Available online at www.fooddynamics.org

Int. J. Food System Dynamics 2 (4), 2011, 392-407

INTERNATIONAL JOURNAL ON FOOD SYSTEM DYNAMICS

Data Availability for Carbon Calculators in Measuring GHG Emissions Produced by the Food Sector

Pegah Amani and Gerhard Schiefer

University of Bonn, Germany
pegah.amani@uni-bonn.de; schiefer@uni-bonn.de

Received September 2011, accepted December 2011, available online March 2012

ABSTRACT

The continuing increase in burning fossil fuels over recent decades along with the changing land use have resulted in a considerable increase in the amount of greenhouse gases (GHGs) which can potentially lead to climate change. Adaptation processes will become necessary in order to cope with these challenges in the future. Despite individuals' and institutions' willingness to reduce the amount of GHG emissions caused by their actions or their "carbon footprints", they may lack the knowledge to make effective choices. Carbon calculators have been developed to address these knowledge gaps by measuring and communicating the overall magnitude of the impacts and also the extent to which different behavior patterns contribute to GHG emissions. LCA databases, as providers of inventory data for carbon calculators, have an important role in helping to develop more complete and accurate tools to measure and report produced GHG emissions. For emissions-intensive behavior patterns, the food life cycle is a significant contributor to emissions resulting from activities including agriculture, processing, transport, storage, retail, consumption, and waste handling. This research seeks to classify and characterize these calculators and the agricultural activities or practices they cover, to provide the reader with an idea on the differences between these calculators, and why some of them could be more applicable to the food sector. The intent is to bring clarity to the discussion which could be a step forward in paving the way for the development of more reliable and comprehensive carbon calculators for measuring the GHG emissions of the food sector

Keywords: GHG emission, Carbon calculator, LCA databases, Food chain

1 Introduction

Agriculture is perceived to be a difficult sector for climate change mitigation due to the total global size of land areas covered by agriculture, the variation in agro ecosystems and farming systems as well as the large numbers of farmers involved. With emissions produced through food processing, refrigeration, packaging, transport, and waste disposal, IPCC (2007) regarded this sector as a major source of national and global emissions as well as personal carbon footprints. In order to develop appropriate strategies for mitigating climate change, the primary concern has to be placed on the production and consumption of food products, requiring adequate and accurate measurements of the carbon emissions.

Carbon calculators are developed as tools used in quantitative GHGs (greenhouse gases) impact assessment resulting from the production of the products by the industry or their consumption by the end consumer. Data collection efforts required in impact assessment involve a combination of research, site-visits and direct contact with experts, generating large quantities of data. Obtaining non-site-specific inventory data reduces data collection time and resources. Several organizations have developed databases containing some of the basic data regarding the GHGs.

This study seeks to provide an overview of different carbon calculators in terms of their scope, approach, scientific underpinnings, and development purposes through classifying and characterizing these calculators based on the food sector products or processes they cover. This can be of help in evaluating the applicability of these calculators for GHG impact assessment of the food sector. The results of this study shed light on the required improvements in adjusting these tools for the application to the food sector. Besides that, through a review of the data covered by LCA databases, it will be made clear to which extent the data provided in LCA databases can be used by the calculators to assess the GHG impact of the food sector. Although the data provided in these databases are not case-specific and cannot have the accuracy of measurements in the field, they can still be of valuable use for carbon calculators when no field data is available.

This study starts with a brief introduction to GHGs and the role of the food sector in producing GHGs and also an introduction to carbon calculators as a tool for measuring GHGs. The method used for this investigation and which resources were employed are explained in the third chapter. An overview of different food-focused carbon calculators is covered in the fourth chapter (4.1), in which different carbon calculators are compared based on the criteria they cover. The second part of this chapter (4.2) includes the review of LCA databases in terms of processes and products included. Afterwards, an evaluation of LCA databases' capability in providing carbon calculators with the required data to measure the amount of GHG produced by the food sector is presented. The results could be helpful in finding out whether carbon calculators make use of all the capabilities LCA databases provide or whether there are still opportunities for improvement. The last part of this chapter (4.3) is focused on evaluating the reliability of the carbon calculators through evaluating the calculators' alignment to the GHG protocol standards for accounting and reporting GHGs. The results of this research are summarized in the last chapter. More detailed information on carbon calculators and LCA databases are presented in Appendix A to C.

2 Background

2.1 Greenhouse gases and the climate change

Gases that trap heat in the atmosphere are often called greenhouse gases (GHGs). Six major anthropogenic GHGs are covered in the International Panel on Climate Change (IPCC) 2006 Guidelines: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). These gases are considered to have global warming potentials (GWPs). A GWP compares the radiative forcing of a tonne of a GHG over a given time period (e.g., 100 years) to a tonne of CO_2. Methane can trap 25 times more heat than carbon dioxide, and nitrous oxide can trap 298 times more heat than carbon dioxide, over a 100-year time frame.

Table 1.
GWP potentials of different GHGs adapted from IPCC (2006)

Carbon dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous oxide (N_2O)	298
Hydrofluorocarbon (HFC)	1,300

2.2 GHG emission and the food chain

Activities performed at different stages of the food chain can result in the production of GHGs. Beginning on farms, that includes emissions from the production and transport of all inputs as well as the emissions from on-farm energy use and non-energy-related emissions from soils and livestock. Methane released from livestock rearing and manure management as well as nitrous oxide released through the production and application of nitrogen fertilizers are two major sources of GHG emissions. The calculation of emissions from agriculture is required under the UN framework convention on climate change and the Kyoto protocol. Based on these agreements, countries generated a considerable amount of information on national emissions from agriculture, using accounting methods developed by the IPCC (Jacobsen, 2008).

GHG emissions are not limited to the production stage of the food chain, but can also be generated during the processing and packaging of food products, caused mainly by the energy used for transportation, refrigeration as well as the establishment of packaging and processing facilities. In distribution, emissions are caused mainly by the energy used for transportation, refrigeration, heating, lighting the warehouses and supermarkets, and also for refrigerating foods (Jacobsen, 2008).

According to Jacobsen (2008), emissions at the consumption stage are primarily the result of the energy used for transportation including personal car trips to grocery stores as well as refrigeration. In this sector, energy is used to refrigerate and cook foods and to wash the dishes. Finally, waste disposal all along the supply chain from the farm through processing, transport, and consumption can add significantly to the life-cycle carbon footprint of many food products.

