focused primarily on the underlying data "catalog" of food items. Given the relative lack of LCA data on U.S. food production, development of the data catalog will likely present the greatest challenges, both in terms of time and resource investment as well as in handling potentially inaccurate results – an inevitable consequence of data gaps.

Additional methods, features, and considerations include:

- Varying calculation methods by life cycle stage: Emissions from production are handled by the underlying food data catalog; delivery emissions – although accounting for a relatively small fraction of total emissions – are set to default values based on common food origins, and can be customized by the user where supply chain information is available; emissions resulting form on-site storage, preparation, consumption and disposal are already accounted for by the existing CA-CP tool.
- Level of product aggregation and geographic relevance: Food LCA models in the data catalog would ideally be specific to method of production and relevant to a U.S. context wherever possible; however, due to data gaps this is currently not viable for most foods. Resulting uncertainties should be communicated to the user. These uncertainties do not preclude opportunities for food service providers to make relative approximate comparisons between procurement methods or over time.
- Impact reporting: Given the magnitude of environmental impacts from the food system beyond GHG emissions alone, the suggested design reports a comprehensive array of impacts. To facilitate interpretation of results, impacts are expressed in standardized metrics such as global warming potential.

Conclusions

A new CA-CP inventory tool, used by food service providers who have the drive and social responsibility to put changes into practice, can guide efforts to reduce food-related GHG emissions and other impacts. In addition, the results of these tools and methods can guide educational campaigns for consumers, helping to further encourage environmentally responsible dietary decisions. Given the powerful environmental impacts of our food system, and the broad reach and purchasing power of institutional dining services, adding this component to CA-CP's toolbox can further advance efforts to reduce contributions from the food system to GHG emissions and other environmental impacts.

PURPOSE

This report is the result of a research project by the Johns Hopkins Center for a Livable Future (CLF), an interdisciplinary academic center based at the Johns Hopkins Bloomberg School of Public Health, for Clean Air-Cool Planet (CA-CP), a U.S.-based non-profit dedicated to global warming solutions. CA-CP currently provides a free, online *Campus Carbon Calculator,* used by nearly 1,000 academic institutions across North America to measure their greenhouse gas (GHG) emissions. This report was developed in response to numerous requests by CA-CP clients to provide an additional tool for measuring the GHG emissions of campus food service providers. The CLF conducted a comprehensive literature review of methods and tools for quantifying the life cycle GHG emissions of foods, for the purpose of generating guiding considerations for the development of a new, publicly available tool for measuring the indirect GHG emissions of food procurement - or **foodprint** - on an institutional level, for U.S. based food service providers at academic institutions. The target user is a campus sustainability coordinator or student, with some familiarity with GHG inventory tools, working in partnership with the management of a campus food service provider. Key considerations gleaned from findings such as methods, features and data were incorporated into a suggested design that serves as a guiding example for the development of a new CA-CP foodprint tool, henceforth referred to as the **new tool**[1].

BACKGROUND

Environmental Impacts of the Food System

Greenhouse gas emissions

The Intergovernmental Panel on Climate Change (IPCC) has identified impacts to water, ecosystems, food, coastlines, and human health, including the extinction of species, increased frequency of severe hydrological events, and increased burden of disease - just to name a few - as a result of global climate change. Although many of these consequences cannot be avoided, the severity of these impacts over the long term can be mitigated by immediate reductions in greenhouse gas (GHG) emissions (IPCC, 2007a). In response to these warnings, and to the recognition that the vast majority of the GHG emissions causing climate change are anthropogenic, individuals, businesses, academic institutions and governments are measuring and tracking the emissions associated with their activities. To address this demand, a variety of tools have been developed to quantify the GHG emissions from these activities, as well as from the production, delivery, use and disposal of various products. Calculation results are often expressed as a **carbon footprint**, or a sum of total carbon dioxide (CO_2) emissions[2]. Results can also be expressed as

[1] Guidelines and considerations discussed below should not be equated with explicit recommendations.

[2] Use of the term 'carbon footprint' varies widely across literature to include CO_2 only or all six major GHGs, as well as direct emissions only or direct and indirect emissions. This report adheres to the definition proposed by Weidmann and Minx that encompasses total CO_2 emissions resulting directly and indirectly from an activity or from the life cycle of a product (Wiedmann & Minx, 2007).

carbon dioxide equivalents (CO_2e) – or **global warming potential** (GWP) - the total climate change effect of the six major GHG emissions specified by the 1998 Kyoto Protocol (carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride) (UN, 1998). Some tools provide an inventory of each GHG, resource inputs such as land, water and/or raw materials use. These inventory tools have a wide range of applications, including measuring impacts from electricity generation, heating and cooling, transportation, construction, and waste disposal. While these direct and indirect emissions sources contribute heavily to climate change, another source exists – one often overlooked in the field of impact inventory methodologies, both for its complexity and a common under-representation of its significance as a contributor to a host of environmental and health impacts: the food system.

Food systems are the networks of activities, individuals, companies and resultant food products involved in the production, transportation, consumption, and disposal of food, as well as the complex relationship between food production and the natural environment (Bertalanffy, 1950; Leischow & Milstein, 2006; Sobal, Kettel Khan, & Bisogni, 1998). Within a food system, these activities associated with individual foods can be expressed as a **life cycle:** A sequence of processes that encompass agricultural production, processing, packaging, storage, distribution, preparation, consumption, and waste management (Andersson, Ohlsson, & Olsson, 1994). At each process along the life cycle of a food product, an interchange of inputs and outputs in the form of raw materials, energy, land and water use, and impacts on the air, water and soil takes place as a flow between the food system and the environment. While sustainable food production practices can achieve a better balanced flow exchange between the food system and the environment, the global food system as a whole – particularly meat production - contributes to an extensive array of environmental and health harms, including the release of GHG emissions (Horrigan, Lawrence, & Walker, 2002).

The main contributors to GHG emissions from the food system are **methane** (CH_4), **nitrous oxide** (N_2O), and **carbon dioxide** (CO_2). Globally, agriculture accounts for the bulk of methane emissions, predominantly from livestock production, and nitrous oxide emissions, primarily from fertilizer use (IPCC, 2007a). Sources of CO_2 emissions include agricultural land use and fossil fuel combustion. While CO_2 is present in much greater atmospheric concentrations, methane has 25 times the GWP of CO_2, while nitrous oxide has 298 times the GWP and can remain in the atmosphere for 114 years (IPCC, 2007b).

The IPCC states that 13.5 percent of global anthropogenic GHG emissions are due to agriculture, and 17.5 percent are attributed to forestry, of which deforestation for food production is a major component (IPCC, 2007a; U.S. Environmental Protection Agency, 2008). In the U.S. alone, where one might expect minimal agricultural contributions relative to industry and transportation related emissions, agriculture accounts for an estimated ten percent of anthropogenic GHG emissions (U.S. Environmental Protection Agency, 2008).

Livestock production is the element of the food industry that contributes the greatest share of GHG emissions. According to the United Nations Food and Agriculture Organization, this process contributes 18 percent of the world's CO_2e anthropogenic GHGs, largely in the form of methane from enteric fermentation (primarily belching by cattle) and manure, as well as releases of CO_2 from soil and vegetation, following deforestation for animal feed production and pasture (UN FAO, 2006). Based on current trends, livestock production is projected to increase significantly over the following decades, exacerbating already substantial effects on atmospheric GHG concentrations (McMichael, Powles, Butler, & Uauy).

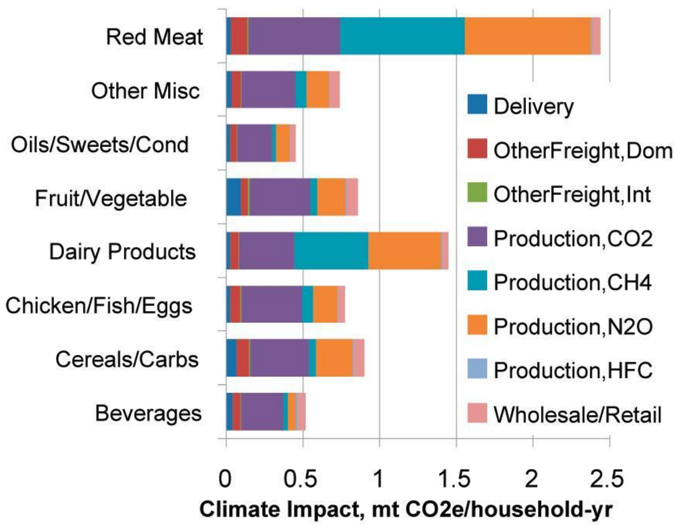
An estimated 19 million tons of nitrogen are applied annually in the form of chemical fertilizers and manure (U.S. Geological Survey, 1999). This heavy use of chemical fertilizers, in addition to soil management practices, is responsible for 72 percent of U.S. nitrous oxide emissions (EPA, 2008).

While close to one third of global anthropogenic CO_2 emissions may come from agriculture and land use changes, such as deforestation for feed crops, much of the remaining two thirds may be attributed to fossil fuel combustion (IPCC, 2007b).

The U.S. food production system, including agricultural processes, accounts for 17 percent of national fossil fuel use (Horrigan et al., 2002; David Pimentel & Pimentel, 2003). Farm operations such as plowing, fertilizer and pesticide use, and irrigation, including indirect emissions from raw material extraction and production of the necessary equipment and materials for these operations, are particularly energy and fossil fuel intensive (Lal, 2004). Following the agriculture stage, the energy inputs for processing and packaging a food product often far outweigh the energy provided by the food itself, as is the case for breakfast cereals (D. Pimentel & M. Pimentel, 1996). While there has been much public interest in the impact of food transportation, or "food miles," in actuality, evidence shows that it accounts for a relatively small share of GHG emissions, on the order of 2-4 percent of the overall total (Collins & Fairchild, 2007; Pretty, Ball, Lang, & Morison, 2005; Saunders, Barber, & Taylor, 2006). One US-based study estimated that about 11 percent of *food-related* GHG emissions might come from transportation, of which final delivery from producer to retail (delivery or distribution phase) accounted for four percent. As shown in *Figure 1,* below*,* in comparison to other food types, red meats and cereals and carbohydrates were the largest contributors of transportation-related GHGs in the U.S. (Weber & Matthews, 2008). After production and delivery, food refrigeration accounted for more than half of the energy consumption in food retail (Heller & Keoleian, 2003).

Foods may be responsible for GHG emissions even after their disposal. According to the USDA's Economic Research Service, an estimated 96 billion tons of food were discarded in 1995, representing 27 percent of edible food available in the entire U.S. (Kantor, Lipton, Manchester, & Oliveira, 1997). This discarded organic matter releases methane during decomposition in landfills. Furthermore, food loss makes inefficient use of the GHG emissions and resource consumption resulting from previous life cycle stages.

Figure 1. Total GHG emissions by supply chain tier associated with U.S. household food consumption



Total metric tons of GHG emissions per U.S. household, per year, are displayed on the horizontal axis.

The delivery stage of production (typically referred to as "food miles"), displayed as the thin dark blue segment on the far left, represents transportation from the farm or production facility to retail. This stage does not include *indirect* transport (represented by *Other Freight*), such as transporting feed to livestock, which accounts for the bulk of transportation emissions for meat and dairy products.

According to this study, CO_2 - denoted by the purple segment - accounts for only 44 percent of GWP associated with food production, underlining the need to measure a broader set of impacts than CO_2 alone. However, these results ignore emissions arising from land use change, underestimating total GHG emissions.

Source: (Weber & Matthews, 2008)

Other environmental and health impacts

The original emphasis of this report was on methods to quantify GHG emissions from food procurement. However, certain aspects of large-scale food production contribute to a number of other environmental impacts, many of which result in more direct and immediate consequences to human and ecosystem health than those of climate change. Further, the suggested design for the new tool is based on data that already captures these additional impacts. Incorporating these into the inventory results of the new tool may encourage food service providers and academic institutions to consider a broader view of impacts and tradeoffs involved in food procurement.

Heavy application of nitrogen based fertilizer presents threats to human health and aquatic ecosystems. Soil erosion, precipitation, and groundwater transport the nitrogen from farmland to streams, rivers, and subsequent coastal waters. The resulting high nitrate concentrations in drinking water have been linked to infant death or "blue baby syndrome," while excess nutrients in surface water can lead to algae overgrowth, subsequent decay, and low oxygen concentrations (hypoxia), followed by massive die-offs of aquatic life (U.S. Geological Survey, 1999). The "dead zone" found in the Gulf of Mexico is a prominent example of these conditions (Rabalais et al., 1996). The World Resources Institute identifies over 131 hypoxic sites with excess nutrient content along coastal North America and the Caribbean, among them are 12 distinct sites in the Chesapeake Bay alone (World Resources Institute, 2008).

The extensive use of pesticides, including herbicides, presents additional threats to the environment, health, and the economy. An estimated 800 million pounds of pesticides are applied annually in the U.S. for agricultural purposes. Overexposure to pesticides in humans has been implicated in the development of cancer, acute toxicity, immunosuppression, disorders of reproductive, endocrine, and nervous systems, and respiratory and dermatological effects (Physicians for Social Responsibility, 2000; U.S. Geological Survey, 1999). In addition to human health impacts, pesticide use has a major impact on the health and populations of beneficial wildlife, including predators, parasites, and pollinators. Adverse effects of pesticides on honeybee colonies, for example, have resulted in decreased honey production, as well as severe crop loss due to lack of pollination. Meanwhile, the heavy use of pesticides has often resulted in the development of resistances in harmful pests, weeds, plant pathogens and arthropod disease vectors. These resistances can, for example, render efforts at insect pest control ineffective, even after repeated applications (David Pimentel & Pimentel, 2008).

Industrial meat production is etiologic in a number of environmental and health harms. Air and water pollutants from animal waste near factory farm operations have been linked to respiratory disease and bacterial infections, as well as a number of other illnesses (Choinière & Munroe, 1997; Glasgow, Burkholder, Schmechel, Tester, & Rublee, 1995; Heller & Keoleian, 2003). Antibiotic use in livestock may promote the development of resistant bacteria, contributing to resistances in humans and compromising antibiotic use in medical settings (Horrigan et al., 2002). Agricultural processes, as a whole, occupy roughly 34 percent of global land area (larger than that of any other human activity), of which 300 million hectares are devoted solely to U.S. livestock feed production (Betts, Falloon, Goldewijk, & Ramankutty, 2006; USDA, 2001). This unsustainable agricultural land use is rapidly eroding topsoil, compromising long term food production. Finally, agricultural processes utilize an estimated two-thirds of water use worldwide, with enormous volumes dedicated to irrigating feed grain crops for U.S. beef production – producing one kg of beef requires 43 times more water than producing one kg of grain (D Pimentel et al., 1997; D. Pimentel & M. H. Pimentel, 1996; Postel, 1996).

While these impacts are not inclusive of the environmental and health effects of industrial food production, they serve to illustrate some of the many impacts beyond GHG emissions that may be taken into consideration when measuring an institutional foodprint.

Steps toward a smaller foodprint

Steps can be taken to minimize or avoid many of the negative outcomes associated with industrial food systems. Sustainable farming practices such as conservation tillage, use of organic fertilizers and pesticides, crop rotation, promoting biodiversity, and rotational livestock grazing can lessen environmental and health impacts of agricultural production (Horrigan et al., 2002; U.S. Environmental Protection Agency, 2008). Substituting cattle production with monogastric (single stomach) animals such as poultry could substantially reduce methane emissions (McMichael et al.). By minimizing packaging and energy-intensive production practices, food manufacturers can reduce energy, fossil fuel and raw material consumption.

Although the aforementioned practices generally result in overall impact reductions, due to complexities in the relationship between food, health, and the environment, changes in production methods may have mitigating or uncertain effects on reducing GHG emissions while adversely affecting other impact categories. For example, research findings comparing GHG emissions from grass fed beef versus confined animal feeding operations (CAFO) are mixed. Grass fed beef operations require less energy and result in lower methane emissions from manure, while conventional feeds are formulated to be highly digestible, reducing cattle belching (Monteny, Bannink, & Chadwick, 2006). Further, conventional livestock production methods use means to encourage rapid animal growth and enhanced milk production, reducing the need for as many cows and consequently decreasing GHG emissions (Ogino, Kaku, Osada, & Shimada, 2004). Due to uncertainties in quantifying GHG emissions, identifying the preferred method of production from a climate change perspective is difficult, and results may vary by study design (Gibbons, Ramsden, & Blake, 2006). However, there are many other adverse health, environmental and animal welfare impacts of conventionally produced beef. If food service providers focus on solely on reducing GHG emissions, opportunities for other meaningful environmental and health impact reductions could be overlooked.

From an individual consumer standpoint, dietary changes can reduce **indirect emissions** from food purchases – GHG emissions that have already been incurred during production, and are embodied in the consumer *product*, in contrast to **direct emissions** that occur directly from the individual's *activities*. Favoring foods such as produce, nuts, seeds and legumes over high-impact foods such as red meat and dairy can dramatically reduce indirect GHG emissions. Further, choosing foods produced locally, using organic methods, and in-season (for produce), with minimal processing and packaging, may further reduce indirect impacts.

While the population's summed individual choices can make an important difference in reducing GHG emissions, decisions on the institutional level can have far greater reach. Food service providers face the need to meet customer demand and satisfaction; reducing carbon emissions provides challenges and opportunities. While there is a growing movement at academic institutions across the country to reduce their campus' carbon footprints, this sentiment is not always held by the majority of consumers. In part because so little information has been communicated regarding the current food system and its significant contribution to GHG emissions, some consumers may object to favorite foods being less available. Food service providers can circumvent much of this tension by assuring that low carbon offerings are appealing, and by strategic use of higher carbon favorites. Another issue is that, because the food industry operates on such narrow profit margins, purchasing food that has a lower carbon footprint may in some cases incur expenses that are not passed on to the customer. In other cases, low carbon foods could save money.

Many dining services have already embraced initiatives that reduce the environmental impacts of their operations. Such measures include forming partnerships with local and organic farms, offering more vegetarian selections, switching to less energy-intensive preparation methods and more efficient utilities, using fewer disposable serving items and discontinuing to provide customers with trays to carry their food – substantially cutting back on food waste and cutting costs. These steps demonstrate an important level of commitment and response to demand. Food service providers, however, need quality impact assessment tools in order to make informed decisions regarding changes to their food procurement processes.

The Need for Food-Based Impact Assessment Tools

As the magnitude and complexity of the food system's contribution to climate change have become more fully understood, demand has increased for a tool that will measure the emissions associated with the growing, processing, transportation, consumption and disposal of food. A 2001 report by Lenzen expressed the concern that GHG emissions calculators often focused solely on direct emissions, namely household energy use and vehicle travel, while omitting indirect emissions resulting from the consumption of goods and services. Doing so neglects to convey the significance of consumer choices such as food purchases (Manfred Lenzen, 2001; M Lenzen & Smith, 2000). Academic institutions in particular have requested that the calculators they use to measure how much their electricity and vehicle use contribute to the atmospheric concentration of GHGs, also allow them to measure the emissions from their dining halls. Due to limited data and the complexities inherent in how food is produced, there are very few available tools designed to measure the GHGs associated with purchased foods at an institutional level; of these, each employs methods and features that may be applicable to CA-CP's purposes, as well as incompatibilities that preclude their direct use as the CA-CP foodprint tool. For example, tools may offer a limited selection of foods, require heavy investments of time and/or money, base calculations on data specific to a particular geographical region, require a level of expertise beyond that of a typical user, and/or apply strictly to a specific subsector of the food industry.

The aforementioned limitations in available GHG emissions data present additional challenges. Based on our review, there are currently very little data on GHG emissions for specific processes in the U.S. food production system. Until a greater breadth of data are available, the results of a CA-CP foodprint tool may not allow for the degree of accuracy necessary for GHG reporting or other specific claims regarding the exact quantities of emissions associated with food sourcing. However, and more importantly, the use the foodprint tool presents opportunities for *relative* comparisons and immediate action.

An accessible, methodologically sound, institutional foodprint calculator based on a comprehensive selection of foods would allow food service providers to estimate GHG emissions, in addition to other environmental and health impacts, associated with food sourcing, preparation, consumption, and disposal. This resulting impact data - or **inventory** - may create opportunities to identify and address areas along the supply chain where significant, cost effective emissions reductions could be made. Emissions inventories could be generated between actual and alternative scenarios to evaluate proposed sourcing changes, or, emissions may be compared over time to track progress in emissions reductions. Retailers may communicate messages to their consumers regarding environmental performance, and market their services accordingly. Academic institutions able to track the GHG emissions of their food service providers may base contracting decisions on emissions profiles. These opportunities can encourage purchasing and practice shifts across the industry. Coupled with a comprehensive education campaign geared towards consumers, particularly those in academic settings – many of whom may be receptive to addressing environmental issues - these tools could engage broad audiences and thus facilitate profound reductions in the food sector's GHG emissions.

Life Cycle Assessment

In order to develop a comprehensive foodprint tool, it is necessary to have specific data on the impacts associated with numerous food items along all relevant stages of production. Food data need to be granular enough to distinguish between various production methods, such as conventional versus more sustainable operations. Given the diversity in quality, content, and relevance of available food impact data, and the inevitable need to parse, prune, modify, combine and interpret said data in the development process of a foodprint tool, it is helpful to first describe the framework upon which much of the data regarding GHG emissions from the food system are based: **life cycle assessment** (LCA). LCA is typically a **cradle-to-grave** approach that measures the environmental impacts arising throughout the entire life cycle of a product system (ISO, 2006). In the context of food, the life cycle begins at agricultural production of raw ingredients and ends at food waste emissions, or in some cases, recycling of raw materials (Andersson et al., 1994).

There are several approaches to LCA. **Process LCA** (PLCA) is based on a network of linked "processes" such as soil tillage, pesticide and fertilizer use, grain processing, transportation, oven use, and so forth that ultimately model the impacts of a final product such as "wheat bread." An alternate LCA method, **Economic Input-Output LCA** (EIOLCA), expresses environmental impacts associated with a given amount of monetary spending in a particular industry sector. PLCA is the preferred approach, but due to the labor-intensiveness of collection, data are often unavailable. **Hybrid LCA** (HLCA) combines the two methods by substituting EIOLCA data where PLCA are lacking. Numerous software packages provide an interface with LCA data for the purposes of modeling and interpreting product impacts.

While the LCA framework, software modeling tools, and databases are later discussed in further detail, the preceding brief introduction may be useful in framing the results of the following review of methods and tools for measuring the indirect environmental impacts of food procurement.

METHODS

In order to review and build upon existing work in quantifying food-related GHG emissions, literature searches were performed in four overlapping stages:

1. First, literature searches targeted existing tools or protocols for measuring individual, household, institutional, process or product-based GHG emissions with regards to the food system. Queries with search keywords such as “foodprint,” “footprint,” “emissions,” “impact,” “LCA,” and “calculator,” combined using logical operators (“and,’ “or,” “not”), were applied to search engines on research websites such as the Pew Center for Climate Change and the World Business Council for Sustainable Development; to peer-reviewed journal databases such as Agricola and Science Direct; and to the Google search engine. Comprehensive manual searches were performed on sites including the Association of Advanced Sustainability in Higher Education (AASHE), the Berkeley Institute of the Environment, the Leopold Center for Sustainable Agriculture, the European Commission, the Food Climate Research Network (FCRN), and the Swedish Institute of Food and Technology (SIK). Initial searches typically expanded to include multiple follow up links to other sites. Finally, additional materials were acquired via phone and email contacts with industry experts. For a list of primary search sources, see *Table 8. Non-inclusive list of primary search sources, p. 48.*

2. A second search phase was conducted in order to compile and review LCA methods, software tools, and databases, with an emphasis on applications of LCA to the food system.

3. Third, comprehensive interviews were conducted with LCA researchers, consultants, software developers and database managers, in addition to corporate representatives from food service providers. Expert correspondence also included live online software demonstrations of LCA modeling tools, as well as active participation in beta-testing of the OpenLCA software tool with numerous databases, including the European ELCD and the Danish Food LCA databases.

4. A fourth stage was conducted to acquire additional peer-reviewed literature, in order to authenticate information gleaned from corporate and institutional websites and correspondence.

The preceding search methodologies produced a wide variety of relevant documents, presentations, websites, software tools and data sources. These were comprised of articles and reports from peer-reviewed journals and governmental departments; websites and documents from corporations, universities, research institutes and consulting agencies; presentations and course materials assembled by industry experts; institutional, individual, process and product-based impact assessment tools; emissions reporting standards, LCA modeling software tools, food LCA studies, and LCA databases. Findings were catalogued accordingly; see *Table 7. Categorization of findings, p. 48.*

Following the search, findings were assessed for their applicability to the new tool.

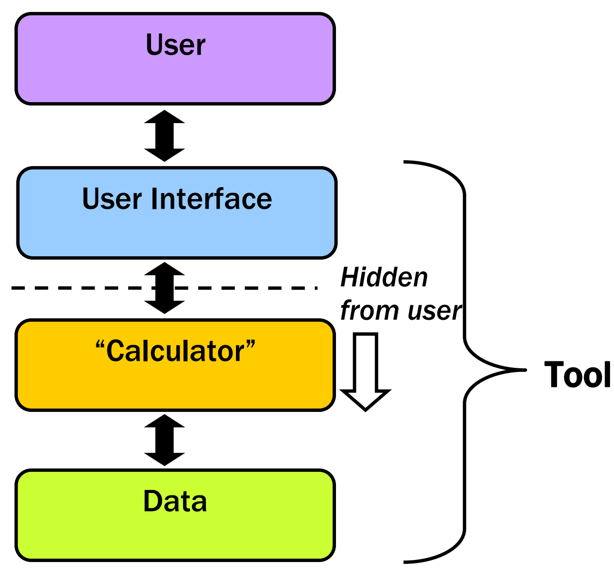
RESULTS

Below, we present findings and discussion of their relevance to the development of the new tool. Topics covered are: a general schema of GHG emissions and other environmental impact inventory tools, discussion of review criteria, opportunities to partner with developers and other organizations, pertinent individual, household, and institutional-impact inventory tools, and a general introduction to LCA methods, data sources, and modeling software.

Impact inventory tools and methods: General schema

The majority of tools reviewed followed the general schema depicted here in *Figure 2.* Users include individuals representing themselves, a household, or an institution. The user interface reads user input and communicates results. "Under the hood," hidden from the user, inventory results are calculated based on user input and underlying data. Existing tools vary widely by features ("what" the tool can do), methods ("how" the tool works) and underlying data.

Figure 2. Inventory tool schema



Of greatest importance to developing the new tool is acquiring quality food impact data, particularly process data (explained below under *Life Cycle Assessment (LCA), p.27*). Breadth of ingredient selection and accuracy of results depend almost entirely on the underlying data. While a user interface and calculator can be developed within CA-CP, secondary food LCA data are extremely limited - particularly for a U.S. context - and primary data are extremely time and resource intensive to collect.

Impact Inventory tools and methods: Review criteria

Existing methods and tools were evaluated for their utility in the development of the new tool.

Evaluations of tools were based on applicability of methods, features, data, cost, availability and customizability to CA-CP's purposes. The first question is whether there is a tool, usable "as-is," that meets these criteria. Such a tool must, at minimum: function on an institutional level, include a breadth of raw ingredients and unprepared foods, make sound use of unaggregated cradle-to-gate PLCA data (explained further under *Life Cycle Assessment (LCA) p. 27* and *THE NEW CA-CP TOOL: Suggested guidelines, p. 39*) and be publicly available and at no cost to the user. Based on the history of refinement of the CA-CP *Campus Carbon* Calculator, a tool should ideally be open to customization and further development within CA-CP. A tool applicable in most but not all of these regards may be modified for use. Tools may be *illustrative* of applicable methods, features and/or use of data even if the tool itself does not contribute to the development of the new tool. Tools such as LCA modeling software may aid the development of the new tool. Most importantly, many tools use underlying data that may be used - sometimes with necessary modifications – as data for the new tool.

Methods such as LCA (also represented in various tools and data) were similarly evaluated for how well they could be employed by the new tool.

Impact inventory tools and methods: Summary of findings

Search results identified over 40 tools for calculating the environmental impacts of products and/or activities at an individual or household level, and over 30 tools and methods (not including LCA modeling tools, described under *LCA Modeling Software, p.37*, and *Table 13. Summary of LCA modeling software*, p. 60) for calculating impacts at an institutional level. Of these, approximately half had some relevance to food production and/or procurement. None were suitable "as-is" for CA-CP's purposes, for reasons including: features limited to an individual user (i.e. inability to enter bulk quantities), use of broad food category data (lack of specificity), lack of food selection (lack of breadth), inability to parse delivery and subsequent stages from food models, use of data specific to non-U.S. contexts, applicability limited to a narrow aspect of production or to a sub-sector of the food industry, unavailability for public use and/or costs to the user in the form of subscription or purchasing fees. Approximately 10 tools used data applicable to the new tool, or were *illustrative of* features, methods or data applicable to the new tool. These are described in further detail below.

For complete listings of individual, household and institutional-level tools, see *Table 9. Summary of individual- and household-level tools that factor food purchasing, p. 49,* and *Table 10. Summary of institutional-level tools and methods applicable to food production or procurement, p.53.*

For comparisons between existing tools of interest and the proposed new tool, see *Table 1. Summary of comparisons between select existing tools and the new tool, p.26.*

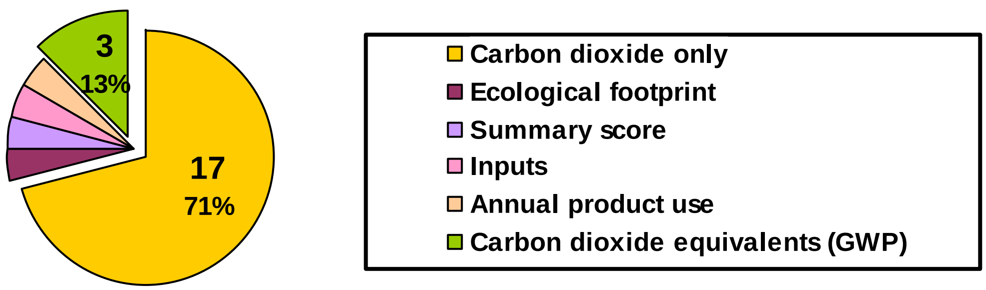
Individual- and household-level environmental impact inventory tools

The following tools allow users to calculate the direct and/or indirect environmental impacts of activities and/or products at an individual- or household-level. All of these tools reviewed are publicly available as web-based calculators that typically considered factors such as home energy use, vehicle miles traveled, vehicle fuel efficiency, and purchasing decisions. Based on user input, calculators reported environmental impacts, most commonly in the form of a carbon footprint.

46 unique individual or household calculators were reviewed. Identical calculators hosted on multiple websites were not double-counted. Of these, 24 factored food purchasing in determining indirect impacts.

Of the 24 calculators that factored food, only three (12.5 percent) reported emissions as CO_2e – surprisingly few, given the importance of non-CO_2 GHG emissions in the food system, while the vast majority - 17 (71 percent) - reported CO_2 impacts only[1]. Additional impacts reported by existing individual-level calculators included inputs such as land, fertilizer, pesticide and manure use; a multi-factorial summary score based on inputs, outputs, and animal welfare considerations; expected quantities of annual consumption of foods and other products, extrapolated from weekly consumption; and finally the user's **ecological footprint** - for an individual, this is a measure of the earth's regenerative capacity to restore the natural resources consumed by the individual over the course of a year, expressed in terms of global hectares (gha) of biologically productive land (Venetoulis & Talberth, 2006). For a distribution of calculator outputs, see *Figure 3*, below.

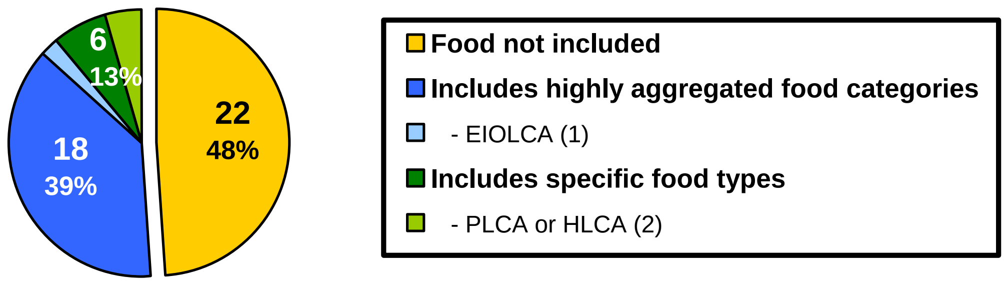
Figure 3. Distribution of outputs among individual or household calculators that include food



Among the 24 tools that factored food purchasing, user inputs for foods ranged from general (number of people in the household who include meat in their diet) to specific (number of servings of a particular food type in a given meal). 18 based results on quantities of broadly aggregated food categories such as *vegetarian, non-vegetarian, meat*, or *organic food*. CO_2 emissions data per category were based on national averages. Six tools offered more specific food types, for example, the two tools developed by the Center for Science in the Public Interest accepted as input weekly servings of a small variety of foods such as beef, chicken, pork, yogurt, hard cheese, and eggs (Center for Science in the Public Interest, 2008). Two PLCA/HLCA tools and one UK-based tool offered the broadest variety of specific food inputs. For a distribution of food inclusion, see *Figure 4*, below.