At the recycle and disposal stage of food and food packaging, waste forms a considerable component of the municipal waste system, and this landfill waste is a significant source of methane emissions. New product carbon footprint tools require users to incorporate estimates of waste-related emissions. As for recycling, the key is the recycling potential of the product's content of raw materials. Moreover, the energy expended on the way from the waste source to the new production system has to be taken into account; for the food sector, this is not a noticeable concern (Jacobsen, 2008).

In the research done in the U.S. food sector by Weber and Matthews (2008), a majority of climate impacts are likely due to non-CO_2 GHGs such as N_2O used in nitrogen fertilizers and also soil management techniques and manure management. Especially in livestock, methane emissions are mainly due to enteric fermentation in ruminant livestock and manure management which are primarily produced in the red meat and dairy categories. The primary conclusion of the mentioned research is that different life cycle stages have different impacts in different food categories. When compared to the production processes, the emission intensity derived from transportation for the red meat and dairy category is lower. In fruit and vegetables however, the GHGs from transportation have an impact that produces a higher amount but is still lower than that of the agriculture and production stage (Weber and Matthews, 2008).

2.3 Carbon calculators as a tool for quantitative GHGs impact assessment

Carbon calculators are provided by government agencies, non-governmental organizations, and private companies. These calculators are employed by the food sector as a tool to measure the carbon foot print of products either produced by the industry or consumed by the end user. This task requires the identification and quantification of direct and indirect GHG emissions combined with associated emission factors. An emission factor is a typical quantity of GHGs released into the atmosphere per unit of activity (i.e. g CO_2e/kg fertilizer in the case of fertilizer production, where CO_2e represents the concentration of CO_2 causing the same level of radiative forcing as equivalent GHGs). The emission factor allows GHG emissions to be estimated from a unit of available activity data and absolute GHG emissions (WBCSD/WRI, 2004).

Carbon calculators focus on the carbon emissions associated with different food types and their origins, energy usage in food preparation, refrigeration, and freezing aside from the modes of transportation used in their distribution.

2.4 Methodologies and standards for measuring, accounting, and reporting GHGs

Businesses and other entities will increasingly have to measure and report GHG´s emissions, both for internal management purposes and to respond to self-imposed or mandated emission-reduction targets. Currently available standards for measuring GHGs include PAS 2050 which was developed by the British standards institution, DEFRA, and BIS British Standards in late October 2008 (British Standards Institution, 2008).

Aside from assessing the life cycle GHG emissions, the more recent GHG Protocol developed by WRI/WBCSD (2004) also contains standards for accounting and reporting the GHGs. It has been adopted by the International Organization for Standardization (ISO) as the basis for its ISO 14064-1 Specification with Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals (ISO, 2006).

In December 2010, the GHG protocol initiative published the final version of its corporate standard protocol. Adherence to accepted methodologies, such as those outlined in these standards, provides organizations with an added level of credibility. Moreover, multiple organizations using the same standards can make meaningful comparisons of emissions results (GHG Protocol, Review Draft for Stakeholder Advisory Group, 2009).

3 Data and methodology

In this study, 25 calculators developed by different organizations with a focus on the food sector have been studied. These calculators have been chosen from a collection of calculators found through the search engine Google. A selection of carbon calculators in peer studies was also taken into consideration, such as Kim et al. (2008), Kim and Neff (2009), Weber and Matthews (2008). In this selection, 20 out of 25 calculators were developed for the individual purposes, i.e. with the intention of calculating GHG emissions of the finished products and their consumption by the end consumers. The 5 others are designed for institutional purposes and calculate GHG emissions of products and processes related to institutions active at different stages of the food chain. Different criteria were introduced in different questionnaires provided by the reviewed calculators to get input data for calculating GHG emissions. A collection of the most common criteria related to products and processes in the food chain has been chosen as the basis to evaluate the calculators. In table A.1 and A.2 in Appendix A and table B.1 in Appendix B, the reviewed calculators and their contributions to the main criteria are listed. The five most common criteria are:

- Food categories covered by the calculators and/or dietary preferences (vegan, vegetarian, fish, selective meats, red meat)
- Production methods (organic or conventionally produced, seasonally grown, or bought)
- Transportation (locally produced or imported)
- Packaging and processing
- Waste handling

These criteria are related to products (different food categories), processes (production, transportation, packaging and processing, waste handling) and the technology used (production methods) at different stages of the food chain. This selection of criteria is further used as the basis for comparing different carbon calculators as it covers a broad range of products, processes, and technology used in the food chain.

The results of that comparison were shown as a number of calculators covering each criterion, summarized in figure 4.1.1 and 4.1.2. The results were later on compared to the peer studies. By analyzing the current status of the calculators and comparing them with the findings, possible gaps and opportunities for their further development can be uncovered.

In the next step, 6 LCA databases developed by different organizations with a focus on the food sector were studied. These were selected from a number of databases found either through the search engine Google or through peer studies such as Kim et al. (2008). With different foci and different criteria, the products and processes covered by them are collected from available data in databases websites and summarized in table 5.1.

They were evaluated based on the GHG protocol review draft (2009) showing to what extent these calculators meet the standards and framework of accounting and reporting GHGs. The criteria covered by the GHG protocol for reporting GHGs include relevance, completeness, consistency, transparency, and accuracy. The “relevance” criteria deal with appropriate system boundaries, ultimately dependent on the substance and economic reality of a company, e.g. organizational strucutre, ownership, or legal agreements. These characteristics are beyond the scope of a study on GHG calculators and their accounting and reporting; therefore the “relevance” criteria are ignored, while the other four criteria will be explained in detail subsequently.

Completeness: According to the GHG Protocol review draft (2009), it is necessary to make a good faith effort to provide a complete, accurate, and consistent accounting of GHG emissions. Should elements be missing, their absence has to be clearly documented together with a justification for their exclusion. The GHG Protocol distinguishes between three scopes of emission sources. Scope 1 covers direct GHG emissions occurring from sources that are owned or controlled by the company, Scope 2 is concerned with indirect GHG emissions accounting for emissions associated with the generation of electricity, heating/ cooling, or steam purchased for a company’s own consumption. Scope 3 includes other indirect GHG emissions. It is considered as an optional reporting category that allows for the treatment of all other indirect emissions (GHG Protocol review draft, 2009).