[1] Tools that reported "CO_2 " or "carbon footprint" without mention of "equivalents," "GWP," or "climate change potential" were assumed to report CO_2, and not CO_2e. This was verified wherever information was available.

Figure 4. Distribution of food inclusion in individual- and household-level calculators



Of the 24 tools including food options, three relied explicitly on LCA. The Bon Appétit Management Company Foundation's *Low Carbon Diet Calculator* uses PLCA, Berkeley Institute of the Environment's *CoolClimate Carbon Footprint Calculator* is based on EIOLCA, and EcoSynergy's *EcoImpact CO_2 calculator* uses HLCA. As these tools are illustrative of LCA methods and data sources applicable to the new tool, they are discussed in greater detail below. For a review of comparisons between these tools and considerations for development of the tool, see *Table 1. Summary of comparisons between select existing tools and the* new tool*, p. 48.*

PLCA tool: *Low Carbon Diet* calculator
Web: www.eatlowcarbon.org

The Bon Appétit Management Company Foundation (a 501c3), an industry leader in providing sustainable, socially responsible dining services to corporations and academic institutions, provides a free tool for estimating the GHG emissions associated with the production, distribution and preparation of foods. As users drag and drop selections from a catalog of prepared foods onto a "virtual pan," the calculator provides the total associated GHG emissions expressed in grams of CO_2e (Bon Appétit Management Company Foundation, 2008a).

Based on the methods and assumptions paper, the *Low Carbon Diet Calculator* uses secondary process data to model **cradle-to-gate** food emissions – those emissions that occur along the life cycle of the product up until the point of delivery from a farm or distribution warehouse gate to final retail. Supply chain management software and other methods were used to calculate final delivery and preparation emissions, based in part on primary data regarding Bon Appétit operations. Given the lack of process data specific to U.S. food production systems (an inevitable challenge for any U.S.-based foodprint tool), mostly European food models were used, with exceptions including North American seafood. Wherever possible, electricity generation processes were replaced with U.S. data to better localize food models. For a small number of foods such as highly processed items (hot dogs, pasta, soda, etc.) and bananas, only transportation emissions were available (Scholz, Ayer, Venkat, Tyedmers, & York, 2008). Data from these calculations were incorporated into the catalog of prepared foods, wherein final emissions results available to the user represent **cradle-to-grave** (full life cycle) emissions, with the exception of nitrous oxide (due to data limitations) and methane from food waste (Bon Appétit Management Company Foundation, 2008b).

Delivery emissions, based on generic national and international distribution chains, were calculated with assistance from *CargoScope* software. Certain produce and seafoods were assumed to have originated from default locations. Seasonality was factored into certain delivery distances; for example, some out of season fruits were assumed to have been air-freighted from South America. In some cases, where final transportation emissions could not be parsed from food models, it is possible that transportation emissions may have been double counted (personal communication, Helene York, *Director*, Bon Appétit Management Company Foundation; 2008), (Scholz et al., 2008).

Finally, cooking and storage emissions were based on the most commonly-used commercial oven, fryer and refrigerator models. Calculations accounted for the mass of foods per volume (for storage and delivery) as well as energy use for various appliances based on data from the Food Service Technology Center and Energy Star (personal communication, Helene York, *Director*, Bon Appétit Management Company Foundation; 2008), (Scholz et al., 2008).

Inapplicabilities

The *Low Carbon Diet Calculator* tool is not applicable "as-is" for CA-CP's purposes as it is not designed for an institutional user – foods are entered one serving at a time, making bulk entries cumbersome. Further, food models, *as they are provided to the user*, are based on cradle-to-grave assessments. Data in this aggregated form does not allow for separate handling of delivery, preparation, consumption and disposal on a per-institution basis. Where a GHG inventory has already been conducted, this could lead to double-counting, as emissions from the latter stages are already taken into consideration by the existing CA-CP tool. Generalizing delivery distances, while practical from a consumer standpoint, does not capitalize on the opportunity to customize delivery data for individual institutions.

Opportunities

The Bon Appétit Management Company Foundation has assembled food LCA models of 60 raw ingredients and menu items[1], adapted to (to the extent possible) or based on a U.S. context, and use disaggregated LCA process data (personal communication, Helene York, *Director*, Bon Appétit Management Company Foundation; 2008), (Scholz et al., 2008). Disaggregated data (explained under *Life Cycle Assessment (LCA), p.27*) can be parsed by life cycle stage in order to address the aforementioned concerns regarding delivery and double-counting of emissions. This data would likely be of great value to the new tool and may reduce development time for CA-CP (Acquisition of LCA data for the new tool is further discussed under *THE NEW CA-CP TOOL: Suggested guidelines, p.39*).

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[1] Menu items are specific to Bon Appétit recipes; however, this does not preclude the use of component raw ingredients in the pilot tool.

EIOLCA Tool: *CoolClimate Carbon Footprint Calculator*
Web: coolclimate.berkeley.edu U.S. EIOLCA Database: www.eiolca.net

The *CoolClimate* tool, based on EIOLCA, calculates indirect GHG emissions for a single user or household based on consumer choices. Users enter U.S. dollars spent on housing, food, clothing, furniture and appliances, and other goods and services. Food categories are broken down by industry sector: meat, fish and eggs; fruits and vegetables; cereals and bakery products; dining out; and other foods (snacks, drinks, etc.). For each dollar spent in a particular industry sector, associated amounts of GHG emissions are tallied, and the calculator displays the resulting tons of CO_2 per year (Jones, 2005; The Berkeley Institute of the Environment, 2008).

Inapplicabilities

The *CoolClimate* tool uses a small selection of very broad food categories for a simpler user experience. The complete U.S. EIOLCA database, available at www.eiolca.net, features somewhat finer distinctions and many more categories to choose from, though still at an industry sub-sector level. This broad aggregation is the main limitation of EIOLCA. GHG emissions may vary widely within an industry sector due to differences in food production methods; failing to capture these differences could give the user the false impression that all of the various production methods within the *cattle production* sector, for example, result in identical environmental impacts. Consequently, the user would see no benefit to procuring more environmentally-friendly versions of food products.

Opportunities

Despite the aforementioned limitations, EIOLCA data may be supplemented where PLCA data are lacking. The complete U.S. EIOLCA database is available free on the web. Additional strengths and limitations of EIOLCA are described under *Economic input-output LCA, p. 34.*

HLCA Tool: EcoSynergy *EcoImpact CO_2 calculator*
Web: www.ecosynergyinc.com/info/widget.php

The EcoSynergy *EcoImpact* calculator is based on HLCA. It employs primary data from clients where available, as well as U.S. EIOLCA data and process data from sources such as the U.S. National Renewable Energy Laboratory (NREL) Database. The tool is the first carbon footprint calculator made available to share freely over the web.

Inapplicabilities

The calculator is designed for an individual user. Primary data collection for cradle-to-gate processes is not typically viable for food service providers due to a lack of access to data and time and resource restrictions. Selection of foods, based on the product demo, is limited to 24 items. The tool outputs CO_2 only.

Opportunities

The *EcoImpact* calculator is illustrative of use of HLCA.

FoodCarbon *FoodCarbon Footprint Calculator*
Web: www.foodcarbon.co.uk/calculator.html

The *FoodCarbon* calculator provides a relatively comprehensive questionnaire of household food purchases including beef, chicken, milk, apples, bananas, potatoes, carrots, beans, bread, and rice; with respective quantities, origins, and production methods (i.e. organic versus conventional, chilled versus fresh, etc.) for each. The calculator outputs resulting "carbon emissions" (actually a combination of CO_2, methane, and nitrous oxide expressed in CO_2e) per year, as well as CO_2 emissions specific to the annual consumption of each food item (FoodCarbon, 2006).

Inapplicabilities

The calculator is designed for an individual user. Questionnaire format does not facilitate product based comparisons. Emissions data are limited a U.K. context[1]. Results are extrapolated to annual consumption.

Opportunities

Developers included the most relevant – in this case, frequently purchased – foods, based on U.K. household consumption data (FoodCarbon, 2006). This use of a "basket" of representative foods is illustrative of the need to identify relevant food data for inclusion in the new tool. The new tool might include, for example, those raw ingredients that are most frequently utilized by food service providers, as well as those with the highest associated GHG emissions. This is further discussed under *THE NEW CA-CP TOOL: Suggested guidelines, p. 39.*

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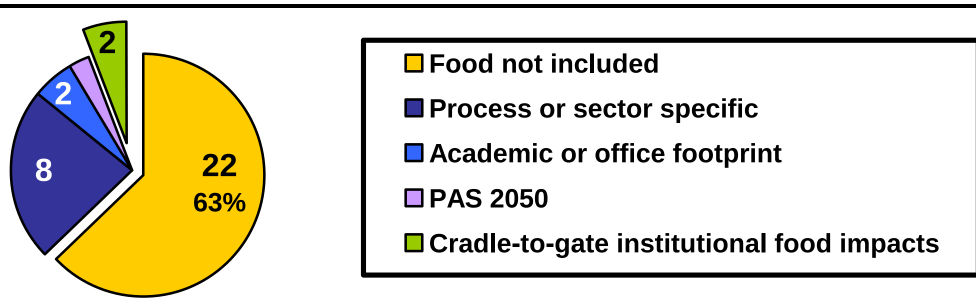
[1] Geographic context of emissions data was not confirmed at the time of this writing.

Institutional-level environmental impact tools and methods

The following tools and methods allow users to calculate the direct and/or indirect environmental impacts of activities and/or products at an institutional-level.

35[1] institutional-level tools, created by 20 different developers or development partnerships, were reviewed. 13 addressed the food-system on some level. Of these, seven lacked specificity to particular food types and were applicable only towards particular processes along the life cycle such as transportation, pesticide, fertilizer, farm fuel, and land use; livestock production, deforestation, or refrigeration. An additional tool was specific to the beverage industry. Publicly Available Specification (PAS) 2050 is an industry-wide, publicly available methodology for quantifying GHGs of goods and services, and is discussed in further detail below (British Standards Institution, 2008). Finally, two tools with the ability to quantify food product-based impacts on an institutional level were illustrative of methods, features and data used in the new tool, and are reviewed below. For a distribution of food inclusion, see *Figure 5*, below.

Figure 5. Distribution of food inclusion in institutional, process and product-based tools



Process- and industry sector- specific tools may aid the development of the new tool by providing process-specific calculation methods or by serving as additional data sources; however, most of these tools are designed primarily for use within the specific industry and context they are geared towards. For example, the *CALM Calculator - CO_2 Accounting for Land Managers* is devised with agricultural or forestry businesses in mind, distinct from tools designed for assessing product-specific impacts using an LCA framework (CLA: Country Land & Business Association, 2008). Other tools are specific to a geographical context, such as *FOOTPRINT: creating tools for pesticide risk assessment and management in Europe* and the *Carbon Calculator for New Zealand Agriculture and Horticulture*. Other process-specific tools and methods, such as those featured in *CargoScope* and *Food, Fuel and Freeways*, are illustrative of methods to calculate emissions from final delivery from farm or processing facility to retail. Finally, the sector-specific *Sustainability Standard for The Global Beverage Industry* may feature methods or data applicable to inclusion of beverages in the new tool; however, this project is currently in development.

[1] Approximate; not including the CA-CP tool; counting each Greenhouse Gas Protocol Initiative, CA Climate Action Registry, and Best Foot Forward tool separately.

Institutional footprint tools: *CarbonScope* and *Footprinter*

CarbonScope: www.cleanmetrics.com   Footprinter: www.custom.footprinter.com

Two tools, CleanMetric's *CarbonScope* and UK-based Best Foot Forward's *Custom Footprinter: Ecological and Carbon Footprint Calculator*, measure food-based GHG emissions on an institutional level. Both tools are illustrative of the general design of the new tool: Both tools use cradle-to-gate food LCA models as underlying data, delivery emissions are handled separately depending on distance and mode of transport, and quantities of multiple food products are taken into consideration, allowing for inclusion of large-scale institutional purchases (*Clean*Metrics, 2008; Footprinter, 2008; Wakeland, Venkat, & Sears, 2007).

CarbonScope is a prototype tool that includes over 100 food products with a high level of specificity (low aggregation), including meats, dairy, seafood, cereals and grains, legumes, vegetables, fruits, frozen foods, baked goods and some processed foods. Specific examples include: *beef – factory-farmed, frozen; tilapia – farmed, frozen; tomato, greenhouse; tomato, conventional; tomato, organic,* etc. U.S. data are used wherever possible, with additional research underway by CleanMetrics to acquire process data specific to various regions within the U.S. Currently, the highest level of confidence in data accuracy is with plant-based foods; however, this may be addressed in the future as additional data are acquired. The tool outputs CO_2 and CO_2e, and displays transportation emissions separately (personal communication, Kumar Venkat, *President and Chief Technologist*, CleanMetrics; 2008), (*Clean*Metrics, 2008; Wakeland et al., 2007).

Footprinter includes a selection of foods based on cradle-to-gate LCA models (delivery is handled separately), based on Ecoinvent and other data sources. Some food LCA models were developed by Best Foot Forward (personal communication, Paul Cooper, *Managing Director*, Best Food Forward Ltd; 2008).

Inapplicabilities

CarbonScope is a prototype tool and is not yet available for public use (personal communication, Kumar Venkat, 2008). Use of CleanMetrics and Best Foot Forward tools require subscription costs to each user.

Footprinter handles foods on a broadly aggregated level, for example: *Dairy, Meat-poultry-fish, Cereals, Beverages*, etc., and does not distinguish between organic and conventional production methods. Furthermore, the tool is designed for a U.K. setting. The tool outputs CO_2 footprint and Ecological Footprint, but does not provide GWP results (Footprinter, 2008).

Opportunities

Both tools are illustrative of the general design for the new tool.

Of key applicability to the purposes of the new tool is the existing and potential future collection of process data regarding U.S. food production. Acquisition of LCA data for the new tool is further discussed under *LCA data sources, p. 36* and *THE NEW CA-CP TOOL: Suggested guidelines, p.39.*

Supply chain tools: *CargoScope* and other methods
Web: www.cleanmetrics.com

Quantifying GHG emissions from final delivery of foods from gate-to-retail (food miles) presents a number of challenges, discussed under *THE NEW CA-CP TOOL: Suggested guidelines, p.39.* Further, the GHG emissions associated with food miles are relatively low, as previously mentioned; however, where information on user supply chains and local food production are available (the latter is rarely the case), inclusion of food miles in final calculations *may* result in more accurate emissions inventories and/or influence food procurement decisions in support of local foods.

To guide calculation of delivery emissions, *CargoScope* software allows institutions to map detailed supply chains and calculate energy use and GHG emissions from transport, processing and storage (personal communication, Kumar Venkat, *President and Chief Technologist*, CleanMetrics; 2008). Methods and data featured in reports such as *Food Fuel, and Freeways, Wise Moves* and *Food-Miles and the Relative Climate Impacts of Food Choices in the United States* can help guide development of the delivery component of the new tool. For example, Weber and Matthews describe applications of EIOLCA to measure emissions of food miles within the life cycle of a food (Weber & Matthews, 2008).

Inapplicabilities

Use of *CargoScope* requires subscription fees and use of a separate tool on the part of each user. Where data on supply chains or local food production are unavailable, environmental benefits of "going local" may be misleading.

Opportunities

Use of tools and/or methods with/in the new tool in order to measure emissions from final delivery may prompt minor reductions in CO_2 emissions.

Institutional method: British Standards Institution *PAS 2050*
Web: www.bsi-global.com/en/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050/

Publicly Available Specification (PAS) 2050, produced by the British Standards Institution (BSI), is an industry-wide, publicly available methodology for assessing the life cycle GHG emissions of goods and services, including foods (British Standards Institution, 2008).

Inapplicabilities

PAS 2050 is currently in development, with a projected completion date of September/October 2008 (British Standards Institution, 2008). Although PAS 2050 includes examples applicable to foods, it is a general methodology and is not specific to the food industry. PAS 2050 is a specification, and is neither a tool nor a data source, nor does it provide guidance (i.e. best practices).

Opportunities

Adhering to accepted methodologies such as those outlined in PAS 2050 provide organizations with an added level of credibility. Multiple organizations using the same standards can make meaningful comparisons of emissions results.

Table 1. Summary of comparisons between select existing tools and the new tool

"Preparation" of foods typically refers to grilling, steaming, baking, mixing, or other processes that prepare foods for consumption. "GWP" is synonymous with CO_2e.

	Target user	Cost to user	Data sources	Food selection	System boundary for food inputs	Impacts
New tool	Institution	Free	Primarily PLCA, may use EIOLCA if needed (HLCA)	Raw ingredients and processed foods, unprepared. Specific to production methods where possible.	Cradle-to-gate; delivery handled separately	GWP, eutrophication, land use, water use, etc.
Bon Appétit Management Company Foundation *Low Carbon Diet Calculator*	Individual	Free	PLCA	60 specific menu items and raw ingredients, mostly prepared. Some specific to production.	Cradle-to-grave	GWP
Berkeley *CoolClimate Carbon Footprint Calculator*	Individual	Free	EIOLCA	6 generalized categories.	Cradle-to-gate	CO_2
EcoSynergy *EcoImpact CO_2 Calculator*	Individual	Free	HLCA	24 foods. Some specific to production.	Cradle-to-grave[1]	CO_2
CleanMetrics *CarbonScope*	Institution	Pay for use	PLCA[2]	Over 100 foods. Some specific to production.	Cradle-to-gate; delivery handled separately	CO_2, GWP
Best Foot Forward *Custom Footprinter: Ecological and Carbon Footprint Calculator*	Institution	Pay for use	PLCA[1]	Generalized foods, UK context.	Cradle-to-gate; delivery handled separately	CO_2, Ecological Footprint

Sources: (Best Foot Forward, 2008; Bon Appétit Management Company Foundation, 2008a; *Clean*Metrics, 2008; EcoSynergy, 2008; The Berkeley Institute of the Environment, 2008)

[1] Presumed; not yet verified with developers.

[2] Possible use of EIOLCA has not yet been verified.

Developers and other organizations: Opportunities for cooperation

In addition to existing tools and methods, software developers, LCA consultants, database managers and other organizations are valuable resources in the technical development of the new tool. In addition to expert guidance, these organizations may offer options to modify existing tools or data for CA-CP's purposes. Of greatest value to the new tool are food LCA data that have been collected within or adapted to a U.S. context – a few such efforts have been completed or are currently underway at select organizations.

Representatives from CleanMetrics (*Carbonscope* and Cargoscope), the Bon Appétit Management Company Foundation (*Low Carbon Diet Calculator*), ecointesys (*green-e* carbon accounting tool), PE (*GaBi* LCA modeling tool), Earthshift (consultants for *SimaPro* LCA modeling tool) have expressed openness to the possibility of sharing or customizing existing tools and/or data for CA-CP's purposes. The open source LCA modeling tool *OpenLCA*, developed by Green Delta TC, is based upon a principle of freely shared modifiable content, and provides access to a community of developers who may be willing to assist in the development of the new tool. Other tools such as *Custom Footprinter* advertise customizability on product websites. Further, many of the aforementioned institutions have already provided invaluable guidance for the development of this report, and may wish to continue to do so for the CA-CP project once underway.

The main advantage to employing expert assistance and existing data is the opportunity to capitalize upon existing resources without "reinventing the wheel," cutting development time and supporting pre-existing efforts to address climate change issues. Further, relying on proven expertise may provide a level of confidence in the quality and methodological soundness of the product.

Disadvantages to this approach may include heavy cost investments to CA-CP and potentially to each user, depending on agreements regarding use of proprietary data or technology. In addition, reliance on external development may preclude the ease with which the tool can be modified or updated over time.

Life Cycle Assessment (LCA)

Of these preceding tools reviewed, those that rely on LCA data offer (or have the potential to offer) the widest selection[1] and specificity of foods, as well as the most comprehensive inventories of associated life cycle impacts. For these reasons, LCA frameworks, data, and tools are employed in the development of the new tool. Further, the developer must be familiar with LCA in order to select appropriate data sources and software packages, to interpret existing food LCA data and identify areas that may need to be modified for the purposes of the new tool, and to interpret and present results of food LCAs to the user.

[1] Although the *CoolClimate Carbon Footprint Calculator* offers a limited selection food categories, EIOLCA on the whole offers a somewhat broader selection of food industry subsectors.

Although detailed explanation of LCA methodologies is beyond the scope of this report, concepts of particular relevance to the development of the new tool are discussed below.[1]

Life cycle assessment (LCA) is a methodological compilation and evaluation of the environmental impacts occurring along the life cycle of a particular product or service (ISO, 2006). LCA is used across industrial, medical, corporate, marketing, retail, policy and research settings, just to name a few. LCA is a system-wide approach that typically encompasses the entire life cycle from cradle-to-grave, including extraction of raw materials, production, product use, end-of-life treatment, recycling and final disposal (ISO, 2006).

LCA has several applications in the food industry, and is fundamental to the new tool. LCA allows for the quantification of impacts along all stages of the life cycle from agricultural production of raw ingredients through food waste emissions, including processing, packaging, refrigeration, cooking, and consumption (Andersson et al., 1994). The results of this analysis enable food producers, distributors or retailers to identify and address areas along supply chains where the greatest reductions in environmental impacts are possible. LCA also allows consumers to make environmentally-conscious food choices by comparing the impacts of different products, while policy makers have used LCA to guide legislation on packaging (Andersson et al., 1994). Of greatest relevance to the goals of this report is the ability of LCA to measure the GHG emissions and other impacts resultant from a single food item, summed to address those of a meal, a café, or an entire food service provider.

LCA is typically comprised of four stages: 1. defining the purpose and system boundaries of the LCA (goal and scope definition), 2. modeling the food and calculating resultant impacts (inventory analysis, or LCI), 3. interpreting results (impact assessment, or LCIA), and 4. exploring conclusions, recommendations, and potential improvements (interpretation) (EPA, 2001; ISO, 2006). Since the new tool is partially reliant on existing LCA models, development of the tool may not require every stage to be addressed in its entirety. These stages are as follows:

1. **Goal and scope definition:**

   The first stage of an LCA is the definition of the goal and scope, including system boundaries and the functional unit to be studied (ISO, 2006).

   Common goals of LCAs include comparing the impacts of products, or identifying stages along a product life cycle where significant impact reductions are possible (EPA, 2001). For the purposes of developing the new tool, LCA is used to quantify impacts in a consistent manner across a variety of foods and raw ingredients.

   The **system boundary** defines which elements of a complete system are included under

[1]We recommend consulting the International Organization for Standardization (ISO) 14040 series for complete descriptions of LCA standards and methodologies. ISO documents are available for purchase at http://www.iso.org/iso/iso_catalogue.htm.,

the assessment. This may involve setting geographic or temporal constraints, or excluding certain processes along the life cycle (Andersson et al., 1994; Keoleian & Menerey, Jan. 1993). For example, a full **cradle-to-grave** LCA quantifies impacts from raw ingredients acquisition through food waste management (EPA, 2001; Keoleian & Menerey, Jan. 1993). Though not considered a "true" LCA by some standards, system boundaries may include only segments of the life cycle. A **cradle-to-gate** food LCA study begins at the agriculture phase and ends at the farm or wholesale gate. Subsequent stages along a food life cycle could be defined as **gate-to-kitchen** or gate-to-retail (encompassing final delivery), followed by **kitchen-to-grave** (encompassing preparation, consumption, and disposal).

The **functional unit** describes the product under analysis to which impact results – the life cycle inventory – are attributed (EPA, 2001). Examples of function units include *one kg cheese wrapped in plastic, 1,000 kg tomato ketchup, 400 g package frozen cod fillets,* and *1,000 L milk (1.5% of fat) transported to a retailer* (Andersson, Ohlsson, & Olsson, 1998; Berlin, 2002; Grönroos, Seppälä, Voutilainen, Seuri, & Koikkalainen, 2006; Ziegler, Nilsson, Mattsson, & Walther, 2002). Descriptive functional units, such as those that specify use of packaging (canned, bottled, shrink-wrapped, etc.) as well as the state of the food (frozen, raw, boneless, etc.), inform the new tool user of the exact nature of the product to which impacts are attributed.

2. **Life cycle inventory analysis (LCI):**

   The **life cycle inventory analysis** (LCI) stage encompasses obtaining data, modeling the product system and calculating the resultant inventory of **inputs** (use of land, water, raw materials, energy, etc.) and **outputs** (emissions to the air, water and soil; resultant products) to and from the environment and within the food system. Data collection is often the most time and resource-intensive process (ISO, 2006). The new tool relies on secondary data, circumventing the need for primary data collection; however, data gaps regarding U.S. food production create the inevitable need to estimate processes along the life cycle using European proxies. Methods to model foods as product systems are described under *The product system model*, below.

   The resultant inventory, calculated using LCA modeling software (described under *LCA Modeling Software, p.37*) comprises the total resource and energy use and emissions to air, water and soil that occur over the life cycle (or partial life cycle, depending on the system boundary) of the product.

3. **Life cycle impact assessment (LCIA):**

   Once the total inputs and outputs are tallied in the LCI stage, life cycle impact assessment (LCIA) is intended to evaluate the significance of inventory results (ISO, 2006).

   Impacts of interest are first grouped by impact categories such as global warming, acidification, or eutrophication (EPA, 2001). Following categorization, inventory results may be **characterized,** or re-expressed in standardized metrics. For example, CO_2, methane, nitrous oxide and other GHGs can be expressed as carbon dioxide equivalents

(CO_2e) by multiplying the mass of each gas by a "characterization factor," then summing the results to provide a single overall indicator of **global warming potential (GWP)** (EPA, 2001). This and other metrics such as ozone depletion potential (CFC-11 equivalents), resource depletion potential, or human health indicators communicate meaningful and simplified results to food service providers and their customers, helping to guide measurable impact reductions (Andersson et al., 1994; Hofstetter & Müller-Wenk, 2005).

4. **Life cycle interpretation:**

   Lastly, LCIA results are considered in the form of conclusions and/or recommendations (ISO, 2006). Although not emphasized in ISO documentation, improvement analysis - an additional component of the final LCA stage - allows institutions to compare alternative scenarios and invoke appropriate action (Andersson et al., 1994). For example, food service providers may wish to compare indirect GHG emissions, water use, soil erosion and financial costs resultant from current ingredient inventories to alternative scenarios that source less meat and processed foods, and/or more organic, local and in-season produce.

The product system model

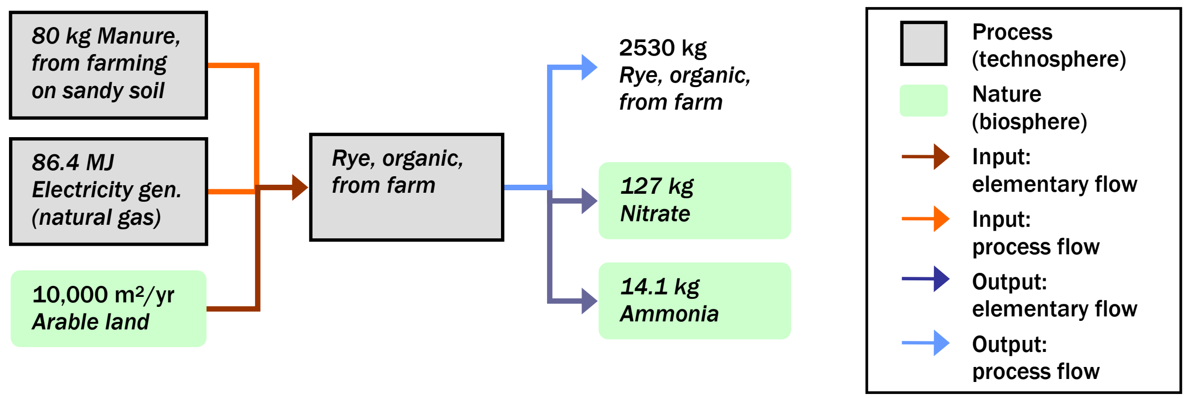
There are a number of approaches to modeling a food product for the purposes of generating LCIA results. These include the use of a process flow diagram, an economic input-output matrix, or a hybrid approach (Suh & Huppes, 2005). Since the process flow diagram provides a helpful visual of process LCA, and is common to most LCA software tools, it is described in detail here.

The **product system** model, within the context of PLCA, typically represents the life cycle of the product as a network of **processes** interconnected by flows (EPA, 2001). Processes are activities (sometimes defined by resultant products) along the life cycle such as *livestock feed (soy)*, *filleting of fish,* or *heating in conventional oven*, and may be expressed in various units such as mass, volume, or energy. A process may occur early in a product life cycle, such as *Natural gas extraction and processing, 1,000 cubit feet* or *electricity from wind production;*, at a retail stage, such as *Bread (wheat), fresh, in supermarket*; or at product end of life, such as *Municipal waste deposition in sanitary landfill* (CPM, 2008; European Commission, 2007; National Renewable Energy Laboratory (NREL), 2007; Nielsen, Nielsen, Weidema, Dalgaard, & Halberg, 2003). A single process may be linked, directly or indirectly via process flows, to hundreds or even thousands of other processes. For an example of a process flow diagram, see *Figure 7. Example LCA model of chicken from farm, p. 33.*

Processes are associated with **flows** - inputs and outputs to the food system, either to or from nature (the **biosphere**), or other processes (the **technosphere**) (Rebitzer et al., 2004). **Process flows** (**intermediate flows** in ISO documentation) are products, materials or energy flowing from one process to another (ISO, 2006). **Elementary flows** are exchanges between the product system and the environment, and include raw materials (oil, gas, metals, wood, etc.), or land use (ISO, 2006). Elementary outputs are flows that leave the product system into the air, water, or soil as atmospheric emissions (GHGs, particulate matter, etc.), water effluents, and solid wastes (Andersson et al., 1994; EPA, 2001). For an example of a process with associated flows, see *Figure 6. Process diagram with associated flows,* below.

Figure 6. Process diagram with associated flows

Partial depiction of input and output exchanges for Danish rye production.



Data source: (Nielsen et al., 2003).

Processes may be **unit processes**, the smallest subdivisions of the product system that cannot be broken down (Frischknecht & Rebitzer, 2005; ISO, 2006). Alternatively, complex processes may be composed of other sub-processes: **unaggregated process** may be broken down into component processes, while **aggregated processes** - analogous to aggregated EIOLCA data - may not be subdivided (2.-0 LCA consultants, 2003). For examples of unit processes and associated inputs and outputs, see *Table 2* and *Table 3*, below.

Table 2. Process: production of domestic corn

Unit process. Functional unit: one planted acre of corn, for one year.
Partial listing of input and output exchanges are displayed, excluding quantities of each flow.

Inputs		Outputs		
Elementary flows (resources, water)	**Process flows**	**Elementary flows: Air**	**Elementary flows: Water**	**Process flow**
Land Use: Cropland (Conservation Tillage), Land Use: Cropland (Conventional Tillage), Water: River, Water: Well, etc.	Agrochemicals, Diesel (Farm Tractor), Electricity, Nitrogen Fertilizer, Potash Fertilizer, Phosphorous Fertilizer, Transport: Rail, etc.	Ammonia, Carbon Dioxide (CO_2, biomass), Carbon Monoxide, Methane, Nitrogen Oxides, Nitrous Oxide, etc.	Acetochlor, Bromoxynil, Cyanazine, Glyphosate, Nitrogenous Matter, Phosporous Matter, Permethrin, etc.	Corn Production, USA domestic production, on the field

Source: (National Renewable Energy Laboratory (NREL), 2007)

Table 3. Process: electricity generation, U.S.

Unit process. Functional unit: one kWh of electricity.