Consistency: The consistent application of calculation methodologies is essential in producing comparable GHG emissions data over time. If there are changes in the methods, data, or any other factors affecting emission estimates, they need to be transparently documented and justified. Estimates for different years, gases, and categories should be made in such a way that differences in the results between years and categories reflect real differences in emissions (GHG Protocol review draft, 2009).

Transparency: This describes the degree to which information on the processes, procedures, assumptions, and limitations and data sources of the GHG inventory are disclosed in a clear, factual, neutral, and understandable manner based on clear documentation and archives. Information needs to be recorded, compiled, and analyzed in a way that enables internal reviewers and external verifiers to attest to its credibility (GHG Protocol review draft, 2009).

Accuracy: This category is about ensuring that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as is practicable. A sufficient accuracy has to be achieved in order to enable users to make decisions with reasonable assurance. Reporting on measures taken to ensure accuracy in the accounting of emissions can help promote credibility while enhancing transparency (GHG Protocol review draft, 2009).

Due to the lack of determination of specific elements for these criteria by the GHG Protocol, a broad range of available related information was gathered for selected calculators which can be used for further categorization and analysis. The result has been summarized in section 4.3, table 4.3.

4 Analysis and Results

4.1 Carbon calculators review

Different food categories provide consumers with different nutrients and are based on consumers' taste and budgets. Therefore, all groups need to be covered by the carbon calculators. Out of 25 calculators assessed by this study, 20 calculators included one or more distinct food categorization(s). Red meat is covered by 19 out of 20 calculators indicating that the importance of red meat in the production of GHG emissions is being considered to a large extent. However, going through more detailed categorization, it can be seen that most of the calculators lack the sufficient categorization necessary to come to conclusions about a product's or food chain's GHG emissions. In the case of red meat, more detailed information about taking different sub-types such as beef or pork into account can be found in table A.1 and A.2 in Appendix A.

In 6 calculators, no food categorization has been made. Some carbon calculators, although being considered food-focused calculators, merely ask for inputs about the number of meals including red meat per week and completely ignore other food categories. The distribution of selected criteria under the scope of reviewed calculators is demonstrated in Figure 4.1.1.

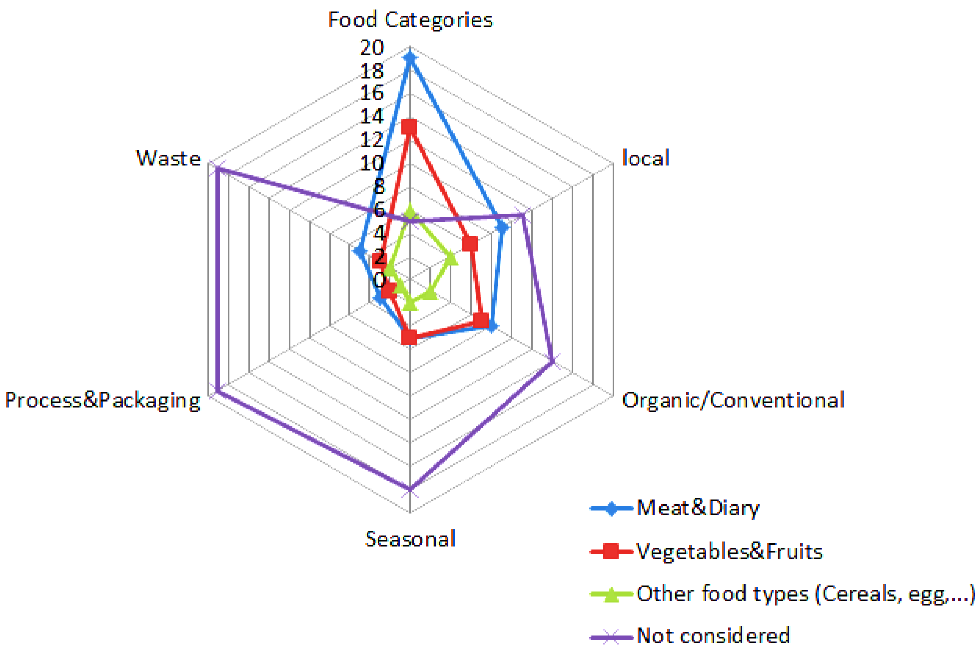

Figure 4.1.1. Distribution of selected (mostly raised) criteria under the scope of reviewed calculators.

Including a food category produced by the company or preferred by a consumer in both calculator types could help with further measurements. As the Weber and Matthews (2008) research results show, local production in the red meat and dairy category can be seen as less important the production method, but the local production still matters for the fruits and vegetable category.

Taking into account whether the food products are produced locally and seasonally or not, more than half of the calculators (9 out of 19) considered the effect of transportation and also energy consumption for the storage and refrigeration of the non-seasonal products. However, no distinction had been made according to the different magnitude of transportation effect required for different food categories.

This question of transportation is more frequently included that the consideration of production methods. Another aspect given low attention is the processing of red meat. Of interest is the comparison, according to Weber and Matthews (2008), between the red meat category on the one hand, and the vegetable and fruits category on the other. While in the latter category, the calculators' attention lies primarily on the production methods rather than transportation, Weber and Matthews' work shows that more attention should be paid to transportation in this category than in the red meat category. Figure 4.1.2 describes the contribution of the transportation stage versus the production and processing stages in the production of the red meat and fruit and vegetables product categories in the reviewed carbon calculators.