Inputs		Outputs		
Elementary flows	**Process flows**	**Elementary flows**	**Process flow**	
None.	Bituminous coal, .53 lbs Lignite coal, 0.049 lbs Residual fuel oil, 0.0022 gallons Natural gas, 1.82 ft^3 Nuclear fuel, $1.40x10^{-6}$ lbs Hydroelectric energy, 0.279 MJ Biomass / Wood, 0.173 Mj Wind, 0.0058 MJ Solar, 0.00065 MJ Geothermal, 0.044 MJ Other fossil, 0.0726 MJ	None.	Electricity generation, U.S.: 1 kWh	While this process is generalized on a country level, quantities of each flow could be modified to adapt this process to particular regions within the U.S. Note that not all processes have elementary flows, as impacts to the environment may be addressed indirectly via other linked processes (i.e. CO^2 emissions would occur from *natural gas* combustion and other process inputs).

Source: (National Renewable Energy Laboratory (NREL), 2007)

Once processes are linked together, LCI tallies the elementary flows of an entire product system. LCIA characterizes these flows for ease of interpretation. For examples of LCIA results, see *Table 4*, below.

Table 4. LCIA examples: conventional chicken, U.S. and Denmark; beef, Denmark

The lesser environmental impacts of U.S. broiler poultry production depicted here do not account for human and animal welfare, heavy antibiotic use and other concerns arising from the intensive nature of the industry. Further, system boundaries between U.S. and Danish production must be scrutinized for consistency before making accurate comparisons.

Note that while GWP values between U.S. and Danish production are within an order of magnitude, discrepancies across results highlight the disadvantage of using European data as proxies for a U.S. context.

	Functional unit and geographic context:	Production of one kg broiler poultry, live weight, U.S.[1]	Production of one kg *chicken, from farm*, live weight, Denmark.	Production of one kg *cattle, ex farm*, live weight, Denmark.
	System boundary:	Cradle-to-farm gate.	Cradle-to-farm gate.	Cradle-to-farm gate.
Inputs	Energy use	14.96 MJ	*	*
	Land use	**	3.6 m^2 / year	18 m^2 / year
Outputs	GWP	1,395 g CO_2e	1,860 g CO_2e	11,600 g CO_2e
	Ozone depletion	0.0322 μg CFC-11 eq.	*	*
	Acidification	15.8 g SO_2 eq.	34.2 g SO_2 eq.	117 g SO_2 eq.
	Eutrophication	3.9 g PO_4 eq.	*	*
	Nutrient enrichment	**	149 g NO_3 eq.	988 g NO_3 eq.
	Smog formation	**	0.335 g ethane eq.	2.4 g ethane eq.

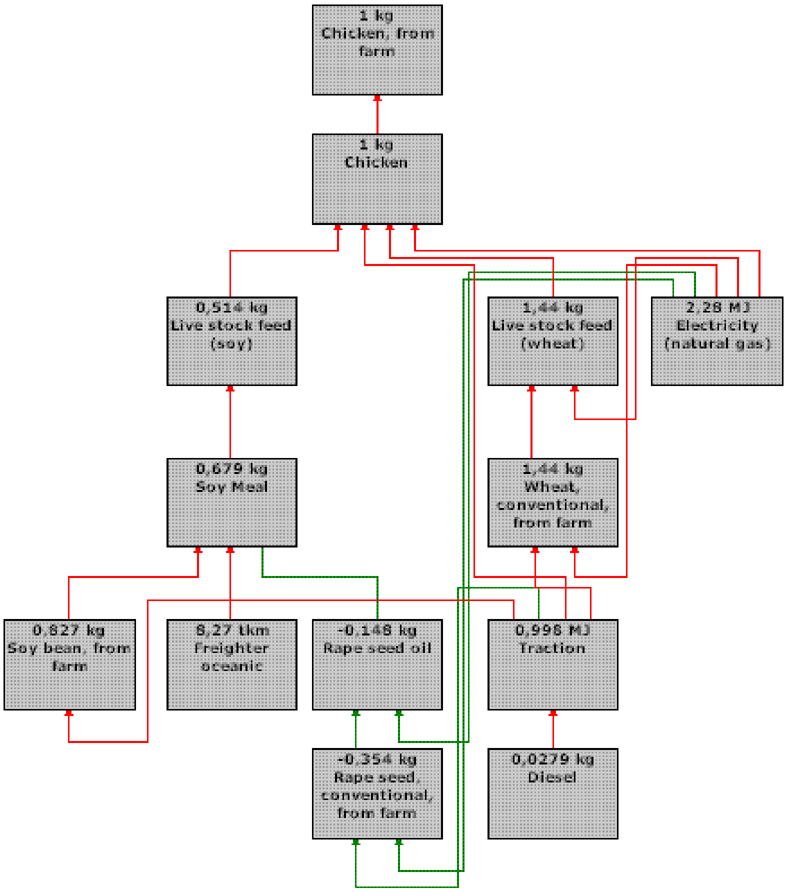
Sources: (Andersen & Jensen, 2003; Jensen & Andersen, 2003; Pelletier, 2008; Weidema, 2003)

[1] The original study assessed one metric ton of broiler poultry as the functional unit.

* Not published under LCI summary. Results could be calculated using necessary process data and LCA modeling software.

** Not included under study.

Figure 7. Example LCA model of chicken from farm



Example LCA product system model of chicken raised in a typical Danish farm, *covering only the most important* processes in terms of GWP. The functional unit is 1 kg of chicken, from farm. This is a cradle-to-farm gate model.

Gray boxes represent processes, arrows represent process flows of materials or energy. Each process may have elementary flows, not shown here, representing inputs from and outputs to the environment, such as GHGs.

Adapting this model to a U.S. setting could, for example, involve replacing *2.28 MJ Electricity (natural gas)* with multiple processes representing electricity generation from coal, natural gas and nuclear power. Furthermore, feed inputs of wheat and soy may be replaced by a mixture of corn and soy. For an institutional food provider setting, it may be appropriate to add additional processes for slaughter, processing and packaging.

Sources: (Andersen & Jensen, 2003; Nielsen et al., 2003). Model displayed using SimaPro software ((PRé Consultants, 2008)).

Table 5. Summary of product system model terminology[1]

Term	Definition
Product system:	Representation of a product as a network of processes linked by process flows, with associated elementary flows to the environment.
Process:	Activity (sometimes defined by resultant product) occurring along the life cycle of a product or service. Processes may be linked, directly or indirectly via process flows, to hundreds or even thousands of other processes.
Aggregated process:	Complex process that cannot be subdivided into individual sub-processes.
Unaggregated process:	Complex process, individual sub-processes can be viewed / modified.
Unit process:	The smallest subdivision of the product system.
Process flow:	Input from, or output to, the technosphere, i.e. other processes.
Elementary flow:	Input from, or output to, the biosphere, i.e. air, water, soil, or resources.

Sources: (2.-0 LCA consultants, 2003; Boustead, 1993; Frischknecht & Rebitzer, 2005; ISO, 2006; Rebitzer et al., 2004)

[1] Use of terminology may vary in existing texts. Refer to ISO 14040 series for widely accepted standards.

As noted above, there are two main LCA approaches relevant to assessing food-related impacts: Process, and economic input-output LCA. These are described below; given their complementary strengths and limitations, an optimal solution for a relatively comprehensive assessment of food-related GHG's is often to combine both methods in a hybrid LCA (HLCA) approach.

Process LCA

As described in stage 2: *Life cycle inventory analysis (LCI)*, PLCA is based on a compilation of data covering each process involved in creating a product, either collected directly, or taken from secondary sources such as LCA databases.

PLCA food data are preferable for use in the CA-CP tool. The main strength of PLCA (as recognized by experts in the LCA community) is that PLCA data are specific to the process level, allowing for detailed assessment of finely aggregated specific food products (Minx, Wiedmann, & Barret, 2008). **Aggregation level** can refer to the degree of specificity regarding the product under analysis, or, to the underlying data. High levels of aggregation, "produce" for example, provide generalized information; a low level of aggregation such as "tomato, hydroponic, grown in California, U.S." is far more specific (C. T. Hendrickson et al., 1997; Minx et al., 2008). While PLCA models may still rely on assumptions – particularly when relying on secondary data sources as representative for a particular process – PLCA is generally accepted (due, in part, to endorsement by the International Standards Organization (ISO)) as a preferred method over EIOLCA, provided system boundaries are well defined, and data are available (Minx et al., 2008).

The main disadvantage of PLCA is a lack of U.S. data, particularly with regard to foods (Andersson et al., 1994). While European process data can be used as proxies, differences in food production may result in inaccuracies. This can be addressed, to a degree, by substituting U.S. process data in European food models wherever possible. Furthermore, collecting primary PLCA data is time and resource intensive. Finally, defining system boundaries of food product systems can be particularly challenging; some processes are inevitably excluded from the model due to complexities and information gaps (Andersson et al., 1994; ISO, 2006; Minx et al., 2008).

Economic input-output LCA

The U.S. economic Input-output life cycle assessment (EIOLCA) database, developed at the Carnegie Mellon University Green Design Institute, is based on a combination of economic and environmental flows between industry sectors. EIOLCA data are available for multiple countries; however, for the purposes of this report it is described within a U.S. context. Financial dependencies between roughly 500 industry sectors, derived from U.S. census data, are recorded in a 500x500 (approximate) matrix. Each entry in the matrix represents a monetary flow from one industry sector to another, allowing for the calculation of financial dependencies for a given sector; for example, every $1 of output from fruit farming requires $.095 of input from agriculture and forestry, $.093 from pesticides and other agricultural chemical manufacturing, $.079 on wholesale trade, $.029 on oil and gas extraction, and so on (note that the cost values refer to *production* costs and not the actual costs to the consumer). Combining this economic data with each industry's associated environmental impact data - acquired from multiple sources, including the U.S. EPA -

allows for the calculation of environmental impacts per dollar spent on a given product within an industry sector (Carnegie Mellon University Green Design Institute, 2008; C. Hendrickson, Horvath, Joshi, & Lave, 1998; C. T. Hendrickson et al., 1997; Weber & Matthews, 2008).

The breadth of food data included under EIOLCA, as well as its system boundaries, may make it a valuable addition to the CA-CP tool; however, there are a number of limitations regarding its use.

EIOLCA data cover a broad range of food-related sectors of the U.S. economy including *grain farming, cattle production, vegetable and melon farming, fruit farming, pasta manufacturing, wineries, food services and drinking places*, and many others (Carnegie Mellon University Green Design Institute, 2008). Furthermore, sectors are linked to comprehensive impact data, including GHGs, pollutants, toxic releases, economic impacts, and fertilizer, fuel, and electricity use; however, the impact set may vary from those featured in PLCA databases (C. T. Hendrickson et al., 1997).

System boundaries of EIOCLA data are well-suited for use in the CA-CP tool. Since EIOLCA considers direct and indirect impacts from all major sectors across the entire U.S. economy, system boundaries are extremely broad and explicitly defined (C. Hendrickson et al., 1998). The supply chain is modeled from cradle-to-gate, allowing emissions from delivery and subsequent stages to be handled separately (Carnegie Mellon University Green Design Institute, 2008).

The main limitation of EIOLCA is its high level of aggregation. Broad industry sector categories such as *cattle production* fail to capture differences in modes of livestock production; however, in some instances categories such as *pasta manufacturing* may be suitable. In addition, EIOLCA data are based on an assumption that increased spending within a given industry sector is correlated with a rise in environmental impacts; this assumption does not always hold true, particularly regarding sustainably produced goods that are typically sold at a higher price. Further, EIOLCA are not compatible with a number of LCA software modeling tools. Other limitations of EIOLCA are covered in the literature; however, in its defense, one study found that results of LCA studies based on EIOLCA were comparable to, and achieved with less effort than, a PLCA approach (C. T. Hendrickson et al., 1997).

Hybrid LCA

There are a number of methods to combine PLCA and EIOLCA in modeling the product system for LCI, capitalizing on the strengths of each. These approaches are generally referred to as hybrid LCA (HLCA) (Suh & Huppes, 2005). For the purposes of the CA-CP tool, PLCA is preferable, with the option of substituting EIOLCA where necessary (Minx et al., 2008). The ability to combine PLCA and EIOLCA data, however, is dependant in part on the features of the LCA modeling software. Additional strengths, limitations, and detailed methodologies of HLCA are covered in the literature and are beyond the scope of this report.

LCA data sources

LCA data comprise the "building blocks" of which product systems are assembled. Data are typically categorized as process data, based on PLCA; or industry sector data, based on EIOLCA. LCA data can be acquired from various sources: The results of LCA studies of particular foods, in document form, provide aggregate LCIA results from product systems that cannot be viewed or dissected unless the principle investigator is willing to provide the underlying data; LCA databases (sometimes referred to as datasets) typically contain more finely aggregated process data across a breadth of modifiable processes; finally, LCA data acquired for the purposes of a particular corporation or research project may be of high quality but not publicly available. A summary of advantages and disadvantages of each source are summarized below under *Table 6*, below.

LCA Studies

The results of published LCA food studies provide aggregate life cycle inventories. As study results are available in document format, data are limited to whatever information is selected for publication, which typically include system boundary description, functional unit, and select LCI and LCIA results. Unless data are provided at the request of the principal investigator(s), it is impossible to reconstruct, examine, or modify product systems used in an LCA study. For this reason, LCI / LCIA results are specific to the product system under study, and may or may not be applicable to the desired purposes. For example, the LCIA results of a cradle-to-grave study *could* be used for the new tool; however, this would double-count gate-to-grave emissions.

LCA Databases (PLCA)

Unlike LCA studies, LCA databases typically provide less-aggregated data across a breadth of specific food-related processes. While the LCI / LCIA results of an LCA study are generally only available for use "as-is," process data from LCA databases can be viewed, combined and modified using LCA modeling software tools.

Developing a new CA-CP footprint tool based on LCA requires identifying and acquiring appropriate databases containing processes relevant to the food system; however, the majority of LCA data on the food system are based on a European context and need to be adapted to a U.S. setting. The most comprehensive source of food LCA currently available is the Danish *Food LCA* Database. Additional sources include the Swiss *EcoInvent Database*, containing hundreds of agricultural and food production processes, and the NREL *U.S. Life-cycle Inventory Database*, featuring processes for U.S. electricity generation, essential for localizing European data to a U.S. setting, as well as some U.S. agricultural processes (Frischknecht & Rebitzer, 2005; National Renewable Energy Laboratory (NREL), 2007). Combining processes from multiple databases may be necessary to ensure data are both up to date and geographically relevant, but identifying which processes are most appropriate for a given scenario requires a level of LCA expertise and knowledge of the relevant system. In addition, the cost of databases must be taken into consideration, as some require licensing fees. Finally, the data format must be taken into consideration to ensure compatibility with LCA modeling software tools.

A summary of reviewed LCA databases is given in *Table 12. Summary of LCA databases, p. 58.*

LCA Databases (EIOLCA)

The only EIOLCA database of interest to CA-CP's purposes is the U.S. EIOLCA database, covering a number of food-related industry sectors. Some LCA modeling software tools can combine EIOLCA and process data in the same product system. The entire database is available free online. EIOLCA is described above under *Economic input-output LCA, p. 34.*

External developers

Several initiatives have been completed, or are currently underway, to acquire U.S. food production process data and/or adapt European data to a U.S. context. These include projects by the CleanMetrics (developers of *CarbonScope* and *CargoScope*), PE (*GaBi* LCA modeling software), the Bon Appétit Management Company Foundation (*Low Carbon Diet*), and the UC Sustainable Agriculture Research & Education Program (personal communication, Gail Feenstra, *Food Systems Analyst*, UC Sustainable Agriculture Research & Education Program, UC Davis Agricultural Sustainability Institute; 2008).

Table 6. Summary of data source advantages and disadvantages

Data source	**Advantages** for use in development of the new tool	**Disadvantages** for use in development of the new tool
LCA Studies	Usually free. Based on specific foods.	Aggregated results, impossible to modify product system. Results may be limited to certain impacts. Most food studies based on European context.
PLCA Databases	Usually free, except for licensing fees (i.e. ecoInvent). Widest breadth of data. Disaggregated unit process data allows for development of specific food models.	Requires purchase of LCA modeling tool, unless using a free tool (i.e. OpenLCA). LCA modeling has steep learning curve. Some process data not compatible with certain modeling tools. Most food product data based on European context.
U.S. EIOLCA Database	Free. Based on U.S. context. Cradle-to-gate system boundaries.	Broad food categories based on industry subsectors. Requires purchase of LCA modeling tool if building complex product systems or combining with process data. EIOLCA data not compatible with certain modeling tools.
External developers	May be based on, or adapted to, U.S. context. Food models may be "ready for use" by CA-CP, cutting development time. Opportunity to capitalize on existing expertise, potentially high confidence in results.	Data may be proprietary. Potential costs.

LCA Modeling Software

For the purposes of developing the new tool (unless data development is relegated to an external organization), LCA modeling software is necessary to view, modify, combine, and interpret process data. Software packages offer a wide spectrum of features, including packaged databases, ability to import and export databases, characterization factors for LCIA, uncertainty analysis, cost analysis, etc. While a complete analysis of software features is beyond the scope of this report, certain software features may facilitate adaptation of food LCA models for use in the new tool. Chief among these is **system representation** – a graphical display of the product system – that allows the user to view and modify the product system as a network or tree (Baisnée & Heintz, 1993; Unger, Beigl, & Wassermann, 2004). An additional helpful feature is the automatic linkage of all **upstream** (earlier along the life cycle) processes by process flows - achieving this result manually can be time consuming; however, doing so allows the user greater control over the inclusion and exclusion of processes. Some tools, such as OpenLCA, offer aides to facilitate manual assembly of product systems. These features are further discussed under *LCA Modeling Software, p.38*, and a summary of reviewed software is provided in *Table 13. Summary of LCA modeling software, p.60.*

Institutional footprint tool with an LCA approach: *green-e*
Web: http://www.green-e.ch/

Ecointesys' *green-e* is unique in that it strikes a balance between the simplicity of institutional footprint calculators and the versatility of LCA modeling software. For its use of LCA databases and the LCA framework, it is categorized here as an LCA modeling tool; however, it could also be categorized above with institutional impact measurement tools.

While support from Ecointensys is recommended, *green-e* does not require as high level of expertise as LCA modeling. With this level of ease-of-use, certain features common to other LCA modeling tools such as system representation are not included. Users can combine process or EIOLCA data, building food LCA models in a downstream direction; however, upstream or "background" processes, while implicitly included in LCI results, cannot be viewed or modified. For CA-CP, this would preclude the ability to modify upstream processes such as electricity generation in European models. Finally, *green-e* includes cost analysis, a feature that may allow food service providers to identify cost-effective strategies to reduce environmental impacts (personal communication, Jon Dettling, *Director – North America*, Ecointesys; 2008).

Inapplicabilities

Use by food service providers requires product support and an investment of time (to build LCA food models) and cost (to purchase the tool). For use by CA-CP in the development of the new tool, *green-e* lacks certain features that would facilitate modification of product systems (i.e. to adapt models to a U.S. context).

Opportunities

green-e is a product-based impact inventory tool developed for use on an institutional level, and is illustrative of some methods and data used in the new tool.

THE NEW CA-CP TOOL: Suggested guidelines

The goal of this section of the report is to outline features, methods, data, development guidelines and other considerations, gleaned from the results of this review, for the new tool.

Overview

The target end user is a campus sustainability coordinator or student, working in partnership with the management of a campus food service provider. Although the underlying food life cycle data is based primarily (or solely) on PLCA, the user is not assumed to have previous knowledge of LCA, nor is such knowledge necessary for utilizing the tool, although a basic familiarity with GHG inventory tools may be helpful. As the tool is designed for use on an institutional level, users enter bulk quantities of ingredients and processed foods. Geographic context for food impacts is the U.S.; however, this does not preclude the inclusion of imported foods.

Structure

The structure of the new tool is defined by the following:

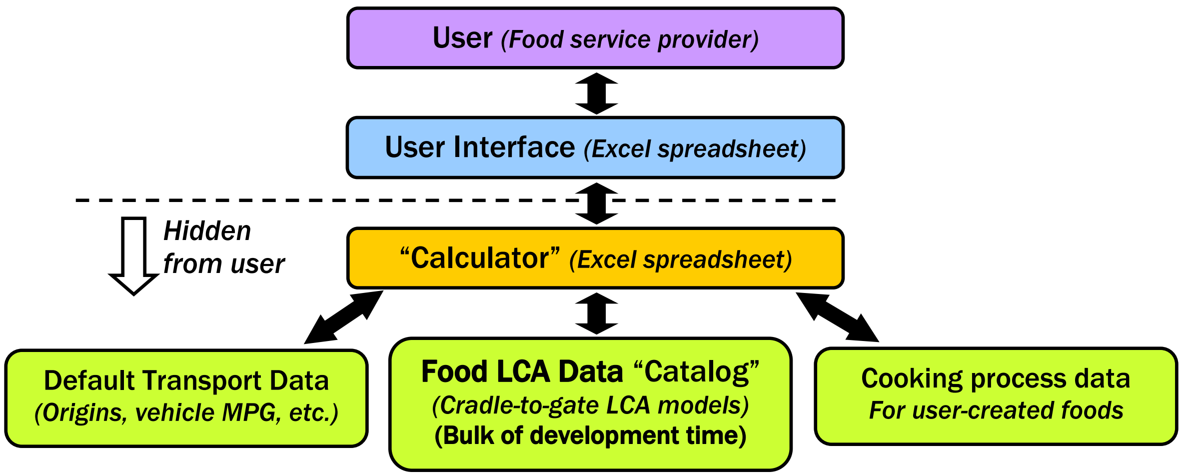
The user enters bulk quantities of raw ingredients and processed foods via a user interface. Impact results are displayed through the interface. In addition, the user may add supply chain information where available, for separate calculation of delivery emissions. The user may combine multiple ingredients and cooking processes to assemble custom entries for bulk entry of foods prepared off-site.

"Behind the scenes," hidden from the user, calculations based on user input and underlying data tally comprehensive environmental impact results.

The underlying data is the foundation of the tool, and includes default transportation data such as common food origins and vehicle mileage, cooking process data for creating custom foods, and most importantly, a "catalog" of cradle-to-gate food LCA models, including raw ingredients and processed foods. All underlying data are secondary, and are intended for shared use by any food service provider.

See *Figure 8*, below.

Figure 8. New tool structure



Calculation methods by life cycle stage

Impacts occurring along the life cycle of foods are handled in three stages using three distinct approaches. The food life cycle, for the purposes of measuring environmental impacts with the new tool, is subdivided into cradle-to-gate and gate-to-kitchen. Food service providers using the current CA-CP carbon accounting tool already measure GHG emissions from kitchen-to-grave (preparation, consumption and disposal). Methods to quantify GHG emissions and other environmental impacts at each subdivision are as follows:

Cradle-to-gate (production)

Food models adapted for inclusion in the data catalog are based on cradle-to-gate LCAs. Final delivery to the food service provider (food miles) and all subsequent **downstream** (later in the life cycle) processes are excluded from LCA models to avoid double-counting emissions from later stages.

Gate-to-kitchen (food miles / delivery)

Measuring emissions from "food miles" presents a number of challenges. Further, the GHG emissions associated with food miles are relatively low, on the order of 2-4% of total life cycle emissions (Collins & Fairchild, 2007; Pretty et al., 2005; Saunders et al., 2006; Weber & Matthews, 2008). However, where information on user supply chains and local food production are available (the latter is rarely the case), inclusion of food miles in final calculations *may* result in more accurate emissions inventories and/or influence food procurement decisions in support of local foods.

Where no user information regarding delivery sources are available, the new tool uses default food origins – varying by time-of-year, for seasonal foods – based on most common sources of production. A sample table with common origins for various produce items is featured in *Food, Fuel and Freeways (Pirog, Pelt, Enshayan, & Cook, 2001).* Default modes of transportation are based on origins, as demonstrated in the *Low Carbon Diet Calculator* research and assumptions paper. For example, unless available information suggests otherwise, products are assumed to be transported via midsize trucks, traveling empty in one direction, for distances of <500 km (Scholz et al., 2008).

Defaults can be substituted with user-specified supply chain data, where available. Methods such as weighted average source distance (WASD) are used to address foods with multiple origins (Pirog et al., 2001). More accurate distances based on delivery routes may be determined using external tools such as Google Maps.

Additional factors for consideration in calculating default and/or user-specified transport emissions may be considered, such as: vehicle mileage and cargo load, additional energy use from refrigerated transport or storage units (used at waypoints along supply chains), weight and volume of the shipped product(s) including packaging considerations and complications due to multipurpose trips. Additional methods or tools that may aid default and/or user-specified calculations include EIOLCA, as demonstrated by Weber and Matthews, and *CargoScope* supply chain management software (Weber & Matthews, 2008).

Using this approach to make comparisons between local and global food sourcing may be misleading. Even where complete and accurate supply chain information is available, evaluating the merits (or drawbacks) of local sourcing requires an assessment of local production methods, for which data rarely exist. Furthermore, reductions in food miles may be offset by inefficient distribution. Due to these concerns, combined with the relatively small potential emissions reductions, sourcing local foods – while encouraged where it promotes social causes – should not be emphasized as a way to reduce GHG emissions from transportation.

Data catalog

The underlying food data catalog is comprised of LCA models for each raw ingredient and processed food. LCA models are developed independently of the user, and only final LCIA (including some un-characterized LCI) results – in addition to data/study sources, date of study, brief description of system boundaries, geographic context and other descriptive information - are available to the user. Depending on the capabilities of the software tool used to develop the models, levels of uncertainty (confidence in results) may also be provided to the user.

Level of product aggregation

The data catalog features foods that are aggregated to the level of production methods, where data are available to do so. High levels of aggregation, "produce" for example, provide generalized information; a low level of aggregation such as "tomato, hydroponic" is far more descriptive, and less likely to produce imprecise results. This level of specificity is essential as the difference in impacts between an environmentally preferable product and one less so within the same product group (i.e. chicken) may be greater than the difference between two products from entirely different product groups (personal communication, Bo Weidema, *Senior Consultant,* 2.-0 LCA Consultants; 2008). Making the distinction between foods such as tomatoes grown in a hothouse, organically, or using hydroponics can inform food service providers and customers of the differences in environmental impacts between sustainable and conventional production methods, a distinction that would fail to be captured if the catalog featured broadly aggregated entries such as "tomato" or "beef." Unfortunately, due to limited data on U.S. food production, this level of specificity is – at present – unlikely for most foods.

Temporal and geographic relevance

Both product systems and individual processes should be based on up-to-date and geographically relevant data. For example, based on our review, the majority of food LCA data are based on European contexts. While in many cases the impacts may be reasonably comparable, key differences do emerge, and steps must be taken to localize food models wherever possible. In one relatively extreme example, an LCA study of frozen cod fillets accounted for the standard routes and modes of transportation from the Baltic sea (where the cod were caught) to the consumer's home in Sweden, and assumed the end user would store, prepare, and cook the cod without any product waste. The final stage of delivery was assumed to have been undertaken via bicycle (Ziegler et al., 2002). Some LCA models based on European studies make assumptions similarly inapplicable to the U.S. context regarding modes of transportation, use of renewable electricity generation, type of feed stock used, etc.

To the extent possible, it is important to identify key areas where product systems differ from a U.S. setting, and restructure them accordingly. Product systems and individual processes are typically labeled with the geographic context to which they pertain. Restructuring product systems can be achieved by replacing individual process data with U.S. equivalents – U.S. agricultural and electricity generation processes, for example, are available in the NREL *US Life-cycle Inventory Database*. Most modifications require insight into the U.S. food system; for example, restructuring the feed stock processes of a beef product system necessitates knowledge of the type and quantity of feed used in the production of a functional unit of U.S. beef.

Even with these modifications, until additional U.S. food production data are collected, results may be considerably imprecise.

System boundaries

As stated above, system boundaries for food models encompass cradle-to-gate impacts. In all other regards, product systems should be as complete, consistent and transparent as possible, including capturing transportation processes *during* production. This can prove challenging, particularly for multi-ingredient, processed, or imported foods - raw ingredients are often acquired from multiple countries, processing methods vary widely, and depending on availability there may be additional data gaps. Due to these complexities and unknowns, particularly with regards to a U.S. context, some upstream processes will inevitably be excluded out of an inability to accurately model a complete system (Andersson et al., 1994). These uncertainties should be made known to the user.

Uncertainty analysis

Imprecise results, as mentioned previously, may arise from the use of proxy data or incomplete product systems. Although a complete discussion of these concerns is beyond the scope of this report, uncertainty analysis – a measure of confidence in inventory results – has been stressed by industry experts as of critical importance, particularly with regards to food LCA (personal communication, Kumar Venkat, 2008; personal communication, Bo Weidema, 2008). Uncertainty analysis is a feature included in some LCA modeling software.

Due to these limitations in capturing accurate impact data, impact results must be recognized as generalizations. However, this does not preclude the opportunity for food service providers to make *relative* comparisons between scenarios, between individual retail sites, and over time. These comparisons present opportunities for reducing GHG emissions and other environmental impacts, as well as charting emissions over time.

Information transparency

If the new tool relies solely on free databases and LCA modeling tools, product systems will be available to the user should they wish to request them, or familiarize themselves with the LCA tools. The use of licensed databases and purchased LCA modeling tools, however, may limit the degree to which underlying process data can be shared with, or modified by, the user.

In general, the use of licensed databases or purchased modeling tools should not present a significant obstacle. It is unlikely that users would need, nor wish, to view food models at a level of detail where transparency issues would arise. Furthermore, it is unlikely that users would have the necessary training in LCA methodologies to effectively modify product systems to their needs, even if they should happen to acquire software themselves. Finally, some level of agency in assembling their own “mini” LCA can be provided to the user by allowing them to combine ingredients and cooking processes, described below.

Additional features

Impact reporting

LCA inventory data typically include a wide range of environmental and human health impacts beyond GHG emissions alone. Given the importance and magnitude of these impacts arising from food production, and the opportunity to quantify these using existing data, the new tool reports a comprehensive array of impacts.

Further, the new tool should communicate results to the user in a clear and comprehensive manner. For example, in addition to providing the user with individual outputs such as CO_2, methane, CFC and ammonia emissions, impact inventories may be presented characterized as global warming potential (GWP / CO_2 equivalent), ozone depleting potential (CFC-11 equivalent), acidification potential (H^+ equivalent), and so on. Certain less detrimental impacts, of which the bulk of most LCA inventories are comprised, may be excluded as to not overwhelm the user.

Characterization factors are typically handled by LCA modeling software; however, since delivery emissions are calculated independently of the data catalog, these emissions would be excluded from consideration by the LCA software. To address this, characterizations can be achieved without the need for LCA software, provided conversion factors are available (i.e. 10 g CH4 ≈ 10 g CO_2 x 23 = 230 g CO_2e).

To provide a visual depiction of impacts, an optional graphs/charts feature may be included in the tool.

User-generated catalog entries

The tool may provide users with basic functions that allow users to generate their own food catalog entries. This feature may apply to food service providers that source multi-ingredient and/or prepared foods that are produced off-site, as the indirect emissions from off-site preparation would not be included in the existing CA-CP *Campus Carbon Calculator*. Foods prepared off-site could include meals pre-prepared in bulk (i.e. "heat and serve" casseroles) by facilities associated with the food service provider.

Bulk entry of these foods can be addressed by providing the user with simple "LCA-lite" functionality, wherein the user can combine multiple raw ingredients and cooking processes to form a new catalog entry. Raw ingredients and cooking processes would be provided by the tool. Transportation from off-site production facilities to kitchen would be handled normally (*see Calculation methods by life cycle* stage, above).

Improvement analysis

The end goal of the CA-CP foodprint tool, in addition to measuring environmental impacts from food sourcing, is to inform and motivate food service providers (and indirectly, their customers) to make alternative food sourcing decisions that reduce those impacts. To facilitate this process, the new tool may provide users with a means to easily generate numerous alternative sourcing scenarios that can be compared alongside actual sourcing. In addition to comparing GHG emissions and other impacts across scenarios, a user may wish to compare costs in order to evaluate cost-effectiveness of impact reductions. Finally, the ability to save impact reports allows for impact data to be compared over time.

Development guidelines

User Interface and Calculator

Development of Excel-based user interface and calculator components is within CA-CP's level of expertise, given the relative simplicity of these components and CA-CP's experience in developing similar components for the *Campus Carbon Calculator.* This approach eliminates costs to CA-CP for employing external developers to create these components from scratch or to modify an existing tool, including potential additional costs to CA-CP and/or each user to purchase or license the original tool. Further, by developing the calculator CA-CP gains greater control of future modifications and refinements to the tool.