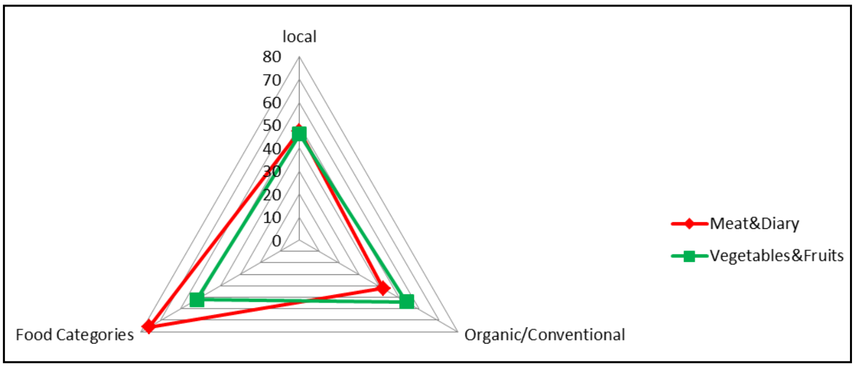

Figure 4.1.2. Ratio of the contribution of the transportation stage versus the production and processing stages in the production of the red meat and fruit and vegetables product categories in the reviewed carbon calculators

Less than half of the calculators considered consumer preferences for those foods which are organically produced, seasonally grown, or locally produced. Out of these preferences, the most frequently considered were organic or conventional.

Of the calculators under review here, 7 reported annual GHG emissions as masses of CO_2e, 16 just reported CO_2 while ignoring the impact of rest of GHGs. However, in some of these calculators, based on Kim et al. 2008, examining the conversion factors used in these calculators shows that methane and NO_2 are also taken into account.

4.2 Data availability of LCA databases

A review of different food-focused carbon calculators revealed a considerable lack of food specification. In some calculators, no food categorization has been reported, and in some, only the number of meals was requested as the input data including the number of meals per week containing red meat, while other food categories were completely ignored.

In this research, six LCA databases developed by different organizations with the focus on the food sector were studied. These databases have different focuses and cover different criteria, the products and processes covered by them are collected from available data in databases websites and summarized in table 4.2.1.

Table 4.2.1.
Process vs. Product covered by LCA databases

Processes / Products	Agriculture	Processing	Packaging	Distribution	Logistics	Consumption
Fruit and vegetables	LCA Food EIO-LCA ESU Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA CPM LCA ESU Eco Invent SALCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA
Meat and egg	LCA Food EIO-LCA ESU Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA
Cereals and pulses	LCA Food EIO-LCA Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA Eco Invent IVAM LCA	LCA Food EIO-LCA Eco Invent IVAM LCA	LCA Food EIO-LCA Eco Invent IVAM LCA
Dairy	LCA Food EIO-LCA ESU Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA SALCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA	LCA Food EIO-LCA ESU Eco Invent IVAM LCA
Processed Food	IVAM LCA EIO-LCA	IVAM LCA EIO-LCA	IVAM LCA EIO-LCA	IVAM LCA EIO-LCA	IVAM LCA EIO-LCA	IVAM LCA EIO-LCA
Beverages	EIO-LCA ESU IVAM LCA	EIO-LCA ESU IVAM LCA	EIO-LCA ESU IVAM LCA	EIO-LCA ESU IVAM LCA	EIO-LCA ESU IVAM LCA	EIO-LCA ESU IVAM LCA

The different food categories covered by LCA databases are presented in Appendix C, tables C1 and 4.2.1. From those, it can be concluded that considerable amounts of inventory data of different food categories are available in databases which are still not being used by the current carbon calculators.

Aside from different food categories, different processes are covered by the databases. However, less than half the carbon calculators contain data regarding processes such as production methods. This indicates the gap between the available inventory data and their application in carbon calculators for the assessment of the GHG emissions in the food sector.

4.3 Calculator assessment based on GHG protocol

This part of the research investigates the strengths and weaknesses of carbon calculators in meeting the GHG Protocol requirements. Due to the amount of effort required to gather data, the focus of this part of research is limited to 6 out of 25 selected calculators. These calculators are CarbonScope™, Footprinter and CALM with institutional focus and Low Carbon Diet, CoolClimate and the FoodCarbon Footprint calculator with individual focus.

These calculators are evaluated based on criteria derived from the GHG Protocol which are completeness, consistency, transparency, and accuracy. Due to the focus this research places on the suitability of these calculators for their use in the food sector, these criteria were further divided into two groups. The first group focused on the completeness, and the second group on consistency, transparency, and accuracy of the carbon calculators. The broadness of related data coverage, i.e. the completeness in the first group, is more informative on whether a calculator is appropriate for a special purpose than the criteria in the second group. Therefore, the main focus of this part of research lies on investigating the completeness of the calculators. However, due to the importance of the other criteria in assessing the alignment of the calculators to the GHG protocol, those have also been investigated. The results of this evaluation are summarized in table 4.3.1.

- Completeness

CarbonScope™ developed by Clean Metrics uses the process life cycle approach (PLCA) to measure GHG emissions from farm to customers (cradle to gate). This calculator covers over 100 food products such as meats, dairy, seafood, cereals and grains, legumes, vegetables, fruits, frozen foods, baked goods, and some processed foods. It has a high level of specificity and low aggregation. A broad range of processes are included in this calculator such as extraction of raw materials and fuel sources, production, processing, transportation and warehousing, including refrigerated options, consumption phase, waste disposal in production and carbon storage as well as sequestration in materials, soil, and vegetation, also land use changes related to the production and/or use of a product. Emission factors employed by this calculator are largely based on a U.S. context (CleanMetrics, 2010; Kim et al. 2008).

Foot printer, developed by Best Foot Forward, like CarbonScope™ LCA, covers the chain up to retailing. In this calculator, delivery data is given by the user directly, thus providing the opportunity to make specific calculations depending on the distance and modes of transportation as well as the quantity of food products (Footprinter, 2010; Kim et al. 2008).

In contrast to CarbonScope™, Footprinter covers foods on a broadly aggregated level such as dairy, meat-poultry-fish, cereals, beverages, etc. Regarding production methods, it does not make any distinction between organic and conventional. Furthermore, the tool is designed for the U.K. context (Footprinter, 2010).

CALM, developed by the Country Land and Business Association (CLA), is a GHG calculator for farmers and land managers. Measurements include both direct emissions of farm activities (e.g. livestock emissions) and indirect emissions (e.g. feed and fertilizer inputs). Furthermore, it calculates the carbon balance. It's the only calculator using three "scopes" to describe emissions arising from a business. Scope 1, applied to a farm or estate, refers to emissions from the direct combustion of fuels in vehicles used in the farm business. On farms, GHG emissions from livestock and their waste, from cultivation and from the application of inorganic and organic nitrogen fertilizers are included. For scope 2, purchased electricity for land management businesses can be mentioned; these emissions are much less significant. The prime examples of scope 3, emissions for land-based businesses, are the emissions associated with the manufacturing of fertilizers and feeds. It calculates the emissions associated with the production of nitrogen fertilizers. These emissions can be significant, however there is little that individual land managers can do to reduce such emissions in the fertilizer industry (Holmes and Metcalfe, 2008).

The Low Carbon Diet (LCD) calculator, developed by Bon Appétit, is similar to CarbonScope™ in using the PLCA approach. It's specifically designed to estimate 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; 2010, Kim et al. 2008).

The LCD calculator divides food consumption into categories such as dairy, fruit and vegetables, cereals, and bakery products. It still lacks a distinct category for high red meat, separate from egg and fish, nor does it have a distinct category for high-protein plant-based food such as nuts. However it is the only calculator which considers highly specific meal items, e.g. roasted beef sandwich, grilled salmon, and seasonal grilled vegetables (Bon Appétit Management Company Foundation, 2010).

Unlike other calculators designed to report annual emissions, the LCD reports emissions for individual meals based on a point system for each type of food. The LCD uses secondary process data captured from data bases to model cradle-to-gate food emissions which occur along the life cycle of the product up to the point of delivery from a farm or distribution warehouse gate to final retail. The final emission results available to the users of this calculator represent cradle-to-grave (full life cycle) emissions, with the exception of nitrous oxide and methane from food waste handling (Bon Appétit Management Company Foundation; 2010, Kim et al. 2008).

Cool Climate Carbon Footprint Calculator is based on EIOLCA (Economic Input-Output Life Cycle Assessment). Its target is an individual end consumer or household, calculating the indirect GHG emissions for that individual. U.S. dollars spent on housing, food, clothing, furniture and appliances, and other goods and services are provided as input by the end consumer. In this calculator, the covered food categories are: meat, fish and eggs; fruits and vegetables; cereals and bakery products; dining out; and other foods such as snacks, drinks, etc. For each dollar spent in a particular food category, associated amounts of GHG emissions are calculated and reported in tons of CO_2 produced per year. Users of the tool can compare their results to typical households in their city or region as well as to households of similar size and income, the US average and the global average (Jones, 2005; Kim et al., 2008; The Berkeley Institute of the Environment, 2010).

FoodCarbon Footprint Calculator is provided by Carbon Footprint Ltd, also targeting the end consumers as its users. The calculations for secondary emissions (including food-related emissions) are based on estimates developed by this calculator to illustrate the impact on the environment from day-to-day activities. The actual emission amount might in reality be either lower or greater than that estimated by the calculator. However, a detailed calculation of indirect emissions is beyond the scope of this calculator (Carbon Footprint Ltd, 2010).

- Consistency, transparency and accuracy

CarbonScope™ complies with applicable international standards (ISO 14040 series, PAS 2050) for life-cycle assessment and product carbon footprint analysis, it will also comply with other major standards that are in development. Users can examine the life-cycle GHG emissions and energy use for a single product, compare two or more product life cycles in detail, or examine/compare two or more collections of products, for instance as shopping baskets. Methods to quantify food miles are utilized by Bon Appétit Management Company Foundation for the development of the Low Carbon Diet Calculator. The highest level of confidence in data accuracy is with plant-based foods (CleanMetrics, 2010; Kim et al. 2008).

Best Foot Forward continues to work with all those involved in facilitating standards including DEFRA (http://www.defra.gov.uk), the Carbon Trust, and the Global Footprint Network, to ensure that Footprinter remains compliant with existing and emerging standards. Standards for methodologies and applications are crucial for the credibility of efforts to measure and monitor footprints. Footprinter is designed to be fully compliant with ISO 14064-1 which describes how organizations should monitor and quantify their emissions and consequently is compliant with the GHG Protocol (Kim et al. 2008).

The CALM calculator made some adjustments in its adaptation of the IPCC methodology to the farm level. Regarding organic manures, the decision was made to only include the emissions of the organic manure that is used or is brought to the farm/estate, whereas in the national inventory, the manure calculations are based on livestock numbers. Livestock emissions are not based on ownership of the stock but where the animals graze. This calculator also offers the possibility for a farm to choose a milk yield class for their dairy cows rather than using a national average yield figure. The CLA CALM calculator follows the GHG Protocol Standard by adopting scopes 1, covering direct GHG emissions from company sources, and 2, taking into account indirect GHG emissions from e.g. the generation of electricity. With this approach, if all farms and estates in the UK carried out a CALM audit, the figures, in principle, should add up to the total national emissions for agriculture and land use change and forestry. Therefore, a reduction in emissions on one farm as measured by a CALM calculation should result in an overall reduction of UK emissions, as currently measured (Holmes and Metcalfe, 2008).

In the Low Carbon Diet calculator, 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. This could lead to double-counting, as emissions from the latter stages have already been taken into consideration by the existing tool. Generalizing delivery distances, while practical from a consumer standpoint, does not capitalize on the opportunity to customize delivery data for individual institutions (Bon Appétit Management Company Foundation, 2010).

The CoolClimate calculator selects a small group of very broad food categories for simplification reasons. The complete EIOLCA database has many more distinctions and categories to choose from. This broad aggregation is considered as the main limitation of this calculator since GHG emissions might vary in the food sector due to different production methods. A lack of coverage of these differences could lead to a wrong impression about the real amount of GHG emission produced (Kim et al. 2008; The Berkeley Institute of the Environment, 2010).

FoodCarbon Footprint Calculator follows the methodology outlined in DEFRA's Voluntary Reporting Guidelines and uses up-to-date emission factors. The only exceptions to this are some country-specific factors sourced from international sources such as the GHG protocol, and the secondary footprint calculations are based on estimates developed by Carbon Footprint Ltd (Carbon Footprint Ltd, 2010).

The calculations for direct emissions employed by this calculator are based on conversion factors sourced from the Department for Environment, Food and Rural Affairs (DEFRA), UK, WRI GHG Protocol, Vehicle Certification Agency (VCA), UK, US Environmental Protection Agency (EPA), USA, US Department of Energy (DOE), USA, Green House Office, Australia, Standards Association (CSA) GHG Registries, Canada (Carbon Footprint Ltd, 2010).