Default transport and cooking process data

Default transport data are available in existing literature such as *Food, Fuel and Freeways (Pirog et al., 2001).* Additional research may identify additional common origins for in- and out-of-season foods. Cooking process data for select ovens and fryers can be calculated from fuel and electricity use statistics available from Energy Star and other sources.

Food data catalog

Development and/or acquisition of food LCA models will require the bulk of time and resources. Given time and resource limitations, initial efforts should focus on preparing "low hanging fruit" foods for which appropriate models already exist that require little or no modification, foods with heavy environmental burdens such as red meat, dairy, imported seafood and highly processed products, and foods that are most commonly procured by food service providers. Cooperation with food service providers such as Aramark and Bon Appétit Management Company Foundation can guide the selection of key ingredients and foods for inclusion in the tool.

Building the data catalog of necessary ingredients is best approached as an iterative process. For piloting purposes, an initial catalog of foods can be developed using free LCA data sources such as studies and publicly available databases in conjunction with a free modeling tool such as OpenLCA. As resources allow, and depending on potential partnerships with other organizations, additional LCA data may be acquired from organizations such as CleanMetrics, PE, and the Bon Appétit Management Company Foundation. Wherever possible, process data is preferred over EIOLCA. Advantages and disadvantages of each data source are discussed above under *Table 6. Summary of data source advantages and disadvantages, p.37.*

The shortage of existing food production process data based on a U.S. context will result in inevitable inaccuracies, and the exclusion of certain foods. Proxies could be provided for missing foods, provided resultant uncertainties are made transparent to the user. Given the expanding nature of LCA data collection, the catalog may become more comprehensive and accurate over time.

Selection of LCA modeling tool

Ease of working with process data, for the purposes of viewing, modifying and building complex product systems, requires use of LCA modeling software on the part of the tool developers (*not* the user). Factors to consider in the selection of an LCA software package include cost (including annual fees), packaged databases (disregarding free databases), level of support, and features. The latter include automatic linkage of upstream processes and a functional system representation, discussed above under *LCA Modeling Software, p.37.* Furthermore, software should be compatible with desired databases. Most software are compatible with the *EcoSpold* format, and some software can combine EIOLCA data with process data. Additionaly, software should be able to import characterization factors for LCIA. Further, depending on the expertise of the CA-CP development team, technical support from the software developer, or an external consultant, may be desired. Optional features include the ability to handle looped processes, and perform uncertainty analyses. For a partial list of modeling software packages, see *Table 13. Summary of LCA modeling software, p. 60.*

Cost

Databases and software tools may require licensing fees, one-time purchase costs, or annual subscription fees. Furthermore, human resources will be required to identify suitable data sources, modify existing product systems to meet the aforementioned criteria, as well as potentially generate new or modified product systems based on user demand. Some or all of these responsibilities could be shifted to an LCA consulting agency or developer. Using publicly available databases, such as the Danish *Food LCA Database*, in tandem with a free LCA modeling tool, such as *OpenLCA*, would cut up-front costs; however, becoming accustomed to LCA may prove time consuming – and lead to potentially inaccurate results – without support or prior experience.

CONCLUSIONS

The urgency to address climate change calls for a need to accurately measure and reduce greenhouse gas emissions. Other environmental harms of the food system also require urgent intervention, and are tracked alongside GHG emissions in existing LCA data. Opportunities exist to make significant reductions via large-scale procurement and production changes, as well as to provide consumers with low-GHG dietary options and educational messages regarding the relationship between the food system, environment, and health.

On the principle that "what is not measured is not managed," foodprint tools based on sound methodologies can facilitate these goals. In particular, a new, publicly available CA-CP tool for measuring GHG emissions and other environmental impacts associated with food procurement on an institutional level, can provide campus food service providers with the means to measure their foodprints - acknowledging inevitable uncertainties. Such a tool could also be disseminated to other institutional food services outside higher education. As described in this review, there are suitable features, methods and data available for CA-CP to begin development of the new tool. Due to the complexity of the food system and data gaps – particularly regarding U.S. food production - precise inventories are beyond the current scope of a foodprint tool; however, key in motivating impact reductions on the part of food service providers is the ability to make *relative* comparisons between food procurement scenarios, and to compare over time. Finally, efforts to measure foodprints can be initiated now, with the expectation that additional U.S. food production data will be available in the future.

The new CA-CP foodprint tool, coupled with food service providers with the drive and social responsibility to put them into practice, can guide efforts to reduce indirect GHG emissions and other environmental impacts from food procurement and production. Further, the results of the tool may guide educational campaigns for consumers, helping to encourage environmentally responsible dietary decisions. Given the powerful environmental impacts of our food system, and the broad reach and purchasing power of institutional dining services, adding this component to CA-CP's toolbox can further advance efforts to reduce contributions from the food system to GHG emissions and other environmental impacts.

APPENDIX

Table 7. Categorization of findings

Articles, websites, reports, presentations

- Food impact studies (primarily based on LCA)
- LCA standards
- Impact protocols and standards
- Corporate, academic, and governmental efforts to measure or reduce environmental impacts
  - Results and methods
- Consulting agencies and research institutions
  - Clients[1]
- News articles
- Impacts of the food system - not a specific focus of literature searches, but used as supporting literature for background

Tools, methods and databases

- LCA background and methods
- LCA data sources
  - Studies
  - Databases
- LCA software modeling tools
  - Developers
  - Clients*
- Individual impact assessment tools[2]
- Institutional impact assessment tools[2]
- Process or product based impact assessment tools, categorized by life cycle stage or industry sector where appropriate[2]:
  - Agriculture, aquaculture, transport, refrigeration, preparation, waste, etc.

1. Where available.
2. Primarily for measuring GHG emissions related to food, but includes other impacts and non-food tools.

Table 8. Non-inclusive list of primary search sources

- Association of Advanced Sustainability in Higher Education (AASHE)
- Agricola Journal Database
- Berkeley Institute of the Environment
- CA Climate Action Partnership (CALCAP)
- California Climate Action Registry
- California Green Solutions
- Carbon Reduction Institute
- CarbonCounted.com
- Carbonfund.org
- Carnegie Mellon Green Design
- Center for Environmental Strategy, University of Surrey, UK
- Climate Conservancy
- Ecosynergy
- Ecotrust
- European Commission
- Google
- Leopold Center for Sustainable Agriculture
- Union of Concerned Scientists
- Ecobusiness links
- Ambio Journal of the Human Environment, Sweden
- Ecobuyer GHG calculators summary
- Swedish University of Agricultural Sciences
- Food Climate Research Network (FCRN)
- FCRN email list
- Pew Center Global Climate Change
- Precourt Institute for Energy Efficiency (PIEE), Stanford University
- Redefining Progress
- Science Direct
- Seattle Climate Action Now
- Springer Energy, Climate, Behavior Journal
- Stockholm Environment Institute
- Swedish Institute of Food & Technology (SIK)
- The Greenhouse Gas Protocol Initiative
- Department of Environment Food and Rural Affairs (DEFRA), UK
- World Business Council for Sustainable Development (WBCSD)

Table 9. Summary of individual- and household-level tools that factor food purchasing

Calculators that include recommended methodologies or noteworthy features are listed first in bold, and are described above in greater detail. These are followed by remaining calculators sorted alphabetically by publisher or developer.

"Ordinal" refers to categorical values such as "never, once a week, every day" or "none, some, a lot" that have a ranked order.

Publisher / Developer	Title	User Input	Calculator Output	Methodology / Data	URL
Bon Appétit Management Company Foundation	***Low Carbon Diet Calculator***	Foods selected from a catalog of Bon Appétit menu items, generic prepared foods, and raw ingredients.	g CO_2e, expressed in "points" as a sliding bar.	PLCA. Limitations described at website under *FAQ*. Research and assumptions paper available at: www.circleofresponsibility.com/page/338/research-and-assumptions.htm	www.eatlowcarbon.org/
EcoSynergy	***EcoImpact CO_2 calculator***	Item from a menu of 24 food products: smoked ham, turkey, egg, ice cream, cola, wine, etc.	g CO_2 per quantity, top three CO_2 contributors (i.e. Power Generation, Fruit Farming, Truck Transportation).	Hybrid LCA.	www.ecosynergyinc.com/info/widget.php
The Berkeley Institute of the Environment	***CoolClimate Footprint Calculator*** Also featured as the *Carbon Calculator* at www.coolcalifornia.org	U.S. dollars spent on housing, food, clothing, furniture and appliances, and other goods and services. Food is defined by industry sector: meat, fish, eggs; fruits and vegetables; cereals and bakery products; dining out; and other foods (snacks, drinks, etc.).	Tons of CO_2 per year, based on user spending in each industry sector and associated emissions.	U.S. EIOLCA. Methods paper available from developer Christopher M. Jones: cmjones@berkeley.edu	coolclimate.berkeley.edu/ Also featured at: www.coolcalifornia.org/calculator.html
FoodCarbon	***FoodCarbon Footprint Calculator***	Relatively comprehensive food purchasing questionnaire covering beef, chicken, milk, apples, bananas, potatoes, carrots, beans, bread, and rice; and respective quantities, origins, and production methods (i.e. organic v. conventional, chilled v. fresh, etc.) for each.	kg carbon per year; kg carbon per year for each food item.	Selection of foods: "The calculation is based upon a selection of representative foods. The basket was created using UK household purchased quantities of food, drink '05 provided by Defra." Sources of emissions data unavailable at time of this writing.	www.foodcarbon.co.uk/calculator.html

Publisher / Developer	Title	User Input	Calculator Output	Methodology / Data	URL
Big Green Switch; UK.	*Big Green Switch Carbon Calculator*	Primary source of food purchases (supermarkets, local stores, both); food miles (not considered, prefer local, only local); frequency of red meat consumption; etc.	Tons of CO_2 per year (accounting for all consumption categories), food and waste emissions expressed as "green ranking" on a sliding scale.	Information unavailable at time of this writing.	www.biggreenswitch.co.uk/carbon/calculator
Carbon Footprint	*Carbon Footprint Calculator*	Dietary questionnaire: vegetarian, mainly fish, mainly white meat, red and white meat, red meat; frequency of purchase of organic produce, seasonal food, locally-produced food or goods.	Tons of CO_2 per year expressed as a "secondary footprint," as opposed to direct emissions from transportation, energy use.	Information unavailable at time of this writing.	www.carbonfootprint.com/calculator.aspx
Carbon Independent; UK	*Carbon Footprint Calculator*	Meat/dairy consumption quantity (ordinal); quantity of diet produced locally, packaged/processed, composted, discarded as waste.	Tons CO_2 per year, including an "almost unavoidable" 0.2 tons.	Calculations based on a breakdown of CO_2e by various stages of production, attributed to a single person in the UK. Data source: Carbon Trust.	www.carbonindependent.org/
Carbonify.com	*Carbon dioxide emissions calculator*	Number of people in household with meat in diet.	Tons of CO_2 per year, per household that result from diet	Calculations are based on the assumption that the average American diet generates the equivalent of 1.5 tons more CO_2 per year than a vegan diet.	www.carbonify.com/carbon-calculator.htm
Center for Biological Diversity	*Carbon Calculator*	percent of diet that is "processed, packaged, and not locally grown," % of meals that include animal-based products (meat, eggs, AND dairy products), $ per month spent eating out.	Tons of CO_2 per year resulting from direct emissions, total tons of CO_2 per year by category (food, housing, waste, transportation, goods and services).	Data source: Redefining Progress.	www.endangeredearth.org/climateneutral/carboncalcc/carboncalcc.htm
Center for Science in the Public Interest	*Six Arguments for a Greener Diet: Eating Green Calculator*	Servings of beef, chicken, pork, yogurt, hard cheese, and egg per week.	Acres of grain and grass, lbs pesticides, lbs fertilizer, lbs manure. Estimated daily nutrient intake.	Information unavailable at time of this writing.	www.cspinet.org/EatingGreen/calculator.html
Center for Science in the Public Interest	*Six Arguments for a Greener Diet: Score your diet*	Servings per week of beef, pork, chicken, milk, fish, fruit, vegetables, candy, etc.; and a dietary questionnaire, i.e. "Do you eat grass fed beef / free-range eggs / poultry?"	Health Score, Environmental Score, Animal Welfare Score. 60+ considered "excellent," 15-59 "Good", etc.	Scores are affected by air and water pollution from manure, cattle belching, depletion of groundwater, hot-iron branding, cramped cages, etc.	www.cspinet.org/EatingGreen/score.html

Publisher / Developer	Title	User Input	Calculator Output	Methodology / Data	URL
Conservation International	*Your Carbon Calculator*	Whether household diet is vegan, vegetarian, mostly vegetarian, or omnivorous.	Tons of CO_2 per year per individual in household, price of suggested offset.	Calculations are based on average CO_2 emissions per diet type.	www.conservation.org/act/live_green/carboncalc/Pages/default.aspx
DoubleTree Hotel & Exec. Meeting Center	*Carbon Calculator*	Number of meals eaten at the hotel.	Metric tons of CO_2e, price of carbon offset ($/metric ton).	Information unavailable at time of this writing.	www.doubletreeportlandgreen.com/calc-guests.htm
EcoMethods	*Reduce Impact*	lbs of meat consumed per day.	lbs CO_2 per year.	Information unavailable at time of this writing.	www.reduceimpact.com/
Fair Shares, Fair Choice; UK	*Fair Shares Carbon Calculator*	Frequency of meat consumption (occasionally, vegetarian, vegan); source of food purchasing (local, seasonal produce, grows own supply); other food questions combined with shopping and recycling behaviors.	Carbohydrates consumed per year, tons of CO_2 per year (accounting for food/diet, shopping, and recycling habits).	Information unavailable at time of this writing.	www.fairsharesfairchoice.com/carbon_calculator.asp
Green Progress	*Carbon Footprint Calculator*	lbs. of meat consumed per day.	lbs CO_2 per year.	Information unavailable at time of this writing.	www.greenprogress.com/carbon_footprint_calculator.php
Mitra Foundation	*Family Carbon Emission Calculator*	Dietary checklist: meat, home-produced fruits and vegetables, only organic, non-organic.	kg CO_2 per year.	Information unavailable at time of this writing.	www.mitrafoundation.org/calculator.php
National Geographic	*Human Footprint*	Item from a menu of products such as an egg, newspaper, banana, tire, etc.; frequency of product use (i.e. how many miles driven per day, how many eggs eaten per week).	User lifetime product use (i.e. 28,080 potatoes); U.S., Japan, U.K. average lifetime product use.	User lifetime averages extrapolated from daily use.	channel.nationalgeographic.com/channel/human-footprint/
National Geographic	*A Calculated Loss: How to Reduce Your Global Warming Emissions*	Manual calculations. Article provides annual emissions by room in the home. Food choices (average U.S. meat consumption or vegetarian) referenced under "kitchen."	lbs of CO_2 per year.	Based on U.S. national averages (typical meat diet, 30% calories from meat/poulty/dairy vs. vegetarian).	www.thegreenguide.com/doc/119/calculator

Publisher / Developer	Title	User Input	Calculator Output	Methodology / Data	URL
Nature Conservancy	*Nature Conservancy Carbon Footprint Calculator*	Frequency of including meat in diet (ordinal), frequency of eating organic food (ordinal).	Tons of CO_2e per year from diet. Comparison to national average.	Emissions based on U.S. national averages/estimates for vegetarian vs. organic vs. high-meat diets.	www.nature.org/initiatives/climatechange/calculator/
Redefining Progress	*Ecological Footprint*	Diet type (vegan, vegetarian, omnivore, carnivore); source of food purchases (local, natural food markets, supermarkets, restaurants, etc.); frequency of organic purchases; frequency of meals; whether user grows own produce.	Ecological footprint: "Global acres" consumed.	Begins with national averages, then adjusts based on user input. General methodology for the per capita figures is described in Venetoulis, Jason and John Talberth 2005, "Refining the Ecological Footprint."	www.myfootprint.org/en/visitor_information/ Methods: http://www.myfootprint.org/en/about_the_quiz/faq/
Resurgence, Mukti Michell	*The Resurgence Carbon Dioxide Calculator*	Estimated personal share of industrial emissions in tons of CO_2; default set at 1 ton.	Total tons of CO_2 from "industry."	Food is combined with other consumables as part of user's share of "Industrial Emissions," calculated on basis of share being proportional to income.	www.resurgence.org/resources/carbon-calculator.html
Stop Global Warming	*Stop Global Warming Calculator*	Checkboxes for action items: Choose organic food, rarely order takeout, eat local once a week, check the oven timer instead of opening the door.	lbs of CO_2 and money saved per year by completing action items.	Data sources include The Rodale Institute, EPA, WRI, Environmental Defense, Rocky Mountain Institute, Leopold Center, etc.	www.stopglobalwarming.org/carboncalculator.asp#604
Wired, Patrick Di Justo	*The Carbon Quiz*	Whether user eats beef; origin of majority of food consumed (local region, continental, overseas).	lbs of CO_2 per year.	Information unavailable at time of this writing.	www.wired.com/wired/archive/14.05/carbon.html

Sources accessed between 6/11 and 6/12, 2008

Table 10. Summary of institutional-level tools and methods applicable to food production or procurement

Although a variety of food- and non-food- institutional and product-based calculators were reviewed, only those with potential pplications to the food system are listed here. Tools that include recommended methodologies or noteworthy features are listed first in bold, and are described above in greater detail. These are followed by remaining tools sorted alphabetically by publisher or developer.