Table 4.3.1.
Summary of selected calculators' assessment based on criteria derived from the GHG Protocol

	Completeness	Transparency, Consistency & Accuracy
CarbonScope™	• Over 100 foods (meat, dairy,…) • Farm to fork • Broad range of processes: manufacturing/construction/ packaging, common industrial processes, agricultural processes and food products, detailed transport models • High level of specificity • Low aggregation • U.S. context	• Material-handling algorithms to track complex material and waste streams in product life cycles • Dynamic life-cycle modelling -- based on "our Deep Carbon Footprinting™methodology" -- accounts for time-dependent emissions, sequestration, and non-linear emission/sequestration characteristics • Hierarchical model-building for complex life cycles • Automatic domestic and international transport distance calculations • User-defined custom emission factors • Complies with standards such as ISO 140140 series, PAS 2050 • High level of accuracy with plant-based food • Automated generation of detailed audit trails to enable reporting/documentation, technical reviews, and certifications of the results
Footprinter	• Highly aggregated food categorization • Farm to fork • Low level of specificity • No distinction for organic/ conventional production • UK context	• Sees all quantitative, qualitative and meta data at the item level • All atomic detail is visible in one view • Reviews assumptions • Changes parameters easily • Documents at the item level (including URLs) • Works with DEFRA, the Carbon Trust, and the Global Footprint Network • Compliant with ISO 14064-1, which in turn is compliant with the GHG Protocol
CALM	• No food categorization • Includes 3 scopes in processes • Farm and land use, so only part of chain included • Includes organic/ conventional distinction	• In calculations, organic manures only include the emissions of the organic manure that is used or brought to to the farm/estate • Manure calculations are based on livestock numbers. • Livestock emissions are based not on ownership of the stock but where the animals graze. • Adapted to IPCC methodology • Adapting scopes 1 and 2 of the GHG Protocol • The calculator has been updated with the latest UK National Inventory Report (1990-2006) data published in April 2009
Low Carbon Diet	• Based on LCA • Cradle to gate (up to distributor) • Production, distribution and preparation of food • Different food categories (highly specific meat,…)	• Data in this aggregated form does not allow for separate handling of delivery, preparation, consumption, and disposal on a per-institution basis • Probability of double-counting of emissions • Generalized delivery data not customized for institutes
Cool Climate	• Based on LCA • Different food categories • Not highly specific • Not process-based	• No data available at the time of writing. • High aggregation by using a small selection from very broad food categories • Generalized results fail to capture differences between different food types
FoodCarbon Footprint	• Different food categories • Cradle to grave • Includes organic/conventional and seasonal, local distinction	• Conversion factors sourced from: Department for Environment, Food and Rural Affairs (DEFRA), UK, WRI GHG Protocol, US Environmental Protection Agency (EPA), USA, US Department of Energy (DOE), USA, Green House Office Australia, Standards Association (CSA) GHG Registries, Canada. • Follows DEFRA's Reporting Guidelines methodology • Uses up-to-date emission factors; exceptions are some country-specific factors and the Secondary Footprint calculations

5 Final remarks

There is an urgent need to reduce GHG emissions due to their impact on climate change and the environment. The food chain contributes a considerable amount of GHG emissions. Based on the principle that "what is not measured, is not managed", there is a demand for reliable and accurate carbon calculators.

Of the significant numbers of calculators designed to measure GHGs, some of them have included food as a part of their focus or are specifically designed for the food chain. Although different food categories, production methods such as organic production, and other criteria such as locally and/or seasonally sourced or produced are considered, substantial opportunities for improvement remain nonetheless. These calculators could be improved by covering more food categories, and also by directing the focus to production- and processing-related procedures.

Similarly, it can be said of the LCA databases reviewed that some have included food production and processing as part of their focus or are specifically designed for the food sector. These databases cover different food categories such as fruits, vegetables, meat, egg, dairy, cereals, pulses, processed food and beverages. Apart from that, different processes such as agriculture, processing, packaging and labeling, distribution, wholesaling, retailing, logistics, transportation, consumption, and waste management are included. Gathering these data required a considerable amount of investment. Therefore, an update in carbon calculators is needed to use LCA databases more efficiently in the assessment of the GHG emissions of the food sector. However, databases still have substantial opportunities for improvement in terms of food categories as well as processes covered.

Considering the current accounting and reporting standards available for the GHG emissions, such as the GHG Protocol, there will be a demand for companies at different stages of the food chain to operate according to these standards. Some of the currently available calculators still offer opportunities for further research, although some considerations has already been given to how to make them suitable for this purpose.

References

Bon Appétit Management Company Foundation. (2010). Low Carbon Diet Calculator. Retrieved April 10, 2010, from http://www.eatlowcarbon.org/

Carbon Footprint Ltd (2010). Corporate Carbon Footprint Calculator, Retrieved April 20, 2010, from http://www.carbonfootprint.com/calculator.aspx

CleanMetrics. (2010). CarbonScope - A Carbon Footprint Analyzer. Retrieved April 1, 2010, from http://www.cleanmetrics.com/html/carbonscope.htm

Confalonieri, U., Menne, B., Akhtar, R., Ebi,K.L., Hauengue, M., Kovats, R.S., Revich, B., and Woodward, A. (007). Human health. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E., Eds., Cambridge University Press, Cambridge, UK, 391-431.

Footprinter. (2010). Custom footprinter: Ecological and carbon footprint calculator. Retrieved April 1, 2010, from http://ecologicalfootprints.com/

GHG Protocol, Product Life Cycle Accounting and Reporting Standard; Review Draft for Stakeholder Advisory Group; November 2009; Copyright World Resources Institute & World Business Council for Sustainable Development, 2009

Holmes, P., Metcalfe, P. (2008). Natural England Carbon Baseline Survey Project, Contract no. FST20-63-025; Contractor Laurence Gould Partnership Ltd‡; April 2008.

IPCC (2007). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (eds)]. Chapter 8 Agriculture, pp 498-540. Cambridge University Press.

IPCC 2006. Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Program, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (eds). Published: IGES, Japan.

ISO 2006. ISO14064 Greenhouse gases – Part 1: Specification with Guidance at the Organization level for quantification and reporting of greenhouse gas emissions and removals. International Organization for Standardization, Geneva.

Jacobsen, C. (2008). “The Food Carbon Story: A Background Paper on Carbon Accounting Practices for the Food System”, Report of the Island Good Food Initiative project sponsored by Nanaimo Foodshare Society under the auspices of the Vancouver Foundation, November 2008.

Jones, C. M. (2005). A Lifecycle Assessment of U.S. Household Consumption: The Methodology and Inspiration Behind the “Consumer Footprint Calculator”, University of California, Berkeley, CA.

Kim, B., Neff, R. (2009). “Measurement and communication of greenhouse gas emissions from U.S. food consumption via carbon calculators”, *Ecological Economics*, Volume **69**, Issue 1: 186-196

Kim, B., Pitkevits Houser, L., Rosenthal, A, and Neff, R. (2008). “Literature Review of Methods and Tools for Quantifying the Indirect Environmental Impacts of Food Procurement” A research report completed for Clean Air-Cool Planet September 1, 2008, The Johns Hopkins Center for a Livable Future.

The Berkeley Institute of the Environment. (2010). CoolClimate Carbon Footprint Calculator. Retrieved April 20, 2010, from http://coolclimate.berkeley.edu/

Weber, C.L., Matthews, H.S. (2008) “Food-Miles and the relative climate impacts of food choices in the united states”, *Environmental Science & Technology,* **42**(10):3508-3513.

World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI) (2004).The greenhouse gas protocol: A corporate accounting and reporting standard. Washington, DC

Appendix A

Table A.1.

Summary of carbon calculators reviewed with institutional focus

Publisher / Developer	Title	Industry Sector(s) or Processes	Output
Clean Metrics	Carbon Scope	Meat, dairy, seafood, cereals and grains, legumes, vegetables, fruits, frozen foods, baked goods and some processed food. Processes: production, processing, packaging, storage, and transportation	CO_2e
Best Foot Forward (UK)	Footprinter	Includes selection of food production, transportation	CO_2
CLA - Country Land and Business Org.	CALM Calculator	Focus on livestock, agriculture, forestry, energy and fuel use, cultivation and land use change, application of nitrogen fertilizers and lime	CO_2e
Clean-Air Cool-Planet	Campus Carbon Calculator	Excel-based calculator developed for university campus emissions inventory. Electricity and steam generation, transportation, agriculture (on site), solid waste, refrigeration, offsets	CO_2e
Lincoln University, NZ	Carbon Calculator	Includes agriculture, horticulture. Factors land use, stock, production, farm fuel, fertilizer, feed, etc. Applications specific to agriculture and in a New Zealand context	CO_2e

Table A.2.
Summary of carbon calculators reviewed with individual focus

	Title	Industry Sector(s) or Processes	Output
Bon Appétit Management	Low Carbon Diet	Different food categories from Bon Appétit menu items, generic prepared foods, and raw ingredients.	CO_2e
EcoSynergy	EcoImpact	24 food products: smoked ham, turkey, egg, ice cream, cola, wine, etc.	CO_2
The Berkeley Institute of Environment	CoolClimate Footprint Calculator	Different food categories such as meat, fish, eggs; fruits and vegetables; cereals and bakery products; dining out; and other foods (snacks, drinks, etc.).	CO_2
FoodCarbon	FoodCarbon Footprint Calculator	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.)	CO_2
Carbon Footprint	Carbon Footprint Calculator	Diet-based: vegetarian, mainly fish or white meat, red meat; frequency of purchase of organic produce, seasonal food, locally-produced food or goods.	CO_2
Carbon Independent; UK	Carbon Footprint Calculator	Meat/dairy consumption quantity; quantity of diet produced locally, packaged/processed, composted, discarded as waste.	CO_2
Carbonify.com	Carbon Dioxide Emissions	Number of people in household with meat in diet.	CO_2
Center for Biological Diversity	Carbon Calculator	Percent of diet "processed, packaged, and not locally grown.” Percent of meals include animal-based products (meat, eggs, AND dairy products), Category (food, housing, waste, transportation, goods and services).	CO_2
Conservation International	Your Carbon Calculator	Diet-based: vegan, vegetarian, mostly vegetarian, or omnivorous.	CO_2
DoubleTree Hotel & Exec. Meeting Center	Carbon Calculator	Number of meals eaten at the hotel.	CO_2e
EcoMethods	Reduce Impact	Lbs of meat consumed per day.	CO_2
Fair Shares, Fair Choice	Fair Shares Carbon Calculator	Frequency of meat consumption (occasionally, vegetarian, vegan); source of food purchasing (local, seasonal), shopping and recycling behaviours.	Carbohydrates consumed
Green Progress	Carbon Footprint	Lbs. of meat consumed per day.	CO_2
Mitra Foundation	Family Carbon	Diet-based: meat, home-produced fruits and vegetables, only organic, non-organic.	CO_2
National Geographic	Human Footprint	Covers different products such as egg, newspaper, banana, tire, etc.; frequency of product use (how many eggs eaten per week).	User lifetime product
National Geographic	Reduce Your GW Emissions	Average U.S. meat consumption or vegetarian , typical meat diet, 30% calories from meat/poultry/dairy vs. vegetarian	CO_2
Nature Conservancy	Carbon Footprint	Frequency of eating meat and organic food. Vegetarian vs. organic vs. high-meat diets.	CO_2e
Redefining Progress	Ecological Footprint	Diet type (vegan, vegetarian, omnivore, and carnivore); source of food (local, natural food markets, supermarkets, etc.); frequency of organic purchases.	"Global acres"consumed
Stop Global Warming	Stop Global Warming	Organic foods, rarely order takeout, eat local.	CO_2
Wired, Patrick Di Justo	The Carbon Quiz	Covers beef; origin of majority of food consumed (local region, continental, overseas).	CO_2

Appendix B

Table B.1.