Publisher / Developer	Title	Description	Industry Sector(s) or Processes	Tool Output	Potential application to food system	URL
Clean Metrics	***CarbonScope***	"…evaluate[s] the carbon footprints of consumer products, taking into account the [CO_2] emissions from energy use as well as other critical GHG emissions… looks at the entire supply chain, and accounts for production, processing, packaging, storage, and transport up to a delivery point such as a retail store, restaurant or home."	Various, including restaurants, retail, food production.	Energy use, GHG emissions.	Includes selection of 100+ foods and associated GHG emissions, based largely on a U.S. context. Transportation handled separately.	www.cleanmetrics.com/html/carbonscope.htm
Best Foot Forward (UK)	***Footprinter: Ecological and Carbon Footprint Calculator***	ISO, GHG Protocol-compliant web-based carbon footprinting tool. Measures scope 1, 2, and 3 emissions. Customizable front end for various industries.	Various. Includes food, energy production, transport, materials and other products.	Carbon footprint (Tons CO_2), ecological footprint.	Includes selection of foods based on cradle-to-gate LCA models (transportation is handled separately), based on Ecoinvent and other data sources. Some food models developed by Best Foot Forward.	www.custom.footprinter.com/
Clean Metrics	***CargoScope***	"…interactive, easy-to-use, web-based analysis tool for modeling and analyzing energy-use and emissions in complex supply chains…every step in a supply chain – transport, storage, or processing – can be modeled in detail from an energy and emissions perspective."	Transportation, storage, processing.	"Detailed energy-use and carbon emissions analysis in complex supply chains."	Methods to quantify food miles. Utilized by Bon Appétit Management Company Foundation for development of *Low Carbon Diet Calculator*.	www.cleanmetrics.com/html/cargoscope.htm
Leopold Center for Sustainable Ag. (Iowa)	***Food, Fuel, and Freeways: An Iowa perspective on how far food travels, fuel usage, and GHG emissions***	Methods for measuring food miles. Discusses transportation from farm to point of sale within local, regional, and conventional food systems.	Fuel combustion during transportation.	Miles traveled, fossil fuels used, CO_2 emissions, etc.	Methods to quantify "food miles," for example, WASD can calculate distances for foods with multiple origins.	www.leopold.iastate.edu/pubs/staff/ppp/index.htm

Publisher / Developer	Title	Description	Industry Sector(s) or Processes	Tool Output	Potential application to food system	URL
Weber and Matthews, pub. Env. Sci. and Tech.	***Food-Miles and the Relative Climate Impacts of Food Choices in the United States***	Analysis of GHG emissions from food miles; relative contributions to emissions relative to entire life cycle. Methods based on EIOLCA.	Transportation.	GHG emissions.	Methods to quantify food miles.	Available at various online peer-review journal databases
Tara Garnett, for Transport 2000 Trust / Campaign for Better Transport	***Wise Moves: Exploring the relationship between food, transport and CO2***	"…focuses on food miles – what they are, whether and how it might be possible to reduce them… consequences of doing so." Less emphasis on methods, but some important considerations regarding measurement.	Transportation.	CO_2 emissions.	Methods to quantify food miles.	http://www.bettertransport.org.uk/local_campaigning/online_guides/food_miles
California Climate Action Registry	*Industry-specific reporting protocols*	Various industry-specific reporting protocols.	Livestock, landfill, cement, power/utility, forestry. Others in development.	Emissions, varies by tool.	Methods to quantify emissions from livestock production.	www.climateregistry.org/
CAP Partnership, Zenith international, NSF, TruCost	*A Sustainability Standard For The Global Beverage Industry*	"…industry wide initiative to help beverage companies [measure] carbon footprint… also other sustainability criteria specific to the industry such as the use of recycled packaging content; efficient use of water; use of renewable energy; carbon reduction; and offsetting." Currently in development.	Beverage.	Various.	Applications specific to the beverage industry; methods may apply in other contexts.	www.cappartnership.com/
Carbon Trust, BSI (British Standards Inst.), Defra	*PAS 2050*	"… standard method for the assessment of the life cycle GHG emissions of goods and services… defines how life cycle GHG emissions of a product should be measured." Currently in development.	Various.	GHG emissions.	Information unavailable at time of this writing.	www.bsi-global.com/en/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050/

Publisher / Developer	Title	Description	Industry Sector(s) or Processes	Tool Output	Potential application to food system	URL
CLA - Country Land and Business Org.	*CALM Calculator - CO2 Accounting for Land Managers*	"...the first business-based calculator available online, showing the balance between annual emissions and... sequestration of the key GHGs associated w/ land-based businesses. This approach for farms and estates is distinct from footprint calculators devised for specific products which are calculated on a life-cycle basis."	Livestock, agriculture, forestry, energy and fuel use, cultivation and land use change, application of nitrogen fertilizers and lime; balanced against CO_2 sequestration in soil and trees.	GHG emissions.	Methods to quantify livestock production and deforestation, with regards to land use.	www.cla.org.uk/Policy_Work/CALM_Calculator/
Clean-Air Cool-Planet	*Campus Carbon Calculator*	Free excel-based tool for conducting a university campus emissions inventory.	Electricity and steam generation, transportation, agriculture (on site), solid waste, refrigeration, offsets	GHG emissions, HFCs, PFCs.	Capturing emissions from on-site operations and	http://www.cleanair-coolplanet.org/toolkit/
European Commission, University of Hertfordshire (UK)	*FOOTPRINT: creating tools for pesticide risk assessment and management in Europe*	"The project aims at developing computer tools to evaluate -and reduce- the risk of pesticides impacting on water resources in the EU (surface water and groundwater)."	Pesticide use.	Contamination pathways in the landscape, levels of runoff towards surface/ground water.	Pesticide use.	www.eu-footprint.org/ataglance.html
Lincoln University, NZ	*Carbon Calculator for New Zealand Agriculture and Horticulture*	"... [estimates] annual GHG emissions produced by either a horticultural farm (no stock) or an agricultural/mixed farm (with stock)."	Agriculture, horticulture. Factors land use, stock, production, farm fuel, fertilizer, feed, etc.	GHG emissions.	Applications specific to agriculture and horticulture in a New Zealand context; methods may apply in other contexts.	campus.lincoln.ac.nz/forms/carboncal/
Oberlin College, Rocky Mountain Institute	*Oberlin College: Climate Neutral by 2020*	GHG assessment and reduction methodologies for a university campus (assessment methods begin at Ch. 3).	Academic Institutions: buildings, transportation, landfill, wastewater, water supply, food and lands, supplies and equipment.	GHG emissions.	Some food-based impacts included under "Food and lands" in very general (highly aggregated) terms.	www.nicholas.duke.edu/news/robertsonseminars/swisher-oberlin2020final.pdf

Publisher / Developer	Title	Description	Industry Sector(s) or Processes	Tool Output	Potential application to food system	URL
The Green Office, Redefining Progress	*Office Footprint Calculator*	"…developed as a joint project of TheGreenOffice.com and Redefining Progress… The self assessment tool aims to promote sustainability in the workplace by increasing awareness…"	Corporate.	Ecological footprint: "Global acres" consumed.	Very limited application. Tool factors water use, type of coffee (fair trade, nor not), use of cups, microwave, and toaster.	www.thegreenoffice.com/carbon/our_calculator.php
The Greenhouse Gas Protocol Initiative, WBCSD, WRI	*Calculation Tools*	Tools to enable companies to "…develop comprehensive and reliable inventories of their GHG emissions… Each tool reflects best practice methods that have been extensively tested by industry experts. Every tool is comprised of an Excel workbook and a PDF guidance document…"	Refrigeration, AC, power plant, business travel, fuel use; production of ammonia, cement, iron, semiconductor wafers, wood products, etc.	Emissions, varies by tool.	Methods to quantify refrigeration* emissions. Tool for organic waste* plus others currently in development. *Waste, refrigeration already captured in CA-CP tool.	www.ghgprotocol.org/calculation-tools

Sources accessed between 6/17 and 6/18, 2008.

Table 11. Examples of LCA studies of food products

The following non-inclusive list of studies and study sources reviewed provide aggregate data. Only partial LCI / LCIA results are displayed here.

Functional unit, geo. context	System description	Inputs	Outputs to biosphere	Source
One kg Hushållsost semi-hard cheese, wrapped in plastic, Sweden	Extraction of ingredients through waste management, excluding capital goods	Land use: 14 m^2 / year Water: 1.2 kg Energy use: 9.1 MJ (electricity) 30 MJ (fossil fuels)	GWP: 8.8 kg CO_2e Acidification: 136 g SO_2e Eutrophication: 2.13 kg O_2e Also discussed: Human toxicity, ozone depletion.	(Berlin, 2002)
400 g package of frozen cod fillets, Sweden	Full life cycle, excluding material and energy use in production of fishing vessel	Land use: 706 m^2 seafloor Energy use: 36 MJ Other inputs: 740 g crude oil, 32 g coal, 38 g natural gas, 2.1 g lead, etc.	GWP by method: Trawl method: ≈4 kg CO_2e Gillnet: ≈1 kg CO_2e Mixed: ≈2.5 kg CO_2e	(Ziegler et al., 2002)
1 kg fat and protein corrected milk, Netherlands	Cradle-to-farm gate	Land use: 1.8 m^2 / kg, organic milk 1.3 m^2 / kg, conventional milk Energy use: 3.1 MJ / kg, organic milk 5.0 MJ / kg, conventional milk	GWP: 1.4 kg CO_2e, conventional 1.5 kg CO_2e, organic Eutrophication: 0.11 kg NO_3e, conventional 0.07 kg NO_3e, organic	(Thomassen, van Calker, Smits, Iepema, & de Boer, 2008)
1,000 kg broiler poultry, live weight, U.S.	Cradle-to-farm gate	Energy use: 14,960 MJ	GWP: 1,395 kg CO_2e Acidification: 15.8 kg SO_2e Eutrophication: 3.9 kg PO_4e Ozone depletion: 32.2 μg CFC-11e	(Pelletier, 2008)
1,000 kg tomato ketchup, Sweden	Cradle through household phase, excluding waste management	GJ of energy use by life cycle stage and source: hydropower, biofuel, uranium, peat, coal, gas, oil.	GWP is listed by life cycle stage, for 20, 50, 100 year time periods. Also discussed: Ozone depletion, acidification, eutrophication, human toxicity, ecotoxicity, etc.	(Andersson et al., 1998)
Salmon fisheries and aquaculture, NE Atlantic, NE Atlantic & Chile	Cradle-to-grave	Pending	Pending	http://www.ecotrust.org/lca/ Accessed July 2008.
Beef production, Iowa, U.S.	Pending	"Pelletier currently is working with the Leopold Center on [an] LCA model for several beef production systems in Iowa. Pelletier has researched salmon and tilapia aquaculture systems, conventional and organic field crop production in Canada, and the U.S. poultry broiler industry…" - http://www.leopold.iastate.edu/news/newsreleases/2008/070708_lca.html accessed July 2008.		

Table 12. Summary of LCA databases

Developer(s)	Title	DB Content	Context	Format	Cost	URL
2.-0 LCA Consultants	*LCA Food Database*	Products: crops and crop based products, dairy, vegetables, meat, fish, packaging. Processes: agriculture, aquaculture, industrial processing, trade, cooking, transport, energy, water supply, waste treatment.	Primarily European	SimaPro, EcoSpold	Free	http://www.lcafood.dk/
Carnegie Mellon Green Design Institute	*eiolca.net*	500 Industry sub-sectors	U.S.	EIOLCA	Free	http://www.eiolca.net/
Center for Environmental Assessment for Product & Material Systems	*CPM LCA Database*	428 Various industrial processes. 110 Transportation processes.	Primarily European	SPINE, ISO/TS 14048 (.html)	Free	http://www.cpm.chalmers.se/CPMdatabase/
CML – IA	*Impact Assessment methods and characterisation factors*	Characterization factors.	n/a	CML	Free	http://www.leidenuniv.nl/cml/ssp/databases/cmlia/index.html
ESU - Services	*LCI's of different materials*	Links to databases, some food processes.	Various	EcoSpold, SimaPro, ÖvE	Varies, none free	http://www.esu-services.ch/cms/index.php?id=database
European Commission	*ELCD Data System*	22 End-of-life treatment (recycling, disposal). 39 Energy carriers (electricity, fossil fuels, etc.). 37 Materials. 16 Transport services.	Primarily European	ELCD	Free	http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm
European Commission	*List of Databases*	Links to databases.	Various	Various	Varies	http://lca.jrc.ec.europa.eu/lcainfohub/databaseList.vm
National Renewable Energy Laboratory (NREL)	*U.S. Life-Cycle Inventory Database*	Agricultural products, building and construction, electricity generation, fuels and energy, automobile materials, non-metallic minerals, plastics, fuel combustion / production, transformation processes, transportation.	U.S.	EcoSpold, Excel	Free	http://www.nrel.gov/lci/

Developer(s)	Title	DB Content	Context	Format	Cost	URL
New Earth	*Earthster*	Publicly available, open source LCA data and information exchange. Currently in development.	TBD	Various	Free	http://www.earthster.org/
Swiss Center for LCI	*Eco Invent DB*	Relevant to food: Five food industry processes: processing sugar from sugar cane or sugar beet, etc. 112 Plant production processes: sorghum, peas, wheat, barley, corn, sugar cane, sunflower, etc. Four animal production processes: sheep for slaughtering, sheep husbandry. >100 Agricultural means of production: buildings, feed, machinery, fertilizer (mineral v. organic), pesticides, seed, work processes (chopping, drying, harvesting, etc.), etc.	Primarily European, some U.S. processes	Various	Licensing fee	http://www.ecoinvent.ch/
University of Washington College of Engineering	*LCA Database Projects*	Links to databases.	Various	Various	Varies	http://faculty.washington.edu/cooperjs/Research/database%20projects.htm

Sources accessed between 6/17 and 6/18, 2008.

Table 13. Summary of LCA modeling software
Partial list based on software reviewed.

Developer	Title	Description	Automatic linkage of upstream processes	System representation allows user to view & modify system as process or tree.	Compatible with EIOLCA	Support	Cost
ecointensys	*Green-e*	Impact assessment tool with an LCA perspective. Does not require as high level of expertise as LCA modeling. Can conduct cost analysis. Developers offer opportunity for custom tool development. **See detailed description above.**	No	No, **See detailed description above.**	Yes	Varies	$3,000 annual license. Support and training priced separately
GreenDelta TC	*Open LCA*	Open source LCA modeling software. Can be customized provided user-created modules are shared publicly, and not for profit.	No; includes features to assist manual calculation.	Yes	No	Community of other users	Free
Leiden University, Netherlands	*CMLCA*	Matrix-based LCA tool.	No	No graphical output.	No	No	Free
PRé	*SimaPro*	LCA modeling software. Most widely used tool by LCA consultants in N. America. Packaged with ecoinvent.	Yes	Yes	Yes	Full support, free for 1st year only	Compact: $6,090, Analyst: $9,570, Plus annual service/support
PE	*GaBi*	LCA modeling software. PE developed comprehensive agricultural modeling tool; results available for use w/*Gabi.* Professional version packaged with ecoinvent.	Yes	Yes	No, due to limitations in EIOLCA; may incorporate in the future.	Included	Lean: $3,800, Professional: $9,300, indefinite license

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