Distribution of selected criteria under scope of reviewed calculators

Title	Meat	Vegtables	other	Local	organic	Seasonal	Process	Waste	CO2	CO2e
Low Carbon Diet Calculator	■	■	■							■
EcoImpact CO2 calculator	■	■	■						■	
CoolClimate Footprint	■	■	■						■	
FoodCarbon Footprint	■	■	■	■	■	■	■		■	
Carbon Footprint	■	■		■	■		■	■	■	
Carbon Footprint	■			■	■	■			■	
Carbon dioxide emissions	■								■	
Carbon Calculator	■		■	■			■		■	
Your Carbon Calculator	■	■							■	
Carbon Calculator										■
Reduce Impact	■								■	
Fair Shares Carbon	■	■		■		■		■	■	
Carbon Footprint Calculator	■								■	
Family Carbon Emission	■	■			■				■	
Human Footprint			■	■						
Reduce Your GW Emissions	■	■							■	
Carbon Footprint Calculator	■	■			■					■
Ecological Footprint	■	■		■	■					
Stop Global Warming				■	■				■	
The Carbon Quiz	■			■					■	
CarbonScope	■	■	■	■	■	■	■	■		■
Footprinter:Ecological&Carbon	■	■		■	■	■	■	■	■	
CALM-Accounting for Land Managers				■	■	■	■	■		■
Campus Carbon Calculator				■		■		■		■
Carbon Calculator				■	■					■

Blank area: related criteria is *not* covered by the related calculator

Appendix C

Table C.1.

Summary of LCA databases

Title, Developer(s), URL	Processes	Products
LCA Food Database 2.-0 LCA Consultants http://www.lcafood.dk/	Agriculture: dairy, pig farms, , vegetables Processing: flour, dairy and feed production and bread baking, fish canning, peeling; pig slaughtering; soy, grass, feed phosphate production Packaging: packing materials, unpacking, peeling, cutting, mixing, heating, cooling, washing and cleaning. Distribution: energy required for the storage, cold and frozen, and lightening Logistics: different means of transportation truck, ship, train, pipeline, air-plane, private car and bicycle Consumption: Wastewater treatment plans	Fruit and vegetables: carrots, onions, tomatoes, cucumbers, vegetable, potatoes, rape seed Meat and egg: pork, beef, chicken, fish Cereals and pulses: grains, soy bean Dairy: milk, cream, butter, cheese Processed food: sugar, bread, flours, oat flakes
EIO-LCA Carnegie Mellon Green Design Institute http://www.eiolca.net/	Agriculture: oilseed, grain, vegetable, fruit and tree nut, sugarcane, sugar beet and all other crop farming, greenhouse and nursery production, tobacco, cotton, cattle ranching and farming, poultry and egg production, wet corn milling Processing: animal production except cattle and poultry and eggs, logging, forest nurseries, forest products and timber tracts, fishing, hunting and trapping Packaging: packaging materials Distribution: light, energy, cooking, refrigerating, cooling Logistics: transportation through air, land, and water Consumption: waste management	Fruit and vegetables: fruit and vegetable Meat and egg: meat, poultry, seafood Cereals and Pulses: rice, malt, breakfast cereal, soybean, cacao beans Dairy: milk, butter, cheese, dry condensed or evaporated dairy, Processed food: chocolate, frozen food, canned and dried fruit and vegetables, coffee and tea, spices, flour, oilseed, bread, sugar, cookie and cracker, flavoring syrup, mixes and dough, dry pasta, tortilla, roasted nuts and peanuts, snack food, ice cream and frozen dessert, mayonnaise, dressing and sausages Beverages: soft drink, breweries, wineries, and distilleries
ESU ESU - Services http://www.esu-services.ch/cms/index.php?id=database	Agriculture: plant production, vegetable mix, vegetable production Processing: animal production, slaughtering, processing, cooking, cooling Packaging: food packaging Distribution: storage, cooking stoves and ovens, microwaves, refrigerators, carbonization devices Logistics: different transportation means such as road, ship, train, comparison of domestic vs. imported Consumption: consumption patterns and waste treatment	Fruit and vegetables: fruits including apples, strawberries, cherries, grapes, oranges; vegetables including spinach, vine, melons,salad, tomatoes, lettuce, potatoes, onions, asparagus Meat and egg: pork, veal, beef, lamb, poultry, eggs Dairy: cheese, butter, milk, milk powder, yoghurt Processed food: coffee, chocolate, noodles, pasta, bread, wheat flour, tofu, lasagna, ice cream Beverages: apple & orange juice, mineral water, tap water, beer, wine, coffee, soymilk
Eco Invent DB Swiss Center for LCI http://www.ecoinvent.ch/	Agriculture: agricultural means of production: feed, machinery, fertilizer (mineral v. organic), pesticides. Seed growing, cultivation, harvesting, organic, integrated production methods, extensive and intensive production. Processing: processing sugar, plant production, animal production, slaughtering, and sheep husbandry. Packaging and labeling: packaging materials Logistics: transport by air, oversee and on land by train, van and truck. Distribution: energy, distribution, building material Consumption waste management, waste treatment	Fruit and vegetables: sugar cane, sunflower, sugar, peas, potato Meat and egg: sheep Cereals and Pulses: sorghum,wheat, barley, corn, maize, rice, soy bean Dairy: cheese, butter, milk
IVAM LCA Data 4.04 IVAM IVAM Environmental Research, University of Amsterdam bv www.ivam.uva.nl	Agriculture: contains over 1,300 unit processes. Food production (including animal, crops and feeds, agriculture plant and seeds production) Processing: slaughtering, pig and chicken fodder, milk powdering, sow meat Packaging: glass, metal, plastic and paper packaging Distribution: fuel, energy, light Logistics: rail, road, water Consumption: waste management, waste treatment	Fruit and vegetables: sugar cane, sunflower, , peas, potato Meat and egg: sheep, beef, chicken, fish, pork Cereals and Pulses: wheat, barley, corn, maize, sorghum, soy bean Dairy: cheese, butter, milk Processed food: sugar Beverages: mineral water
SALCA 06, SALCA 071 Agroscope Reckenholz-Tänikon http://www.agroscope.admin.ch/oekobilanzen/01199/index.html?lang=en	Agriculture: contains models for assessing direct field and farm emissions, such as nitrate, nitrous oxide, methane, ammonia, phosphorus and heavy metals for the purposes of analyzing and optimizing the environmental impacts of agricultural production. Processing: animal production, Packaging: packaging	Fruit and vegetables: potato Meat and egg: beef, pork, poultry, egg Cereals and Pulses: wheat, maize, seed, corn Dairy: cheese, butter, milk